The Nimrod Review

An independent review into the broader issues
surrounding the loss of the RAF Nimrod MR2
Aircraft XV230 in Afghanistan in 2006

Charles Haddon-Cave QC

Report

Return to an Address of the Honourable the House of Commons
dated 28th October 2009
for

AN INDEPENDENT REVIEW INTO THE BROADER ISSUES SURROUNDING THE LOSS OF THE RAF NIMROD MR2 AIRCRAFT XV230 IN AFGHANISTAN IN 2006

Charles Haddon-Cave QC

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THE NIMROD REVIEW

Rt Hon. Bob Ainsworth MP
Secretary of State for Defence
Ministry of Defence
Main Building
Whitehall
London SW1A 2HB

October 2009

Dear Secretary of State,

I was appointed by your predecessor, the Rt Hon. Des Browne MP, on 13 December 2007 to conduct a Review into the wider issues surrounding the loss of Nimrod XV230 in Afghanistan on 2 September 2006.

I have now completed my inquiries in accordance with my Terms of Reference and have pleasure in presenting my Report.

Yours sincerely.

Charles Haddon-Cave QC

The Loss of RAF Nimrod XV230

A Failure of Leadership, Culture and Priorities

Dedication

This report is dedicated to

Gary Wayne Andrews
Stephen Beattie
Gerard Martin Bell
Adrian Davies
Oliver Simon Dicketts
Steven Johnson
Benjamin James Knight
Leigh Anthony Mitchelmore
Gareth Rodney Nicholas
John Joseph Langton
Gary Paul Quilliam
Allan James Squires
Steven Swarbrick
Joseph David Windall

and their families and loved ones

in the hope and expectation that lessons will be learned from their sacrifice.

XV230

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PART I:

INTRODUCTION

CHAPTER 1 – INTRODUCTION AND EXECUTIVE SUMMARY

Introduction

Loss of XV230 on 2 September 2006

1.1 On 2 September 2006, RAF Nimrod XV230 was on a routine mission over Helmand Province in Southern Afghanistan in support of NATO and Afghani ground forces when she suffered a catastrophic mid-air fire, leading to the total loss of the aircraft and the death of all those on board. XV230 had a full crew complement of 12 on board, together with two mission specialists: Flight Lieutenant A J Squires (Captain), Flight Lieutenant S Johnson, Flight Lieutenant L A Mitchelmore, Flight Lieutenant G R Nicholas, Flight Lieutenant S Swarbrick, Flight Sergeant G W Andrews, Flight Sergeant S Beattie, Flight Sergeant G M Bell, Flight Sergeant A Davies, Sergeant B J Knight, Sergeant J J Langton, Sergeant G P Quilliam, Lance Corporal O S Dicketts and Marine J D Windall. This was an unusually experienced crew with two of the Nimrod Force's most capable and knowledgeable aviators, Flight Lieutenant Squires and Flight Sergeant Davies, on the flight deck.[1]

1.2 XV230 had taken off from the Deployed Operational Base (DOB) at 09:13 hours that morning. All went according to plan until 11:11:33 when, some 1½ minutes after completion of Air-to-Air Refuelling (AAR) from a Tristar tanker, the crew were alerted that something was amiss by two almost simultaneous warnings: a fire warning in the bomb bay and a smoke/hydraulic mist warning in the elevator bay. At 11:12:26 the aircraft depressurised. At 11:13:45 the camera operator reported *"we have flames coming from the rear of the engines on the starboard side".* Upon receiving the first warning, the crew immediately commenced emergency drills and at 11:14:10 transmitted a MAYDAY whilst diverting to Kandahar airfield. Faced with a life-threatening emergency, every member of the crew acted with calmness, bravery and professionalism, and in accordance with their training. They had no chance, however, of controlling the fire.

1.3 At 11:16:54 the Nimrod was observed by a Harrier GR7 pilot in a descent with flames emitting from the starboard wing root and the starboard aft fuselage. Shortly thereafter, several members of 'A' Squadron Royal Canadian Dragoons (RCD) observed the aircraft as it passed to the south of their position; the fire appeared to them to be on the port side of the aircraft, although it was in other respects similar to that seen by the GR7 pilot. At 11:17:39, the Harrier GR7 pilot reported that the aircraft had exploded, at what he believed to be 3000 feet above ground level, and he observed wreckage striking the ground. The RCD also witnessed the explosion, although they reported it as being at a lower altitude. XV230 came down in open fields, close to the village of Farhellah, in an area called Chalaghor in the Panjwaye District of Kandahar, Afghanistan.

Immediate Aftermath

1.4 A Scene of Action Commander was established over the crash site and a Combat Search and Rescue (SAR) team was immediately deployed. No survivors were found. The crash site was secured by the RCD unit supplemented by members of 34 Squadron RAF Regiment from Kandahar airfield. The crash site was in a known area of Taliban activity and proximate to combat operations. Initial priorities were the recovery of the crew's bodies, personal effects, classified documentation, flight recorders and other equipment. The Canadian unit was withdrawn the following day. Several hundred local nationals, including Taliban elements, began to enter the site. The remaining RAF Regiment personnel formed a defensive position in an irrigation ditch crossing the site. Shortly thereafter, in an increasingly unstable and hostile situation, they were withdrawn by air, 21 hours after the initial arrival of ground forces. Fortunately, a detailed photographic record of some key parts of the wreckage had been made by (Officer Commanding (OC) 904 EAW[2], which proved invaluable. Subsequently, most of the aircraft wreckage was removed from the site by the Taliban and local villagers.

[1] See Comments on BOI Report by Station Commander, Group Captain Jerry Kessel, paragraph 15 [3-4].

[2] Expeditionary Air Wing.

RAF Board of Inquiry

1.5 The Board of Inquiry (BOI) presented its Report to the Convening Authority (AOC2 Group) on 20 April 2007. An Addendum to the Report was issued on 25 July 2007. The Board's findings were made public on 4 December 2007.

1.6 The BOI concluded that the loss of XV230 was caused by:

1.6.1 *Fuel Source*: The escape of fuel during Air-to-Air Refuelling (AAR), occasioned by an overflow from the blow-off valve to No. 1 tank, causing fuel to track back along the fuselage, or alternatively, a leak of fuel from the fuel system (fuel coupling or pipe), leading to an accumulation of fuel within the No. 7 Tank Dry Bay. Although of a lower probability, the fuel leak could have been caused by a hot air leak damaging fuel system seals; and

1.6.2 *Ignition Source*: The ignition of that fuel following contact with an exposed element of the aircraft's Cross-Feed/Supplementary Cooling Pack (SCP) duct.

1.7 The BOI found that fuel was most likely to have accumulated in the Refrasil insulation muff around the SCP elbow at the bottom of the starboard No. 7 Tank Dry Bay. The BOI also found that a 'Safety Case' prepared in respect of the Nimrod MR1 and MR2 aircraft between 2002 and 2005, the Nimrod Safety Case, contained a number of significant errors. It was not within the BOI's remit to consider, or attribute, responsibility for the accident. I analyse the Board of Inquiry's findings in detail in **Chapter 3**.

The Nimrod Review

Terms of Reference

1.8 This Review was announced on 4 December 2007 by the then Secretary of State for Defence, the Rt Hon. Des Browne. My appointment to conduct the Nimrod Review was announced on 13 December 2007, with the following broad Terms of Reference:

> *"In light of the board of inquiry report:*
>
> *To examine the arrangements for assuring the airworthiness and safe operation of the Nimrod MR2 in the period from its introduction in 1979 to the accident on 2 September 2006, including hazard analysis, the safety case compiled in 2005, maintenance arrangements, and responses to any earlier incidents which might have highlighted the risk and led to corrective action;*
>
> *To assess where responsibility lies for any failures and what lessons are to be learned;*
>
> *To assess more broadly the process for compiling safety cases, taking account of best practice in the civilian and military world;*
>
> *And to make recommendations to the Secretary of State as soon as practicable, if necessary by way of interim report."*

1.9 In his statement to the House of Commons on 13 December 2007, the Secretary of State for Defence said:

> *"The review will have the full support of the Ministry of Defence. All relevant papers will be made available and everyone who can assist the review will be instructed to do so. In order to encourage openness, evidence given during the course of the review will not be used in disciplinary proceedings against the individual who gave it unless there is evidence of gross misconduct. The MOD will also provide Mr. Haddon-Cave, at his request, with a secretariat for the review.*
>
> *BAE Systems and QinetiQ have confirmed that Mr. Haddon-Cave will have their full co-operation. The MOD and the companies are committed to ensuring that the review has available to it all the technical expertise that it will require. I would expect any other companies whose assistance may be required to follow suit."*

The Nimrod Review Offices and Team

1.10 The Review established independent and secure offices within St George's Court in London, and I made the following appointments:

Senior Counsel to the Review:	Luke Parsons QC[3]
Junior Counsel to the Review:	Caroline Pounds[4]
Additional Counsel:	Peter Ferrer[5]
Secretary to the Review:	Darren Beck[6]
Documents Manager:	Dominic van der Wal[7]
Office Manager:	Dipack Maisuria[8]
Personal Assistant:	Stella Chan

1.11 I also appointed the following experts to assist the Review:

Technical Advisor:	Air Vice-Marshal Charles Ness
Former President of Board of Inquiry:	Group Captain Nick Sharpe
Former Member of Board of Inquiry:	Squadron Leader John Nelson

1.12 The Review received invaluable advice and assistance from the following organisations in particular:[9]

1.1. The US Air Force, particularly the Air Force Safety Center (AFSC);
1.2. The US National Aeronautics and Space Administration (NASA);
1.3. The Royal Australian Air Force;
1.4. The Canadian Air Force;
1.5. British Airways;
1.6. The UK Civil Aviation Authority (CAA);
1.7. The UK Health & Safety Executive (HSE);
1.8 The UK Air Accident Investigation Branch (AAIB); and
1.9. The University of York.

Review interviews, documents and witnesses

1.13 The Review conducted a wide-ranging inquiry over some 20 months in the course of which it studied many thousands of documents (spanning the 1930s to the present day), interviewed hundreds of witnesses of all ranks and in all relevant organisations, visited numerous locations in the UK including RAF Kinloss, RAF Waddington, RAF High Wycombe, RAF Wyton, Chadderton, Heathrow, Southampton, Taunton, Farnborough, Boscombe Down and Petersfield, and travelled to the US AFSC at Kirtland Air Force Base, New Mexico, and NASA in Washington DC. I have flown in a Nimrod and examined Nimrods on numerous occasions, including the Nimrod aircraft in teardown at Boscombe Down.

1.14 The Review received assistance, advice and documentation from a large number of organisations and individuals, including from some unsolicited and anonymous sources. I am grateful to all those who have assisted the Review in a wide variety of ways.[10]

---

[3] Quadrant Chambers.
[4] Ibid.
[5] Ibid.
[6] Civil Servant seconded from the Ministry of Defence (MOD); former Secretary to the Deepcut Review.
[7] Civil Servant seconded from the Treasury Solicitor's Department (TSol) (Barrister).
[8] Civil Servant seconded from the MOD.
[9] Individual acknowledgements appear at the end of the Report.
[10] A list of acknowledgements appears at the end of the Report.

Procedure

1.15 The Procedure adopted by the Review was simple, straightforward and informal, but with due regard to the requirements of fairness and the Salmon principles (see http://nimrod-review.org.uk/linkedfiles/nimrod_review/procedure.pdf).

Urgency

1.16 I was asked to report as a matter of urgency, in view of the potential significance of my findings and recommendations as to the current safety and airworthiness regime, with implications for the RAF Nimrod fleet involved in current operations and for the MOD generally. I have done everything possible to report in as short a timescale as practicable, given the wide range of the investigation, the large number of documents and witnesses involved, the complexity of some of the issues and the need to ensure fairness to all parties and individuals involved. I have not sought to explore every conceivable lead or issue. I am, however, satisfied that I have heard, seen, and read more than enough to get to the bottom of the crucial issues to meet my Terms of Reference and properly inform my findings and recommendations.

1.17 I am grateful to my Team and advisors who have worked tirelessly over many months with great intelligence and determination.

Criticisms and naming of organisations and individuals

1.18 In this Report, I specifically name, and criticise, key organisations and individuals who bear a share of responsibility for the loss of XV230. I name individuals whose conduct, in my view, fell well below the standards which might reasonably have been expected of them at the time, given their rank, roles and responsibilities, such that, in my view, they should be held personally to account. I have not named individuals who were merely part of the story and gave evidence to the Review, for the most part freely and frankly, because, in my view, this would not be in the public interest and might inhibit others from coming forward in future inquiries. Nor have I named individuals who made errors (even if they had significant consequences), and/or whose acts and omissions might be open to question and censure with hindsight, but whom, given their rank, role, experience and the particular circumstances in which they found themselves at the time, it would not, in my view, be necessary, fair, proportionate and in the public interest to name.

1.19 I have only named and criticised organisations and individuals where, in my view, it is necessary, fair, proportionate and in the public interest to do so.

Executive Summary

Introduction

Loss of XV230

1. RAF Nimrod XV230 was lost on 2 September 2006 on a mission over Afghanistan when she suffered a catastrophic mid-air fire, leading to the total loss of the aircraft and the death of all 14 service personnel on board. Investigation of the crash scene had to be curtailed because of enemy presence but, fortunately, photographs were taken and crucial recording equipment recovered. Subsequently, most of the aircraft wreckage disappeared. (**Chapter 1**)

History

2. The Nimrod, a derivative of the De Havilland Comet, has a long and distinguished record in maritime reconnaissance and other roles over 40 years, and continues to play an important role in Defence. XV230 was the first Nimrod to enter service with the RAF on 2 October 1969. (**Chapter 2**)

Board of Inquiry

3. The Board of Inquiry conducted a seven-month inquiry and, despite the absence of physical evidence, was able to determine that the most probable physical causes of the fire and explosion were: (1) *Fuel source:* The escape of fuel during Air-to-Air Refuelling, or a leak from a fuel coupling or pipe, led to an accumulation of fuel within the No. 7 Tank Dry Bay; alternatively, although of a lower probability, a hot air leak damaging fuel system seals. (2) *Ignition source:* Ignition of that fuel by the Cross Feed/SCP duct. The main conclusions of the Board of Inquiry have been confirmed by two leading agencies, the UK Air Accident Investigation Branch and the United States Air Force Safety Center. I am satisfied that the BOI's findings are a sound basis upon which to found this Review. (**Chapter 3**)

Physical Causes

Ignition source

4. There can be no doubt that the ignition source was the Cross-Feed/SCP duct in the starboard No. 7 Tank Dry Bay, and the most probable point of ignition was the SCP muff. (**Chapter 4**)

Probable fuel sources

5. I have concluded that the most likely source of fuel was an overflow during Air-to-Air Refuelling. New evidence has come to light which points to this being the most probable cause (**Chapter 6**). The second most likely source of fuel was a leak from either an FRS or an Avimo fuel coupling in the starboard No. 7 Tank Dry Bay (**Chapter 5**). The third, and only other viable,[11] source of fuel could have been coupling damage caused by a Cross-Feed/SCP duct failure, but this mechanism is much less likely than the other two. (**Chapter 7**)

Responsibility for design flaws

6. Design flaws introduced at three stages played a crucial part in the loss of XV230. First, the original fitting of the Cross-Feed duct by Hawker Siddeley[12] in about 1969 (**Chapter 4**). Second, the addition of the SCP by British Aerospace[13] in about 1979 (**Chapter 4**). Third, the fitting of the permanent Air-to-Air Refuelling modification by British Aerospace in about 1989. (**Chapter 6**)

[11] Other theories which have been put forward, are not realistic and can be discounted (**Chapter 5**).

[12] Which became part of British Aerospace on 29 April 1977.

[13] Which became BAE Systems Plc in November 1999 on the merger with Marconi Electronic Systems.

Previous incidents

7. There were a number of previous incidents and warning signs potentially relevant to XV230; in particular, the rupture of the SCP duct in Nimrod XV227 in November 2004 should have been a *"wake up call".* (**Chapter 8**)

Nimrod Safety Case

8. The drawing up of a 'Safety Case', to identify, assess, and mitigate potentially catastrophic hazards before they could cause an accident, was mandated for military aircraft and other military platforms by regulations introduced in September 2002. (**Chapter 9**)

Loss of XV230 avoidable

9. The Nimrod Safety Case was drawn up between 2001 and 2005 by BAE Systems (Phases 1 and 2) and the MOD Nimrod Integrated Project Team (Third Phase), with QinetiQ acting as independent advisor. The Nimrod Safety Case represented the best opportunity to capture the serious design flaws in the Nimrod which had lain dormant for years. If the Nimrod Safety Case had been drawn up with proper skill, care and attention, the catastrophic fire risks to the Nimrod MR2 fleet presented by the Cross-Feed/SCP duct and the Air-to-Air Refuelling modification would have been identified and dealt with, and the loss of XV230 in September 2006 would have been avoided.

Lamentable job

10. Unfortunately, the Nimrod Safety Case was a lamentable job from start to finish. It was riddled with errors. It missed the key dangers. Its production is a story of incompetence, complacency, and cynicism. The best opportunity to prevent the accident to XV230 was, tragically, lost. (**Chapters 10A** and **10B**)

General malaise

11. The Nimrod Safety Case process was fatally undermined by a general malaise: a widespread assumption by those involved that the Nimrod was 'safe anyway' (because it had successfully flown for 30 years) and the task of drawing up the Safety Case became essentially a paperwork and 'tick-box' exercise. (**Chapter 11**)

Criticisms of BAE Systems

12. BAE Systems bears substantial responsibility for the failure of the Nimrod Safety Case. Phases 1 and 2 were poorly planned, poorly managed and poorly executed, work was rushed and corners were cut. The end product was seriously defective. There was a big hole in its analysis: BAE Systems had left 40% of the hazards *"Open"* and 30% *"Unclassified".* The work was, in any event, riddled with errors of fact, analysis and risk categorisation. The critical catastrophic fire hazard relating to the Cross-Feed/SCP duct (Hazard H73) had not been properly assessed and, in fact, was one of those left *"Open"* and *"Unclassified".* Further, at handover meetings in 2004, BAE Systems gave the misleading impression to the Nimrod IPT and QinetiQ that the task had been properly completed and could be signed off and deliberately did not disclose to its customer the scale of the hazards it had left *"Open"* and *"Unclassified"* (many with only vague recommendations that 'further work' was required). The Nimrod IPT and QinetiQ representatives were lulled into a false sense of security. These matters raised question marks about the prevailing ethical culture at BAE Systems. (**Chapter 11)**

13. Three key BAE Systems management personnel involved in the Nimrod Safety Case bear primary responsibility for the above matters and are the subject of significant criticism: (1) the Chief Airworthiness Engineer; (2) the Task Leader; and (3) the Flight Systems and Avionics Manager. (**Chapter 11**)

Criticisms of Nimrod IPT

14. The Nimrod IPT bears substantial responsibility for the failure of the Nimrod Safety Case. The Nimrod IPT inappropriately delegated project management of the Nimrod Safety Case task to a relatively junior person without adequate oversight or supervision; failed to ensure adequate operator involvement in BAE Systems' work on Phases 1 and 2; failed to project manage properly, or to act as an 'intelligent customer' at any stage; failed to read the BAE System Reports carefully or otherwise check BAE Systems' work; failed to follow its own Safety Management Plan; failed properly to appoint an Independent Safety Advisor to audit the Nimrod Safety Case; and signed-off BAE Systems' work in circumstances where it was manifestly inappropriate to do so. Subsequently, the Nimrod IPT sentenced the outstanding risks on a manifestly inadequate, flawed and unrealistic basis, and in doing so mis-categorised the catastrophic fire risk represented by the Cross-Feed/SCP duct (Hazard H73) as *'Tolerable'* when it plainly was not. The Nimrod IPT was sloppy and complacent and outsourced its thinking. (**Chapter 11**)

15. Three key Nimrod IPT personnel involved in the Nimrod Safety Case bear primary responsibility for the above matters and are the subject of significant criticism: (1) the Nimrod IPT Leader, (2) the Head of Air Vehicle, and (3) the Safety Manager. (**Chapter 11**)

Criticisms of QinetiQ

16. QinetiQ also bears a share of responsibility for the failure of the Nimrod Safety Case. QinetiQ failed properly to carry out its role as 'independent advisor' and, in particular: failed to clarify its role at any stage; failed to check that BAE Systems sentenced risks in an appropriate manner and included risk mitigation evidence in its Reports; sent someone inadequately briefed to the critical handover meeting; failed to read the BAE Systems reports or otherwise check BAE Systems' work properly; failed to advise its customer properly or ask any intelligent questions at the key handover meetings; and subsequently 'signed-off' BAE Systems' work in circumstances where it was manifestly inappropriate to do so: in particular, without even having read any of the BAE Systems Reports and contrary to relevant regulations and standards.[14] QinetiQ's approach was fundamentally lax and compliant. (**Chapter 11**)

17. Two key QinetiQ personnel involved in the Nimrod Safety Case bear primary responsibility for the above matters and are the subject of significant criticism: (1) the Task Manager and (2) the Technical Assurance Manager. (**Chapter 11**)

Organisational Causes

18. Organisational causes played a major part in the loss of XV230. Organisational causes adversely affected the ability of the Nimrod IPT to do its job, the oversight to which it was subject, and the culture within which it operated, during the crucial years when the Nimrod Safety Case was being prepared, in particular 2001-2004.

History of MOD In-Service Support

19. Huge organisational changes took place in the MOD in-service support and airworthiness arrangements for Defence equipment and RAF aircraft in the years prior to the loss of XV230. There were three major themes at work: (a) a shift from organisation along purely 'functional' to project-oriented lines; (b) the 'rolling up' of organisations to create larger and larger 'purple' and 'through-life' management structures; and (c) 'outsourcing' to industry. (**Chapter 12**)

[14] *i.e.* in the absence of an ISA audit report, contrary to Joint Service Publication 553 and Defence Standard 00-56.

Warning in 1998

20. A Nimrod report in 1998 warned of *"the conflict between ever-reducing resources and ... increasing demands; whether they be operational, financial, legislative, or merely those symptomatic of keeping an old ac flying"*, and called for Nimrod management that was *"highly attentive"* and *"closely attuned to the incipient threat to safe standards"*, in order to safeguard the airworthiness of the fleet in the future.[15] These warnings were not sufficiently heeded in the following years. **(Chapter 13)**

Organisational trauma 1998-2006

21. The MOD suffered a sustained period of deep organisational trauma between 1998 and 2006, beginning with the 1998 Strategic Defence Review. Financial pressures and *cuts* drove a cascade of multifarious organisational *changes,* which led to a *dilution* of the airworthiness regime and culture within the MOD, and *distraction* from safety and airworthiness issues as the top priority. There was a shift in culture and priorities in the MOD towards 'business' and financial targets, at the expense of functional values such as safety and airworthiness. The Defence Logistics Organisation, in particular, came under huge pressure. Its primary focus became delivering 'change' and the 'change programme' and achieving the 'Strategic Goal' of a 20% reduction in output costs in five years and other financial savings. Airworthiness was a victim of the process started by the 1998 Strategic Defence Review. (**Chapter 13**)

22. Two senior personnel who presided over the Defence Logistics Organisation during the crucial period 2000-2004 bear particular responsibility for the episode of cuts, change, dilution and distraction and its consequences, and are the subject of significant criticism: (1) the first Chief of Defence Logistics (April 1999 to August 2002); and (2) the second Chief of Defence Logistics (September 2002 to December 2004). (**Chapter 13**)

Procurement

23. But for the delays in the Nimrod MRA4 replacement programme, XV230 would probably have no longer have been flying in September 2006, because it would have reached its Out-of-Service Date and already been scrapped or stripped for conversion. The history of Procurement generally in the MOD has been one of years of major delays and cost overruns. This has had a baleful effect on In-Service Support and safety and airworthiness generally. Poor Procurement practices have helped create 'bow waves' of deferred financial problems, the knock-on effects of which have been visited on In-Service Support, with concomitant change, confusion, dilution, and distraction as occurred in the post-Strategic Defence Review period 1998-2006. As the Rt Hon. John Hutton stated the day before his resignation as Secretary of State for Defence, *"we have no choice but to act with urgency"* on Procurement. (**Chapter 14**).

Aftermath

BOI Recommendations and post-XV230 events and measures

24. A large number of steps have been taken post-XV230 in relation to the Nimrod fleet to address the Board of Inquiry Recommendations and other maintenance and airworthiness issues which have since been revealed by subsequent incidents and investigations. I have been kept closely informed of all such developments. Pursuant to my Terms of Reference, I would have issued an immediate interim report if, at any stage, a matter of concern had come to my attention which I felt affected the immediate airworthiness of the Nimrod fleet or safety of its crews. I have not felt it necessary to issue an interim report at any stage. The continued successful deployment and operation of the Nimrod fleet post-XV230 is a tribute to the dedication of the Nimrod community and leadership at RAF Kinloss and RAF Waddington and their parent Headquarters. (**Chapter 15**)

[15] Nimrod Airworthiness Review Team Report, dated 24 July 1998, paragraphs 13 and 30.

Coroner's Inquest

25. The Coroner's Inquest produced little factual evidence of value to the Review. The Coroner's finding as to the likely source of fuel did not accord with the realistic probabilities, or the evidence before him, and his Rule 43 recommendation (that the Nimrod fleet should be grounded pending certain repairs) was based on his misunderstanding of the meaning of As Low as Reasonably Practicable (ALARP). The Coroner's widely-publicised remark that the MOD had a *"cavalier approach to safety"* was unjustified. The fundamental problems are ones of structure, culture, and procedure, not indifference. (**Chapter 16**)

Lessons and Recommendations

26. The lessons to the learned from the loss of Nimrod XV230 are profound and wide-ranging. Many of the lessons to be learned are not new. The organisational causes of the loss of Nimrod XV230 echo other major accident cases, in particular the loss of the Space Shuttles *Challenger* and *Columbia,* and cases such as the *Herald of Free Enterprise,* the *King's Cross Fire,* the *Marchioness Disaster* and *BP Texas City.* (**Chapter 17**)

27. Those involved in Military Aviation Airworthiness would benefit from an understanding of Accident Theory. (**Chapter 18**)

28. The shortcomings in the current airworthiness system in the MOD are manifold and include (**Chapter 19**):

    (1) a failure to adhere to basic Principles;

    (2) a Military Airworthiness System that is not fit for purpose;

    (3) a Safety Case regime which is ineffective and wasteful;

    (4) an inadequate appreciation of the needs of Aged Aircraft;

    (5) a series of weaknesses in the area of Personnel;

    (6) an unsatisfactory relationship between the MOD and Industry;

    (7) an unacceptable Procurement process leading to serial delays and cost-overruns; and

    (8) a Safety Culture that has allowed 'business' to eclipse Airworthiness.

29. I make Recommendations in the following eight key areas:

    (1) **A new set of Principles:** I recommend adherence to four key principles (**Chapter 20**):

    - ✔ *Leadership*
    - ✔ *Independence*
    - ✔ *People*
    - ✔ *Simplicity*

    (2) **A new Military Airworthiness Regime:** I make detailed and comprehensive recommendations under 10 headings comprising a blueprint to enable the MOD to build a New Military Airworthiness Regime (under the control of an independent Military Airworthiness Authority), which is effective, relevant and understood, which properly addresses Risk to Life, and which drives new attitudes, behaviours, and a new Safety Culture. (**Chapter 21**)

    (3) **A new approach to Safety Cases:** I make recommendations for best practice for Safety Cases for the future, which are to be brought in-house, re-named 'Risk Cases', and made more focused, proportionate, and relevant. (**Chapter 22**)

(4) **A new attitude to Aged Aircraft:** I recommend that generic problems associated with aged and 'legacy' aircraft are addressed. (**Chapter 23**)

(5) **A new Personnel Strategy:** I recommend that current weaknesses in the area of personnel are addressed. (**Chapter 24**)

(6) **A new Industry Strategy:** I recommend that flaws in the current bilateral and triangular relationships between the MOD, BAE Systems, and QinetiQ revealed by the Nimrod Safety Case are addressed. (**Chapter 25**)

(7) **A new Procurement Strategy:** I recommend that Bernard Gray's Report on Procurement is published without delay[16] and appropriate action taken as a matter of urgency. (**Chapter 26**)

(8) **A new Safety Culture:** I make recommendations for a new Safety Culture comprising a *Reporting Culture, a Just Culture, a Flexible Culture, a Learning Culture, and a Questioning Culture.* (**Chapter 27**)

30. I also make a number of further Recommendations. (**Chapter 28**)

31. The ultimate aim of this Report is to improve Safety and Airworthiness for the Future. The duty of those in authority reading this Report is to bring about, as quickly as possible, the much-needed and fundamental improvements for the Future which I have identified. This is not only for the safety of the men and women in the Services most immediately at risk, but also for the benefit of the effectiveness of Defence generally. A safe and airworthy fleet is also a more capable and effective fleet.

32. I welcome the setting up by the MOD of the Haddon-Cave Review Implementation Team[17] to implement the Recommendations in this Report as rapidly as possible.

Military Covenant

33. In my view, XV230 was lost because of a systemic breach of the Military Covenant brought about by significant failures on the part of all those involved. This must not be allowed to happen again. (**Chapter 29**)

[16] Bernard Gray's Report on Procurement was suddenly published on 16 October 2009, after completion of this Report for printing

[17] Led by my Technical Advisor, Air Vice Marshal Ness.

CHAPTER 2 – HISTORY OF THE NIMROD AIRCRAFT AND TECHNICAL DESCRIPTION

"And Cush begat Nimrod: he began to be a mighty one in the earth.
He was a mighty hunter before the Lord."
(Book of Genesis X, 8-12)

Contents

Chapter 2 sets out the history of Nimrod aircraft from 1969 to the present day and includes a short technical description.

Summary

1. The Nimrod was developed from the De Havilland Comet.

2. The first Nimrod to enter service with the RAF was XV230, on 2 October 1969.[1]

3. A total of 49 Nimrod airframes were built.

4. The Nimrod has served for nearly four decades in anti-submarine warfare, anti-surface unit warfare, maritime reconnaissance and search-and-rescue roles. More recently, it has played a valuable role as an intelligence-gatherer over land in conflicts such as Afghanistan and Iraq.

5. The Cross-Feed duct fitted in the initial Nimrod MR1 1960s design introduced a major potential source of ignition to the aircraft. In the late 1970s, Nimrod MR1s were upgraded to MR2s and fitted with Supplementary (air) Conditioning Packs which increased the potential for ignition. In the 1980s, an Air-to-Air Refuelling capability was fitted for the Falklands War which increased the risk of an uncontained escape of fuel. These modifications gave rise to design flaws which contained the seeds of the loss of XV230 in 2006.

6. There are currently 11 Nimrod MR2s and three Nimrod R1s in service.

History of the Nimrod type

Introduction

2.1 The Nimrod has had a long and distinguished history. It is a unique military aircraft with remarkable longevity, flexibility and capability. Named the 'Mighty Hunter',[2] the maritime version has for over 40 years had a pre-eminent role patrolling the seas around the British Isles, in anti-submarine warfare, anti-surface unit warfare, maritime reconnaissance and search and rescue roles. Following the end of the Cold War, its role and reach has expanded to cover vital intelligence gathering over land, in conflicts such as Afghanistan and Iraq. Throughout its life, the Nimrod has proved a remarkable and adaptable workhorse.

2.2 The Nimrod is a relatively rare type, with a production run of only 49 airframes. A total of 43 Nimrod Maritime Reconnaissance Mk 1s (MR1s) were built by Hawker Siddeley and delivered to the RAF: 38 Nimrod MR1s were built at Woodford between 1967 and 1972 and, from a further batch of eight Nimrods, five became MR1s between 1973 and 1975.[3] Of the remaining three aircraft of this batch, two were built as AEW Mk3s and one was built directly to MR2 standard. The remaining three airframes were used as Nimrod Reconnaissance Mk 1s (R1s) and delivered prior to 1973.

2.3 XV230 was the first Nimrod to enter service with the RAF. It was delivered to RAF St. Mawgan, Cornwall, on 2 October 1969.[4]

2.4 There are currently 11 Nimrod MR2s and three Nimrod R1s in service.

The De Havilland Comet

2.5 The Nimrod was developed from the world's first pressurised jet-propelled commercial airliner to reach production, the De Havilland Comet.

2.6 The Comet had its maiden flight on 27 July 1949.[5] The first Comet to receive a Certificate of Airworthiness was on 22 January 1952. The first commercial passengers were carried with the British Overseas Aircraft Corporation on 2 May 1952. H.M. The Queen Mother was an early passenger and became the first member of the British Royal Family to fly by jet. Early Comet models suffered metal fatigue and other problems, causing a series of well-publicised accidents, notably at Karachi (March 1953), at Elba (January 1954) and at Naples (April 1954). The Comet was temporarily withdrawn and redesigned (in particular, the rectangular shape of its passenger windows was found to have caused metal fatigue leading to the loss of at least two aircraft and was changed to an oval shape). The final marks of the Comet, the Comet 4 series, proved more successful. Subsequently, however, larger more efficient jet airliners, such as the Boeing 707, became more popular and superseded it in the commercial passenger world.

Replacement for the Avro Shackleton

2.7 In July 1963, MOD Air Staff Target (AST) 357 called for a sophisticated, medium-sized, jet-powered, long-range maritime reconnaissance aircraft to replace the piston-engine Avro Shackleton[6] which had had its maiden flight in March 1949,[7] and entered service in 1951[8] becoming the United Kingdom's principal Maritime Patrol Aircraft (MPA). The Shackleton had witnessed the growth of the Soviet surface vessel and submarine fleet as the Cold War intensified throughout the 1950s and 1960s, increasing the importance of the MPA role. It was realised,

[1] www.raf.mod.uk/rafkinloss/aboutus/nimrodthroughtheyears.cfm

[2] Book of Genesis X, 8-12.

[3] The remaining 33 in the first order of 38 aircraft were numbered sequentially XV231-263.

[4] www.raf.mod.uk/rafkinloss/aboutus/nimrodthroughtheyears.cfm

[5] Comet Chief Test pilot was John Cunningham.

[6] Named after the Polar explorer, Sir Ernest Shackleton.

[7] The Avro Shackleton was reputedly very cold, noisy and uncomfortable for crews. It was often said the one of the nicest sounds in the world was a Shackleton getting airborne, because that meant you were not on board.

[8] The maritime role had been carried out in the Second World War by flying boats such as the Short Sunderland and Consolidated Catalina and by long-range land-based aircraft, such as the Lockheed Liberator, Boeing Flying Fortress and Handley Page Halifax.

however, that the requirements of AST 357 could never be met in the timescale necessary to replace the Shackleton and Air Staff Requirement (ASR) 381 was issued specifying a less complex requirement.

2.8 In July 1964, Hawker Siddeley Aviation (formerly De Havilland) made a formal proposal to convert the Comet 4C turbo-jet powered airliner into a military aircraft (designated HS801). The underside of the Comet fuselage was to be substantially reconfigured to fit a large bomb-bay, extra fuel tanks were to be fitted to give greater range and endurance, and the engines were to be changed from Rolls-Royce Avon engines to Spey 250 engines.

2.9 In February 1965, it was announced in Parliament that the HS801 had been selected to replace the Shackleton.

Nimrod MR1

2.10 The HS801 became the first Nimrod, the Nimrod MR1. The type was designed for anti-submarine and anti-surface unit warfare, surface reconnaissance and for search and rescue operations, i.e. the traditional roles of the MPA.[9] The Nimrod MR1 was equipped with a wide range of radar and acoustic equipment and had the ability to drop sonobuoys, to detect and track submarines, as well as carrying weapons such as torpedoes and Search and Rescue (SAR) equipment.

2.11 The first flight of a prototype Nimrod MR1 was on 23 May 1967.[10] The first flight of a new-build production Nimrod MR1 was on 28 June 1968. As stated above, the RAF took delivery of its first Nimrod MR1 on 2 October 1969, at RAF St. Mawgan when it was handed to No. 236 Operational Conversion Unit.[11] This was XV230.

2.12 The Nimrod MR1 enabled the newly formed No. 18 (Maritime) Group[12] of Strike Command to fulfil its task:

> *"The undertaking of surveillance operations to maintain a flow of information about the movement of potentially hostile surface vessels and submarines over vast ocean areas."* [13]

2.13 The 43 Nimrod MR1s were operated primarily from RAF Kinloss, Morayshire, and RAF St. Mawgan, Cornwall. No. 203 Squadron at Luqa, Malta, were also equipped with Nimrods but, following the 1974 Defence Review, this Squadron was disbanded and its Nimrod MR1s flown back to the UK and placed in storage.

Nimrod R1

2.14 Three additional airframes were also ordered from Hawker Siddeley to replace the ageing Comet R2s still used by the RAF for Electronic Intelligence (ELINT) duties. The first of these three extra airframes was delivered to RAF Wyton in July 1971. They were each fitted with a suite of sophisticated and sensitive electronic intelligence-gathering equipment and antennae and were designated Nimrod Reconnaissance Mk 1 (Nimrod R1). The principal external difference from the maritime Nimrod was that they did not have the Magnetic Anomaly Detector probe fitted in the tail. As stated above, the three original Nimrod R1s were built by Hawker Siddeley at Woodford and delivered to the RAF between 1970 and 1973. There are currently three Nimrod R1s in existence, operated by No. 51 Squadron from RAF Waddington.

2.15 In 1995, a Nimrod R1 (XW666) was lost following an engine fire (see below). It was replaced in December 1996 by the conversion of a Nimrod MR2 (XV249), then in storage at RAF Kinloss, into a Nimrod R1.

2.16 The Nimrod R1 played a key role in the Falklands Conflict of 1982. Its increasingly important electronic intelligence (ELINT) capabilities have been employed in almost every conflict involving UK forces since then.

[9] Paragraph 4 of BAE Nimrod Task 06-3409 (September 2004).

[10] Paragraph 4 of BAE Nimrod Task 06-3409 (September 2004).

[11] This unit trained aircrew to operate the Nimrod; it was renumbered No 42(R) Sqn in 1992 and continues to fulfil the training role.

[12] The RAF's Coastal Command became No 18 (Maritime) Group of Strike Command on 27 November 1969.

[13] Definition of the role of No. 18 (Maritime) Group of Strike Command, BAe Nimrod, John Chatres, London, 1986.

Nimrod MR2

2.17 In 1975, a comprehensive programme of upgrading the avionics on the MR1 began, including fitting the new Thorn EMI Searchwater radar,[14] a new GEC Central Tactical System and the AQS-901 acoustics system compatible with the latest generation of sonobouys, and the Loral Electronic Support Measures System located in two new wing tip pods. The upgraded aircraft became the Nimrod MR2. A total of 35 Nimrod MR1s were upgraded to the Nimrod MR2 standard by BAE Systems between 1975 and 1984. The first Nimrod MR2 was delivered to 201 Squadron at RAF Kinloss on 23 August 1979.[15]

2.18 The decision by the Argentinean *junta* to invade the Falkland Islands in April 1982 gave rise to an Urgent Operational Requirement (UOR) to equip the Nimrod MR2 with an Air-to-Air Refuelling (AAR) capability as part of Operation Corporate. In just 18 days, eight Nimrod MR2s were fitted with in-flight refuelling probes, taken from Vulcans, and stabilising winglets on the tailplane. The probes were linked to ordinary ground refuelling hoses running through the cockpit, down the centre aisle of the aircraft and exiting the cabin in the galley area to join the refuel gallery in the wings. The fitting of the AAR capability extended the Nimrod's endurance to 20 hours in the air.[16] The Nimrod MR2's self-defence capability was also enhanced by modifying their under-wing hard points to take AIM-9L Sidewinder air-to-air missiles.[17] They flew numerous patrols over the South Atlantic from Ascension Island in support of British operations during the Falklands War.

2.19 In more recent years, the MR2 has been fitted with an electro-optical camera for imagery intelligence (IMINT) tasks.

2.20 The operating crew of the MR2 comprises two pilots and a flight engineer, two weapon systems officers (WSO) (tactical and route), and a WSO who is the sensor and communications coordinator and who, in turn, is supported by a team of two 'wet' weapon systems operators (WSOps) and four 'dry' WSOps. The 'wet' team supervise the aircraft's acoustic processors, which monitor active and passive sonobuoys, whilst the 'dry' team manage a range of radar and non-acoustic sensors.

2.21 There are currently 11 Nimrod MR2s in existence, operated by No. 120 Squadron, No. 201 Squadron, and No. 42(R) Squadron at RAF Kinloss.[18]

Nimrod AEW3

2.22 In August 1972, the RAF issued an AST to replace its Airborne Early Warning (AEW) variant of the Shackleton operated by No. 8 Squadron. In March 1977, the procurement was announced of a specialised version of the Nimrod. This variant would have a large bulbous radome in the nose and tail to house Marconi scanners providing 360° radar coverage. Three AEW3 development aircraft were manufactured and the first one flew on 16 July 1980. A production batch of eight Nimrod AEW3 aircraft was then laid down using a further eight redundant Nimrod MR1 airframes.[19] The first flew on 9 March 1982 and by late 1984 the first 'interim standard' Nimrod AEW3 aircraft was delivered by British Aerospace to No. 8 Squadron to allow crew training to commence.[20] In September 1986, however, technical problems with the AEW3 system led to the programme being re-opened to competing bidders. In December 1986 the Boeing E-3 Sentry AWAC was awarded the contract. The Nimrod AEW3 programme was cancelled. The Nimrod AEW3 airframes were stored at RAF Abingdon until they were scrapped in the 1990s.

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[14] A radar specifically designed for the maritime role, which replaced the ASV 21 radar.

[15] XV236.

[16] Nimrods fitted with AAR were known as MR2Ps until the fleet were all at Mod 715 standard.

[17] Which led to the Nimrod MR2 being called "the largest fighter in the world".

[18] A detailed history of the Nimrod fleet up to 1985 can be read in "British Aerospace Nimrod – Modern Combat Aircraft No 24" by John Chartres. Ian Allan, UK, April 1986 ISBN 0711015759.

[19] Causing Air Marshall Sir John Curtiss, AOC 18 Group to remark – "*We don't have enough Nimrods.*"

[20] www.aeroflight.co.uk/types/uk/bae_systems/nimrod/nimrod.htm

Nimrod 2000/MRA4

2.23 In 1993, Air Staff Requirement (ASR) 420 called for a replacement for the MR2. On 25 July 1996, the contract was awarded to BAE Systems who proposed using the existing MR2 airframes, fitting larger wings (127 feet), Rolls-Royce BMW BR.710 engines, new radar and sensor systems and a new tactical computer system. In February 1997, the first three stripped-down Nimrod fuselages were delivered to FR Aviation in Bournemouth, who were contracted to refurbish them. By 1999, however, the programme was three years behind schedule and the first prototype Nimrod MRA4 flight did not take place until 26 August 2004. In September 2004, the planned order for Nimrod MRA4 was reduced from 18 to "*about 12*".

2.24 The original planned in-service date for the MRA4 was April 2003, but was delayed five times and now stands at 2010. This has meant that the out-of-service date of the existing MR2 fleet has had commensurately to be put back several times and Nimrod MR2 aircraft have had to remain in service far longer than anticipated (see **Chapter 14**).

Nimrod aircraft – technical description

2.25 The Nimrod is of a conventional aluminium alloy, semi-monocoque pressurised fuselage construction. It has a low, cantilevered monoplane wing which has a 20-degree swept-back all metal two-spar structure. It is approximately 129 ft long, 30 ft high, with a wingspan of 115 ft and wing area of 2,121 sq ft. It weighs 96,000 lbs without fuel, and 184,000 lbs fully loaded with fuel and stores. It has a maximum speed of 360 kts, a service ceiling of 42,000 ft and a maximum range of about 3,800 nautical miles without AAR. It has a typical maximum flight time of eight hours on internal fuel and maximum endurance of about ten hours; this was achieved by routinely shutting down two engines for fuel economy. Flight times can be further extended to 20 hours with multiple AAR.

2.26 The aircraft is powered by four Rolls-Royce RB 168-20 Spey 250 engines embedded in pairs in the root of each wing. The Spey 250 is a two-spool, low ratio, by-pass turbo-fan engine with a tubo-annular combustion system, developing 12,160 lb of thrust. An Auxiliary Power Unit (APU) is used to supply air for engine starts on the ground. The air supplied by the APU is ducted to a Cross-Feed duct running across the bomb bay between the port and starboard engines.

2.27 The MR1 was designed and certified to MOD Specification No. MR 254 D&P dated 1965. MR 254 D&P accepted that the basic Comet 4C aircraft design was certificated to British Civil Airworthiness Requirements (BCAR) 1956 Edition.[21] The MR2 was designed and certified to MOD Specification No MR286 D&P dated 6 May 1975. Specification No MR286 D&P accepted the same general certification base as MR 254 D&P. The change in design from a Comet 4C to a Nimrod MR1 was required to comply with AvP 970 1965 Edition (Re-issue).

Fatigue and Corrosion

2.28 The flight profiles of the Nimrod MR2s and R1s have been very different. The maritime patrol work of the Nimrod MR2 has required it to fly 'in the weather' and frequently at low level (200-300 feet) over the sea, causing the structure to fatigue at a faster rate than for normal cruise flight profiles. By contrast, the R1 has tended to fly only at high level and, therefore, in a structurally more benign environment. As a result, the fatigue and corrosion levels of the MR2s have been greater than the R1s. The corrosion suffered is not only evident on the structure but on some components, such as elements of the fuel system.

2.29 The number of sorties and hours flown by the Nimrod types has been relatively low compared with civilian commercial aircraft.[22] This is not unusual for military aircraft.

[21] Section D, Issue 3, dated 1 July 1956 and Section J. Issue 2, dated 1 June 1953.

[22] BAE Systems in BAE Report MBU-DEF-R-NIM-SDC-076 Review of Nimrod In-Service Accident History dated September 2004 noted that the Nimrod MR 2 and R 1 fleet collectively had accumulated approximately 400,000 flying hours. As at the present date, the aircraft in the fleet which have accumulated the most flying hours have flown more than 18,000 flying hours.

Nimrod Technical Developments

2.30 The modification of the design of the Comet to allow the birth of the Nimrod involved a significant redesign and the addition of new fuselage elements as mentioned above. The conversion of the Nimrod MR1 to the MR2 was driven principally by a need to upgrade the aircraft's sensor systems. However, as a result of the additional electronics of the MR2, the aircraft's air conditioning system had to be supplemented to ensure additional cooling. AAR was introduced to the Nimrod as part of the urgent response to the Falklands crisis as noted above.

2.31 The following paragraphs set out the timeline of those changes in design which are relevant to the loss of XV230 many years later.

Conversion from Comet to Nimrod MR1

2.32 The replacement of the Comet's Avon powerplants with the Spey 250 engine necessitated the introduction of an air starter system. To provide this, APU was installed in the tail area and a duct used to take hot air from the APU to the engine starter turbine. The endurance of the Nimrod could be increased by shutting down up to two engines. As and when it was necessary to re-start engines during flight, hot, pressurised air could be routed through the Cross-Feed duct from engines on one side of the aircraft to re-start the engines on the other side. Therefore, there were occasions, both on the ground and airborne, when the Cross-Feed duct would contain very hot air and consequently it was insulated with a fibreglass covering contained within a stainless steel outer layer. This insulation was primarily designed to prevent heat damage to the surrounding structure.

2.33 In order to further extend the endurance of the MR1, additional fuel tanks, No. 5 and No. 6, were added below the fuselage cabin floor, in what were previously baggage compartments, and two further tanks, No. 7 tank port and starboard, were attached on either side of the fuselage within the wing root area. The Cross-Feed duct passed in front of the new No. 7 tank, running through an area known as the No. 7 Tank Dry Bay on the port and starboard side.

Conversion from MR1 to MR2

2.34 The principal reason for the conversion of the Nimrod from MR1 to MR2 was to upgrade the aircraft's sensor systems. The heat generated by the new electronic equipment on board required additional air supplies for cooling. For this purpose, a Supplementary Conditioning Pack (SCP) was fitted to the Nimrod MR2 in the rear of the aircraft. The SCP was supplied with engine bleed-air from a branch taken off from the Cross-Feed duct. This air was ducted through a pressure regulating valve in the bomb bay and then ducted rearwards outside the bomb bay. At the point where the SCP leaves the bomb bay, it is routed through the lower part of the starboard No. 7 Tank Dry Bay. With engines at high power at low altitude, the temperature of the air in the SCP duct could be in the region of 470°C. Thus, this addition to the already existing Cross-Feed duct placed a potential source of ignition in the aircraft, the significance of which was not recognised until over 25 years later, with the investigation into the loss of XV230; this is discussed in more detail in **Chapter 4**.

Development of the AEW Mk3 and AAR Capability

2.35 As explained above, the original Nimrod AAR installation was fitted during the Falklands conflict in 1982. Subsequently, the MOD decided to upgrade the AAR system and move the refuelling pipes, for the most part, out of the cabin and into the bomb bay. In 1985, in the course of the AEW3 programme, which was also required to have an AAR capability, the AAR system design was refined, to enable its incorporation as a formal modification to the aircraft design.

2.36 During the initial incorporation of AAR into the AEW3, one of the fuel system design features which was considered by British Aerospace was the effect of the fuel tank blow-off valves. These valves are fitted to all, bar two,[23] of the aircraft's fuel tanks and operate as pressure relief valves: should the pressure in a fuel tank exceed

[23] The No. 4A tanks.

a prescribed limit, fuel is ejected from the tank through the valves to the atmosphere. The blow-off outlet for the No. 5 tank is situated forward of the port engine intakes and there was concern that, should fuel be ejected during AAR, it might enter these intakes. Therefore, the No. 5 tank blow-off valve was disabled to prevent this occurring. Nonetheless, the AEW3 flight trials team noted that there was a potential risk from other blow-off valves, including that of No. 1 tank, and recommended investigation to determine the effect should blow-off occur from these tanks.

2.37 Unfortunately, it appears that the subsequent demise of the AEW3 project led to these recommendations remaining on the shelf, and potential sources of fuel blow-off and overflow during AAR remained unremedied. The contribution of blow-off and overflow during AAR to the loss of XV230 must be carefully considered in any comprehensive analysis of the loss of the aircraft. It is analysed in **Chapter 6**.

Nimrod in-service safety record

2.38 The Nimrod had historically been considered by its crews to be a safe aircraft. In the years prior to the loss of XV230, the Nimrod had completed some 400,000 flying hours with only four accidents recorded resulting in the loss of an aircraft, namely:

2.38.1 *Nimrod MR2 XV256:* The first Nimrod to be lost in an accident was Nimrod MR2 XV256 on 17 November 1980. Shortly after take-off from RAF Kinloss, the aircraft flew through a dense flock of seagulls. Ingestion of a large number of birds into the engines caused a significant loss of power and the aircraft crashed in woods close to the airfield. Although, tragically, both pilots were killed in the accident, their skill in crash landing the aircraft ensured that their crew survived.

2.38.2 *Nimrod MR2 XV257:* Nimrod MR2 XV257 made an emergency landing at RAF St. Mawgan on 3 June 1984, following an uncontained fire, caused by the ignition of one of its load of flares in the bomb bay. The flare, at the rear of the bomb bay, ignited shortly after take-off, initiating the bomb bay fire warning, followed one minute later by the centre section overheat warning and an underfloor alarm in the aileron bay. As the underfloor alarm sounded, smoke began to enter the cabin. The captain completed a dumb-bell turn to return to St. Mawgan as quickly as possible. Despite the fact that the aircraft was landed within four minutes of the bomb bay fire warning's initiation, the aircraft suffered extensive (Category 5) damage, including a breached pressure hull.

2.38.3 *Nimrod R1 XW666:* On 16 May 1995, Nimrod R1 XW666 suffered a mechanical failure in the No. 4 engine, as a result of which a starter turbine blade punctured the No. 2 fuel tank. This allowed fuel to enter the space between the tank and the engine bay titanium fire wall where it ignited, provoking a fire which could not be suppressed. Although the aircraft initially diverted towards RAF Lossiemouth, the captain decided to ditch in the Moray Firth, following reports from a crewman at the starboard escape hatch that the starboard wing was rapidly disintegrating. Subsequent analysis of the aircraft's rear spar determined that, during the four minutes of fire, the rear spar's strength had deteriorated by 25%, illustrating the fine judgment of the aircraft captain in ditching when he did.

2.38.4 *Nimrod MR2 XV239:* On 1 September 1995, whilst conducting an air display at the Canadian International Air Show in Toronto, Nimrod XV239 crashed into Lake Ontario, killing the seven man crew. The accident was attributed to human factors, in that the aircraft had been manoeuvred at a speed and G-loading causing it to stall at a height from which recovery was impossible.

2.39 Of these accidents, only one (XW666) could be attributed to a failure of the aircraft's systems. There was a further incident, on XV227 on 22 November 2004, in which, unbeknown to the aircraft crew, a hot air duct disintegrated, which led to the airframe concerned being retired early. However, there is no discernable pattern to the aircraft accidents detailed above. None of the accidents illustrated a pattern of faults with the aircraft or was directly relevant to the loss of XV230. I discuss the wider relevance of the XV227 incident and other previous incidents in **Chapter 8**.

Military role and importance of the Nimrod MR2

2.40 The Nimrod was originally designed as a successor to the Avro Shackleton Maritime Patrol Aircraft (MPA) in the maritime reconnaissance role.[24] The aircraft was specifically designed and built for maritime reconnaissance. Since 1969, it has fulfilled a largely maritime role, until its more recent involvement overland in Afghanistan and Iraq. The ability of the Nimrod to transit at high speed and then 'loiter' at a lower speed for long periods made it ideally suited to the task of maritime reconnaissance. The terms MPA and Maritime Reconnaissance are effectively interchangeable and encompass a number of key subsidiary roles. The first is that of Anti-Submarine Warfare (ASW). The Nimrod is equipped with a range of sensors, including sonobuoys and radar to detect submarines, and torpedoes to attack them if required. The aircraft can also undertake Anti Surface-Unit Warfare (ASUW), using its sensors to detect, identify and track surface vessels; and, if required, the Nimrod can also use the same sensors to guide other aircraft to attack these surface vessels. While carrying out both roles, the Nimrod will collect and convey intelligence information to its operating authority. The final core role of the MPA is that of Search and Rescue (SAR). Nimrods can utilise all of their sensors to undertake long range SAR missions and are capable of dropping survival equipment and of guiding helicopters to specific locations to rescue survivors.

2.41 During the *Cold War* the RAF Kinloss and RAF St. Mawgan Nimrod squadrons maintained regular surveillance of Soviet maritime activities and supported UK and allied naval forces. Although the Nimrod's principal area of operations was destined to be the North Atlantic, its specification[25] required it to be capable of world-wide employment. It was deployed regularly to the Mediterranean and the Gulf; indeed, Nimrods were even used to rendezvous with Royal Navy (RN) submarines surfaced at the North Pole in 1988. The MR2 was also involved in fishery protection in the *Cod Wars* (1973-1976) and SAR operations such as the *Fastnet Race* (1979), *Alexander Kielland* (1980), *Virgin Atlantic Challenger* (1985), *Piper Alpha* (1988), as well as numerous other maritime support operations. For many years, a Nimrod and crew were held at 60 minutes readiness to conduct SAR operations within the UK's area of responsibility, an area which stretches out into the middle of the Atlantic.

2.42 As noted above, the Nimrod fleet was adapted for AAR and deployed in the *Falklands War* (1982), where it provided much needed support to the deploying British fleet and ensured that the UK's forward deployment base at Ascension Island remained secure.

2.43 The fall of the Berlin Wall in 1989 and the subsequent end of the decades long *Cold War* witnessed the demise of the vast Soviet naval arsenal against which the Nimrod fleet had been ranged. However, new, equally challenging tasks soon presented themselves. Nimrods were deployed in the *Persian Gulf War (First Gulf War)* of 1990, when, amongst other things, they provided targeting information against Iraqi naval units, and participated in the UN blockade of Iraq (1990-1991). The aircraft also found gainful employment patrolling the waters of the Adriatic during the conflicts that followed the collapse of Yugoslavia.

Evolution and expansion of the Nimrod's role

2.44 Advances in computer technology meant that it became increasingly possible to co-ordinate the activities and products of military information gatherers. The importance of ensuring that commanders had access to all the information that they required led to concepts such as Network Enabled Capability, in which multiple gatherers of information feed an interlinked network, supplying data to multiple recipients. Whether the gatherer is an individual on the ground, a tank, an aircraft or a satellite does not matter. Thus developed the concept of Intelligence, Surveillance, Target-Acquisition and Reconnaissance (ISTAR). Clearly the Nimrod (in both MR and R roles) is a major ISTAR asset. The size and flexibility of the Nimrod airframe and its crews allowed Nimrod to assume new intelligence roles as and when required.[26] The aircraft's ability to loiter for long periods was utilised, in combination with a new optical sensor, in operations over Afghanistan and Iraq. The fact that the aircraft was

[24] Although 3 aircraft were built to fulfil an ELINT role for No. 51 Sqn, replacing Comet aircraft.

[25] Aircraft Specification No MR254 D&P for HS801 Maritime Reconnaissance Aircraft, page 1, paragraph 2.1.

[26] The use of aircraft in roles for which they were not originally designed is not a new development. Most of the land-based MPA of the Second World War were converted bombers. The Nimrod's predecessor, the Shackleton had been used as a bomber (in Aden) and as a troop transport during the Suez crisis. During operations in support of ground forces in Oman in the late 1950s Shackletons flew 429 sorties, dropped 1500 tons of bombs and expended 700,000 rounds of ammunition. One crew even performed a close air support mission, using their nose cannons against a rebel position.

now operating over land, rather than in its traditional maritime environment, was not significant as it continued to fly within its cleared operational parameters.[27]

2.45 Nimrods have been extremely successful in this new role. They have proved pivotal to the successful completion of many missions and enabled risks to allied ground forces to be reduced significantly. Although the Nimrod is no longer cleared to undertake AAR, limiting the time that it can provide support to ground forces, it has continued to make a valuable contribution to current operations in theatre.

2.46 The combination of traditional and innovative roles means that the contribution that the Nimrod and its crews makes to UK defence has, if anything, grown over recent years, despite the demise of the Soviet fleet. The Nimrod platform contributes to a significant majority of British defence tasks and the Nimrod force will continue to do so until replacement of the MR2 by the MRA4 (and in the case of the R1, the Rivet Joint Boeing 707 aircraft).

Conclusion

2.47 The modification of the Comet design to create the Nimrod produced a unique and outstanding aircraft which for many years had a rightful claim to be the world's premier MPA. Throughout its 40-year life, the Nimrod has very successfully and safely fulfilled a wide range of complex roles, including monitoring Soviet maritime activity and, more recently, in support of land conflicts. The Nimrod has been a British success story. The Nimrod has been, and remains, important to many aspects of British Defence.

2.48 How was it, therefore, that XV230 suffered a catastrophic failure on 2 September 2006 with the loss of 14 lives? In this Report, I explain the manner in which the conditions for a major catastrophic accident can be created by lurking weaknesses, errors and omissions sometimes set in train years apart. The history of the development of the Nimrod from the Comet and its subsequent modification to the MR2 and fitting of AAR, show the insidious manner in which several potential weaknesses can weave into a dangerous design over time. It is important to analyse and understand how such individual weaknesses can coalesce and have unforeseen ramifications far beyond their perceived significance when each is simply viewed in isolation.

2.49 The seeds of the disaster which befell the XV230 in September 2006 lay in the Nimrod's design and modifications decades before. I discuss this in detail in **Chapters 4** to **6**.

[27] As mentioned earlier the Nimrod MR versions had a long history of operating in the Gulf prior to the more recent Gulf conflicts; a history stretching back to its predecessor, the Shackleton. The Nimrod R has a similar history and has operated in the Gulf for considerable periods during and since the first Gulf conflict.

CHAPTER 3 – THE BOARD OF INQUIRY REPORT

Contents

Chapter 3 explains the findings of the Nimrod XV230 Board of Inquiry.

Summary

1. The XV230 Board of Inquiry conducted a seven-month inquiry into the accident and concluded that XV230 suffered an uncontrollable fire leading to a mid-air break-up and the loss of all lives onboard.

2. Despite being unable to examine the crash site and physical evidence because of the high level of enemy threat, the Board of Inquiry was nevertheless able by a process of careful deduction, and with the assistance of the UK Air Accident Investigation Branch, to determine that the most probable physical causes of the fire and explosion were:[1]

   a. The escape of fuel during Air-to-Air Refuelling (AAR), occasioned by an overflow from No. 1 tank, or a leak from the fuel system (fuel coupling or pipe), led to an accumulation of fuel within the No. 7 Tank Dry Bay. Although of a lower probability, the fuel leak could have been caused by a hot air leak damaging fuel system seals; and

   b. The ignition of that fuel following contact with an exposed element of the aircraft's Cross-Feed/Supplementary Conditioning Pack duct.

3. The broad findings of the Board of Inquiry have not been seriously challenged. There has been agreement as to the Board of Inquiry's identification of the ignition source, but there have been some differing opinions expressed as to the fuel source.

4. The United States Air Force Safety Center conducted a review of the Board of Inquiry Report and have endorsed the Board of Inquiry's work. They agree with its broad findings, although differ on some matters of detail.

5. The main conclusions of the Board of Inquiry Report have, therefore, been confirmed by two leading agencies, the UK Air Accident Investigation Branch and the United States Air Force Safety Center. The various occurrences since 2006 and other evidence which I have examined, also all tend to support the Board of Inquiry's analysis.

6. I am satisfied that the Board of Inquiry's findings are a sound basis upon which to found this Review.

[1] BOI Report, paragraph 60 [2-44 to 2-45].

BOI Report

Board of Inquiry convened

3.1 Immediately following the news that XV230 was down, a Board of Inquiry (BOI) was convened by the Air Officer Commanding (AOC) No. 2 Group in accordance with the requirements of Joint Service Publication 551. The BOI comprised Wing Commander Nick Sharpe (President), Squadron Leader John Nelson, and Squadron Leader Andrew Gransden. The BOI members assembled on 3 September 2006 at the Headquarters of No. 2 Group at RAF High Wycombe and were flown to Kandahar together with a Defence Aviation Safety Centre BOI Advisor, RAF Accident Recovery personnel and Royal Navy Flight Safety/Accident Investigation team personnel. The BOI was prevented, however, from visiting the crash site because of the high level of enemy threat. It set about gathering evidence and conducting interviews. On return to RAF Kinloss, on 18 September 2006, it began the task of analysing such evidence as had fortunately been gathered by allied troops first on the scene (of which the Data Acquisition and Recording Unit (DARU) and the Mission Tape proved invaluable), photographs taken at the crash site, and some recovered items of equipment, together with the Air Traffic Control (ATC) recordings, the witness evidence, and records of previous Boards of Inquiry and other investigations relating to accidents involving Nimrods.

3.2 After nearly seven months of painstaking work, the BOI delivered its Report to the Convening Authority on 20 April 2007 and a further supplementary report on 25 July 2007. The President and members of the BOI received praise from all quarters for the thoroughness of their Report which demonstrated "*tenacity and determination*" in seeking to ascertain the true causes of the accident.[2] I entirely agree with, and endorse, this consensus. Within a relatively short period of time, and despite the formidable forensic difficulties faced due to the lack of physical evidence, the BOI produced a thorough and logical report which clearly identified the most likely causes of the fire and explosion, highlighted a number of significant failings, and made a series of valuable and practical recommendations.

3.3 It was not within the BOI's remit to consider, or attribute, responsibility for the accident.

3.4 The BOI found that XV230 was lost because of an uncontrollable fire in the fuselage which led to a break up of the aircraft in mid-air. The entire BOI Report should be treated as incorporated into this Report. A copy of the redacted version is publicly available and can be found at: http://www.mod.uk/defenceinternet/aboutdefence/corporatepublications/boardsofinquiry/boinimrodmr2xv230.htm.

BOI's Conclusions as to the Location of the Fire

3.5 The BOI's first task was to identify the location of the fire, particularly given the apparently contradictory evidence of the Harrier GR7 pilot and that provided by 'A' Squadron Royal Canadian Dragoons (RCD).[3] The BOI's conclusion was that the fire had originated on the starboard side of the aircraft.[4] Whilst it was impossible to discount completely the existence of a fire on the port side of XV230, if there was one, it was subsidiary to the main fire and caused by it.[5] Having reconstructed the possible view of the aircraft held by the RCD as it passed their position, and with the benefit of independent analysis by the Air Accident Investigation Branch (AAIB), the BOI determined that both the aspect of the aircraft and its relative size could have led the RCD to conclude that the aircraft was banking to the left and that the large, luminous starboard fire was on the port side.[6]

3.6 From the evidence available, the BOI considered that the fire may have initiated in one of four locations, namely: (1) the bomb bay; (2) the No. 3 engine; (3) the starboard Rib 1 landing; and (4) the dry bay forward of the starboard No. 7 fuel tank, which has since come to be known as the starboard No. 7 Tank Dry Bay.[7] The BOI

[2] See Comments on BOI Report by the RAF Kinloss Station Commander, paragraph 1 [3-1]; and Comments by Air Member for Materiel, Air Marshal Sir Barry Thornton, Air Officer Commanding No. 2 Group, Air-Vice Marshal Andy Pulford, and Commander-in-Chief Air Command, Air Chief Marshal Sir Clive Loader.

[3] BOI Report, paragraph 22 [2-13].

[4] BOI Report, paragraph 22a [2-13].

[5] BOI Report, paragraph 22c [2-14].

[6] BOI Report, paragraph 22b [2-13].

[7] BOI Report, paragraph 23 [2-14].

ruled out the first possibility, considered the second and third to be most unlikely and unlikely, respectively, and concluded that the last was the most likely source of the fire. The BOI's analysis was that the starboard No. 7 Tank Dry Bay contained numerous fuel pipes running through it, in addition to the Cross-Feed duct, and thus contained all the elements necessary to be the origin and the sustainment point of a fire.[8] A study commissioned with QinetiQ[9] confirmed the viability of the BOI's assessment.[10]

BOI's Conclusions as to the Sequence of Events

3.7 Notwithstanding the absence of physical evidence, by a process of careful analysis and deduction, the BOI was able to determine the following probable sequence of events, and possible alternatives, as having led to the loss of XV230 and its crew:[11]

3.7.1 As the Air-to-Air Refuelling (AAR) serial drew to a close, fuel escaped, either from overflow from No. 1 fuel tank,[12] or from a leak in the fuel pipe work (probably a fuel coupling, but possibly a fuel pipe). It was possible, but less likely, that the fuel leak was provoked by a hot air leak.

3.7.2 The escaped fuel tracked rearwards, either internally or externally. If the fuel had escaped from the No. 1 tank blow-off valve, it would track rearwards against the skin of the aircraft penetrating the fuselage along external panel joints. If fuel overflowed during AAR, fuel leaking internally from the vent system could also be involved.

3.7.3 Some fuel accumulated on the lower panel of the starboard No. 7 Tank Dry Bay and fuel also entered the Supplementary Cooling Pack (SCP) fairing immediately aft of that bay.

3.7.4 Fuel made contact with one of the areas of exposed ducting (or soaked into pipe insulation). The ducting's high temperature led to auto-ignition within seconds and ignited the fuel on the lower panel of the starboard No. 7 Tank Dry Bay.

3.7.5 Combustion products escaped from the dry bay, exiting outwards, through gaps in the wing structure and, internally, into the bomb bay. Simultaneous heating of the aileron bay caused hydraulic fluid present in that bay to reach ignition temperature and a fire commenced in the aileron bay.

3.7.6 The fire, now on both sides of the aileron bay wall, penetrated that wall and the aircraft depressurised. Depressurisation increased the flow of air over the fire and hastened the destruction of nearby wing panels. At the same time, the couplings to the fore of No. 7 tank began to leak and supply more fuel to the fire. The effect of the depressurisation and venting of the fire to the outside air would have been to draw any remaining combustion gasses from the bomb bay and away from the cabin.

3.7.7 The crew had no means of attacking the principal fire, but attempted to subdue the secondary fire initiated in the aileron bay.

3.7.8 No. 7 tank was protected for some five minutes by the fuel within it. However, at about this time, the tank's fuel began to boil and reached pressures which could not be contained by the tank structure. The fuel escaped as a sonic jet from a breach in the upper surface of the fuel tank. Although initially igniting as it escaped the tank, the velocity of the jet soon exceeded the burning velocity and the start of combustion moved along the jet, downstream of the source. This fuel jet arc was probably the second fire observed by the Harrier GR7 pilot.

3.7.9 At some stage, a short-lived fire was initiated in the rear tail compartment. This may have been as a result of fuel leaking into the compartment being ignited by the fuel jet.

[8] BOI Report, paragraph 28 [2-16].

[9] BOI Report, Exhibit 30.

[10] BOI Report, paragraph 29 [2-16].

[11] BOI Report, paragraphs 46 to 57 [2-41 – 2-43].

[12] Previously described by the BOI as a combination of blow-off and leaking from the vent system (BOI Annex M).

3.7.10 The fire would have considerably weakened the aircraft's spar and the aircraft's hydraulic systems would have begun to fail as hydraulic liquid boiled and pipe unions melted. The loss of primary and back-up hydraulic systems and possible fire damage to flying control cables and pulleys, probably led to a loss of control at some stage during the last 60 seconds of flight. During this period, the No. 7 tank was probably subjected to a boiling liquid expanding vapour explosion (BLEVE), either as a result of wing deformation or as internal pressure began to rise to a point at which it ruptured. The BLEVE was probably the fireball reported by the GR7 pilot and Canadian witnesses.

3.7.11 Very shortly afterwards, and at a height of about 700 feet above ground level, the weakened starboard wing failed, breaking from the aircraft and striking the tail structure. As the remaining aircraft structure began to roll to the right, the port wing also failed and, shortly thereafter, the tail structure broke from the aircraft. All four principal elements of the aircraft structure struck the ground within close proximity. The accident was not survivable.

BOI's Conclusions as to the Probable Physical Causes of the Accident

3.8 In summary, therefore, whilst the BOI was unable to determine positively the exact source or causes of the fire which led to the loss of XV230 and its crew,[13] the BOI found that the following were the most probable physical causes of the fire and explosion:[14]

3.8.1 The escape of fuel during AAR, occasioned by an overflow from No. 1 tank, or a leak from the fuel system (fuel coupling or pipe), led to an accumulation of fuel within the No. 7 Tank Dry Bay. Although of a lower probability, the fuel leak could have been caused by a hot air leak damaging fuel system seals; and

3.8.2 The ignition of that fuel following contact with an exposed element of the aircraft's Cross Feed/SCP duct.

3.9 The BOI also identified the following as being possible contributory factors to the accident:[15]

3.9.1 The age of the Nimrod MR2's non-structural system components;

3.9.2 The Nimrod MR2 maintenance policy in relation to the fuel and hot air systems;

3.9.3 The lack of a fire detection and suppression system within the No. 7 Tank Dry Bay;

3.9.4 The fact that the Nimrod Safety Case (NSC) did not correctly categorise the potential threat to the aircraft caused by the co-location of fuel and hot air system components within the No. 7 Tank Dry Bay (see further below); and

3.9.5 The formal incorporation of the AAR capability within the Nimrod did not identify the full implications of successive changes to the fuel system and associated procedures.

3.10 The BOI further made a number of additional observations, including:[16]

3.10.1 Changes to RAF Kinloss' management structure as a result of Project Trenchard removed the SO1 engineer (OC Engineering Wing) from the station structure, with the consequence that engineering personnel were distributed between the station's two remaining wings under non-specialist leadership and Queen's Regulation 640 responsibility was delegated to a squadron leader. Both operational and engineering witnesses believed that this change had had a negative effect on aircraft availability. I consider this issue further in **Chapter 13**.

[13] Given that the BOI was unable to investigate the wreckage at the crash site and it proved impossible to recover more than a few small components from the aircraft.

[14] BOI Report, paragraph 60 [2-44 to 2-45].

[15] BOI Report, paragraph 61 [2-45].

[16] BOI Report, paragraph 64 [2-45 to 2-46].

3.10.2 Service training courses were perceived by a number of witnesses no longer to impart the skill of hand and depth of knowledge necessary to maintain an aircraft built around a design philosophy now some 40 years old. This, combined with a tautly-manned engineering establishment and a recent outflow of skilled personnel, had led to an effective dilution of engineering skills, although the BOI found no evidence that this contributed to the loss of XV230. I also consider this issue further in **Chapter 13**.

3.10.3 Other aircraft types in the MOD inventory use fuel seals similar to those fitted on the Nimrod. I consider this issue further in **Chapter 5**.

BOI's Conclusions in relation to the Nimrod Safety Case

3.11 The NSC was compiled between 2001 and 2005. In its Report, the BOI drew attention to a number of errors contained within the NSC, including the following:[17]

3.11.1 The NSC quoted the potential for fuel system leakage as 'Improbable', which is defined as '*Remote likelihood of occurrence to just 1 or 2 aircraft during the operational life of a particular fleet*'. The BOI's analysis of fault data, however, indicated an average of 40 fuel leaks per annum for the Nimrod MR2 fleet between 2000 and 2005;

3.11.2 The NSC stated that the Cross-Feed duct was only pressurised during engine start, not taking into account the lengthy periods it can be pressurised (at a working temperature of up to 420°C) when feeding the SCP; and

3.11.3 The NSC noted as mitigation for Zone 614 hazards (which included the starboard No. 7 Tank Dry Bay) the provision of an aircraft fire detection and suppression system, when neither existed within Zone 614.

3.12 The BOI concluded that the above inaccuracies led to an overly optimistic assessment of the hazards relating to Zone 614, which in turn affected the assessment of the probability of the loss of an aircraft to an uncontrolled fire/explosion – given as 'Improbable'. Had the NSC's inaccuracies been noted earlier, the BOI considered that a more intense review of the hazards concomitant on airframe fuel leaks might have been instigated. Moreover, the higher assessed risk which necessarily would have been attributed to such a hazard would have required sanction at a higher level of management, or active mitigation, such as not using the SCP.[18]

3.13 It was therefore the BOI's conclusion that the overly optimistic hazard/risk categorisation of the potential threat to the aircraft caused by the co-location of fuel and hot air system components within the No. 7 Tank Dry Bay was a contributory factor in the loss of XV230.[19]

3.14 **Chapters 9** to **11** of this Report contain a detailed analysis the NSC, the facts surrounding it, the roles of those responsible for it, and its part in the loss of XV230.

Validation of the BOI

3.15 The Review's Terms of Reference are expressed to be "*in light of the findings of the BOI*". It has therefore been important for me to satisfy myself as to the accuracy and completeness of the findings of the BOI. I summarise below why I am satisfied that the reasoning and main conclusions of the BOI are correct.

[17] BOI Report, paragraph 64 [2-45 to 2-46].

[18] BOI Report, paragraph 32c(2) [2-23 – 2-24].

[19] BOI Report, paragraph 32c(3) [2-24].

No significant challenges to the BOI's findings

3.16 There have been few challenges to the BOI's basic findings whether from the Nimrod community or elsewhere. In a letter to the Review dated 22 April 2008, BAE Systems stated that "*to date we have no reason to contradict the fundamental conclusions of the [BOI] report*". BAE Systems is not alone in this position. Indeed, since publication of the BOI's report, there has been no real challenge made to the BOI's conclusion that an exposed element of the aircraft's Cross-Feed/SCP pipe work was the most likely ignition source for the fire. I explain in detail in **Chapter 4** why I consider that conclusion to be plainly correct.

3.17 Some differing opinions have been expressed, however, in relation to the most probable fuel source for the fire. Whilst agreeing with the BOI's overall conclusions, BAE Systems explained to the Review the reasons why it considered the source of fuel was, on balance, more likely to have been a fuel seal failure than AAR blow-off, rather than the two being equally probable as the BOI found. I consider these issues in detail in **Chapters 5** and **6**. I also explain why other theories as to the fuel sources, notably that of Mr Andrew Walker, the Oxfordshire Assistant Deputy Coroner who conducted the Inquest (see **Chapter 16**), and Mr Graham Bell (brother of Flight Sergeant Gerard Bell, deceased), can be dismissed as not credible and why the BOI are correct in their analysis as to the two most probable sources of fuel. I also make findings as to which is the more probable of the two.

3.18 In view of the fact that BOI findings are a foundation for this Review, I contacted the United States Air Force Safety Center (AFSC) and asked them to conduct a review of the BOI report. The AFSC has a world-class reputation and its personnel are very experienced in carrying out military aircraft accident investigations. The AFSC has a wide-ranging remit to promote aviation safety. To quote from its mission statement:

> *"The Air Force Safety Center develops and manages Air Force mishap prevention programs and the Nuclear Surety Program. It develops regulatory guidance, provides technical assistance in the flight, ground and weapons and space safety disciplines, and maintains the Air Force data base for all safety mishaps. It oversees all major command mishap investigations and evaluates corrective actions for applicability and implementation Air Force wide. It also develops and directs safety education programs for all safety disciplines."*

3.19 I am grateful for the assistance of the AFSC and that of the Executive Director, William C. Redmond. The AFSC dispatched a team of four senior staff to RAF Kinloss, where they spent time examining the Nimrod aircraft and considering the BOI report. I also travelled to the US to consult them on this aspect and other aspects of flight safety. The AFSC team carried out further significant additional work in the US and have conducted a detailed, meticulous and comprehensive review of the BOI.

3.20 The conclusions of the AFSC were that the XV230 BOI "*was thorough and professional*", "*meticulous in gathering and reviewing available evidence" and "demonstrated exceptional investigative diligence*".[20] Importantly, the AFSC agreed with the BOI's deduction as to point of ignition and endorses the BOI's conclusion as to the three potential sources of fuel. The difference of emphasis between the AFSC and the BOI is as to the relative likelihood of the two most probable sources of fuel for the fire on XV230 as found by the BOI: fuel seal failure or overflow from No. 1 tank. The BOI decided these two sources were equally likely, whereas, the AFSC believed that the former was more likely than the latter. Nonetheless, the AFSC made clear that all other postulated sources of fuel are much less likely than these two. (As I make clear in **Chapter 5** however, new evidence has since come to light which points to the most probable source of fuel). The only minor criticism that the AFSC made of the BOI's analysis of this area is that experimental evidence could have been used to possibly substantiate the BOI theory concerning the migration path of fuel which may have overflowed from No. 1 fuel tank.

3.21 As the AFSC made clear, "*different investigative agencies reviewing the same evidence may reach somewhat different conclusions*".[21] In explaining the precise sequence of propagation of the fire on XV230, the AFSC also took a slightly different view to the BOI, but not one that has a material effect on the BOI's conclusions. Essentially, the difference in interpretation centres on the ability of No. 7 fuel tank to withstand the effects of thermal heating. The BOI's combustion experts determined that the final explosion reported by eyewitnesses

[20] AFSC Response to Questions from the Nimrod Review, pages 1 and 2.

[21] Ibid, page 5.

had been either the failure of the starboard wing, causing the rupture of the No. 7 fuel tank (the fuel of which had been pressurised by the fire's temperature), or a BLEVE caused by the over-pressurisation of the No. 7 tank as the result of the fire's heat. The AFSC experience is that pressure is much less likely to have played a part in the destruction of the fuel tank which they believe "*suffered a large-scale structural failure due to flight loads imposed upon the fire-weakened structure*".[22]

3.22 In all significant respects, however, the AFSC agreed with the findings of the BOI.

Conclusion

3.23 The main conclusions of the BOI are, therefore, confirmed by two leading agencies, the AAIB and the AFSC. The various occurrences since 2006, and other evidence which I have examined, also all tend to support the BOI's analysis. In these circumstances, there is no doubt in my mind that the BOI's findings are a sound basis upon which to found this Review; and further, that the BOI Report represents as true and accurate a record as we will ever have of the final tragic minutes of XV230 and her crew.

[22] Ibid, page 4.

PART II:
PHYSICAL CAUSES

PART II: PHYSICAL CAUSES

Contents

Part II contains the findings of the Review as to the physical causes of the loss of XV230.

Introduction to PART II

1. XV230 was lost because of a fire which broke out in an inaccessible part of the aircraft which had no fire protection (the starboard No. 7 Tank Dry Bay). The crew had no chance of controlling this fire. It quickly spread and led to the mid-air break-up of the airframe, tragically only minutes before the crew could make an emergency landing at Kandahar airfield.

2. The cause of the fire was aviation fuel coming into contact with a high temperature ignition source.

Probable ignition source and seat of fire

3. The BOI found that the most likely source of ignition was the high temperature Cross-Feed/Supplementary Conditioning Pack duct (Cross-Feed/SCP duct);[1] and the most likely initial seat of the fire was the dry bay located forward of the starboard No. 7 tank which contained numerous fuel pipes juxtaposed to the Cross-Feed/SCP duct. "*It thus contains all the elements necessary to be the origin and sustainment point of a fire*".[2] The BOI's combustion experts, QinetiQ, found that the most likely ignition point was "*the SCP wing pannier fairing immediate aft of the blended section of the lower bay hinged panel where the bellows is covered with a glass fibre muff*"[3] (but observed that other sections of the Cross-Feed/SCP duct system were also potentially exposed to fuel leaks).[4]

4. For reasons explained in **Chapter 4** of this Report, I am satisfied that the BOI's conclusion that the source of ignition was the Cross-Feed/SCP duct in the starboard No. 7 Tank Dry Bay is correct. I also agree that the SCP elbow was the most likely point of ignition. It lay at the lowest point in the bay. Fuel could pool in a ribbed horizontal panel immediately adjacent to the SCP duct. As QinetiQ found, the panel could hold an estimated 0.3 litres of fuel,[5] and the insulation muff close to the elbow of the SCP would "*very easily*" allow fuel ingress at either end, and possibly through the laces along the longitudinal seam. No more than 0.3 litres of fuel would have been required to sustain a fire large enough to disrupt other elements of the fuel system.[6]

5. In my view, there can be no doubt about the probable ignition source and seat of the fire.

Probable fuel sources

6. The issue as to the most probable fuel source is, however, more complex. Due to the lack of physical evidence, the BOI was unable definitively to determine the source of fuel which came into contact with the Cross-Feed/SCP duct; but, by a process of deduction and experiment, the BOI was able to narrow down the most likely sources of fuel to the following three ((1) and (2) of which were of equal probability, and (3) of a lower probability):

   (1) A leak from the fuel system (fuel coupling or pipe) leading to the pooling of fuel in the starboard No. 7 Tank Dry Bay; or

[1] BOI Report, paragraph 28 [2-16].

[2] BOI Report, paragraph 42 [2-29].

[3] QinetiQ Combustion Analysis of Nimrod MR2 XV230 Accident, paragraph. 3.2.3 (BOI Report Exhibit 30).

[4] Ibid.

[5] Less than a Coke can.

[6] QinetiQ Combustion Analysis of Nimrod MR2 XV230 Accident, paragraph 3.2.3 (BOI Report, Exhibit 30). See further **Chapter 4**

(2) The escape of fuel during Air-to-Air Refuelling (AAR) occasioned by an overflow from No. 1 tank (from the No. 1 tank blow-off valve and/or vent pipe connection); or

(3) A hot air leak (from the Cross-Feed/SCP duct) causing damage to adjacent fuel seals.

7. In **Chapters 5**, **6** and **7** below, I consider each of these three mechanisms separately, on their merits:

Chapter 5: LEAK FROM FUEL COUPLING

Chapter 6: OVERFLOW OR PRESSURE FROM AIR-TO-AIR REFUELLING

Chapter 7: DAMAGE FROM CROSS-FEED/SCP DUCT FAILURE

8. Each of these three sources of fuel is potentially relevant to the cause of the loss of XV230. Each raises significant issues regarding the airworthiness of the aircraft over many years. Each raises serious questions about the management of airworthiness by the various organisations involved. Each gives rise to important lessons for the future.

9. I have concluded, in the light of all the evidence, that the probable sources of the fuel for the fire which caused the loss of XV230 should be ranked as follows (i.e. in order of likelihood):

(1) The most likely source of fuel was an overflow during AAR (**Chapter 6**);

(2) The second most likely source of fuel was a leak from a fuel coupling in the starboard No. 7 Tank Dry Bay (**Chapter 5**);

(3) The third, and only other viable, source of fuel could have been coupling damage caused by a Cross-Feed/SCP duct failure, but this mechanism was in my view much less likely than (1) or (2) (**Chapter 7**).

10. The ranking of the three potential sources of fuel should not detract from the potential causative potency of each, or the lessons to be learned from what the investigation of them by the Review has revealed.

Other theories

11. I have carefully considered various other alternative theories which have been put forward as to the causal mechanism of the fire on XV230. In my view, none of these theories are viable or credible. Although, in the absence of the physical evidence, nothing can be ruled out entirely, I am satisfied that all such theories are far less likely than the BOI's findings which, subject to the above ranking, I accept.

Defective design

12. The Nimrod suffered from fundamental design flaws which played a crucial part in the loss of XV230. There are three stages at which defective design occurred:

(1) First, the original fitting of the Cross-Feed duct to MR1s and R1s (1969-1975);

(2) Second, the addition of the SCP to MR2s (1979-1984); and

(3) Third, the fitting of permanent AAR modifications to MR2s and R1s (1989).

13. These three design flaws were contrary to sound engineering practice at the time and contrary to design regulations in force in 1969, 1979 and 1989 respectively.

14. Hawker Siddeley[7] was responsible for (1), the original design flaws in the MR1 and R1. British Aerospace[8] was responsible for (2) and (3), the subsequent design flaws in the MR2 and R1.

(1) Cross-Feed duct

15. First, the original fitting of the Cross-Feed duct to MR1s and R1s (1969-1975) was to enable the distribution of Auxiliary Power Unit (APU) air, and then engine bleed-air, to the engines for ground starting. It also enabled engines to be shut down in flight and re-started, using hot bleed-air routed from another engine *via* the Cross-Feed duct. The Cross-Feed duct gave rise to a serious fire hazard, particularly in No. 7 Tank Dry Bay. The Cross-Feed duct was located athwart the fuselage, in close proximity to fuel pipes and outside any fire zone. It gave rise to two risks: (a) fuel leaking from adjacent fuel couplings, or other parts of the fuel system onto exposed or vulnerable parts of the Cross-Feed duct could ignite; or (b) a leak of hot air from the Cross-Feed duct could cause heat damage to the fuel couplings in close proximity and ignite escaping fuel. (See further **Chapter 4**).

(2) SCP duct

16. Second, the addition of the SCP to MR2s (1978-1984) provided additional cooling for the extra electronic equipment when MR1s were upgraded to MR2s. The SCP required bleed-air taken off the Cross-Feed duct. The fitting of the SCP take-off duct significantly exacerbated the fire hazard posed by the bleed-air system because: (a) the SCP duct was routed through the bottom of the starboard No. 7 Tank Dry Bay, thereby increasing the chances of fuel from fuel couplings above dripping onto it and causing a pool fire at the bottom of No. 7 Tank Dry Bay; (b) immediately aft of the elbow of the SCP duct, an expansion bellows was fitted with a laced muff which was vulnerable to the ingress of fuel; (c) the elbow was encased in a fairing proud of the fuselage hull which was vulnerable to fuel tracking along the outside of the fuselage; and (d) the flow of air through the Cross-Feed duct increased the duct temperature whenever the SCP was on. (See further **Chapter 4**).

(3) Air-to-Air Refuelling

17. Third, the fitting of the permanent AAR modification to MR2s (1982/1989) to enable refuelling in flight to take place. The addition of AAR capability further increased the fire hazard posed by the Cross-Feed/SCP duct in three ways: (a) first, the refuel gallery was now pressurised whilst airborne and undertaking AAR, thereby increasing the chance of leaks in flight contacting the Cross-Feed/SCP duct; (b) second, it gave rise to the risk that blow-off valves on the side of the fuselage of the aircraft (which can automatically release excess fuel from tanks during refuelling to prevent fuel tank over-pressure) might now operate in-flight, and lead to fuel tracking back along the aircraft and re-entering the fuselage through ports, vents and gaps in the aircraft structure; and (c) third, it gave rise to the risk that fuel would enter the air vent system during AAR in flight and leak (both (b) and (c) are because of an existing design problem with asymmetric filling of No. 1 tank). Previously, such blow-off valves and fuel entering the vent system did not pose a hazard as refuelling was only conducted on the ground.

18. The AAR modification was initially fitted in May 1982 to MR2s (including XV230) and, later, R1s as an Urgent Operational Requirement (UOR) for the Falklands Campaign (Mod 700). Because of the imperative to enable the Nimrod to conduct AAR during the Falklands campaign the initial UOR design did not meet all the requirements of Aviation Publication (AvP) 970 (subsequently Defence-Standard (Def-Stan) 00-970). Therefore, a modified design, intended to meet this standard, was fitted, beginning in 1989, to MR2s and R1s (Mod 715). The risk of fuel from the blow-off valve of No. 5 tank on the Nimrod's port side entering engine intakes was addressed in Mods 700 and 715, but the risk from the blow-off valve of No. 1 tank on the starboard side was not. It is important to note that the effect of fitting the AAR modification was to change the function of the refuel pipes within No. 7 Tank Dry Bay port and starboard. Previously, these pipes had not been used in flight

[7] Hawker Siddeley became part of British Aerospace on 29 April 1977.

[8] British Aerospace became BAE Systems Plc in November 1999 on the merger with Marconi Electronic Systems.

because Nimrods were only refuelled on the ground by bowsers. In making these pipes "live", the AAR modification introduced a significant new element to the risk of fire because of their close proximity to the hot Cross-Feed/SCP duct. (See further **Chapter 6**).

Why were the design flaws not spotted for decades?

19. The juxtaposition of hot ducting and fuel pipes in both No. 7 Tank Dry Bays, and the threat from fuel from the starboard No. 1 tank blow-off valve entering the fuselage, represented serious, ever-present and, once pointed out, obvious risks to the Nimrod fleet for several decades. The question is: why then did nobody spot these design flaws during the intervening years? Many competent, hard-working and dedicated engineers had worked on the aircraft; and, whilst No. 7 Tank Dry Bay was not frequently examined during maintenance, numerous trained eyes would have looked inside these bays and observed fuel pipes and couplings within inches of hot ducting. The answer lies in an understandable assumption by operators that aircraft are designed properly and delivered in an airworthy condition. The best opportunity to capture these flaws, during the Nimrod Safety Case produced between 2001 and 2005, was lost (see **Chapter 10**).

20. This case starkly illustrates how dangerous such fundamental "embedded" design defects can be, and how important it is not to make blanket assumptions about safety.

Conclusion

21. BAE Systems designed, manufactured and installed both the SCP duct and the AAR capability for the Nimrod, but failed properly to understand or assess the risks inherent in their designs and modifications.

Section One: Ignition Source

CHAPTER 4 – CROSS-FEED/SCP DUCT

Contents

Chapter 4 addresses the ignition source, the Cross-Feed/SCP duct. It answers the following questions:

- What was the history of the fitting of the Cross-Feed/SCP duct?
- What was the purpose of the Cross-Feed/SCP duct?
- How and why did the Cross-Feed/SCP duct pose a risk to the Nimrod?
- Was the Cross-Feed/SCP duct in breach of design standards and regulations applicable of the time?
- Who was responsible for any breaches of design standards and regulations?

Summary

1. The Cross-Feed duct was part of the original specification of every Nimrod MR1 and R1.[1] The Supplementary Conditioning Pack (SCP) duct was added to the upgraded Nimrod MR2s.[2] The combined duct is known as the Cross-Feed/SCP duct.

2. The purpose of the Cross-Feed/SCP duct was to allow high pressure, high temperature (around 400°C+) "bleed-air" to be transferred between the engines and to the SCP.

3. It was always intended and understood that the Cross-Feed/SCP duct would be used regularly by crews in-flight.

4. The Cross-Feed/SCP duct posed a potentially catastrophic fire risk to the Nimrod fleet from the very beginning.

5. The Cross-Feed/SCP duct posed a serious fire risk to the aircraft for four separate reasons due to design flaws:

   (a) its location at the bottom of a bay closely packed with fuel pipes and couplings;

   (b) the design of the No. 7 Tank Dry Bays, which allowed fuel pooling;

   (c) inadequate insulation, which was vulnerable to fuel ingress; and

   (d) the absence of fire protection in those bays.

6. The Cross-Feed/SCP duct gave rise to two main fire risks to the aircraft. First, the Cross-Feed/SCP duct was vulnerable to fuel and/or hydraulic oil coming into direct contact with its very hot[3] metal surfaces as a result of leaks from couplings or other sources, leading to auto-ignition. Second, the Cross-Feed/SCP duct itself posed a direct threat to the fuel system because an escape of hot air could degrade fuel seals in close proximity in the No. 7 Tank Dry Bays, leading to the escape of fuel and auto-ignition.

[1] MR1s and R1s were delivered by Hawker Siddeley to the RAF between 1969-1975.

[2] MR2s were delivered by British Aerospace to the RAF between 1979-1984.

[3] The AAIB report into the loss of XV230 shows that air in the duct at the point it leaves the engine could be at up to 510°C (depending on altitude and external air temperature) and would have cooled by about 10 deg by the time it reached the No. 7 Tank Dry Bay area. At the time of the initiation of XV230's fire, the air in the ducts within the bay would probably have been at approximately 420°C or higher.

7. The Cross-Feed/SCP duct system represented a clear breach of good design standards and was contrary to design regulations applicable at the time. In particular, the SCP adjunct to the Cross-Feed duct was a manifest breach of the standards of Aviation Publication (AvP) 970.[4] This appears not to have been appreciated at the time.

Primary physical cause

8. The Cross-Feed/SCP duct represented a fundamental flaw in the design of Nimrod aircraft and was the primary physical cause of the accident.

Responsibility

9. Hawker Siddeley[5] was responsible for the original Cross-Feed duct design in the MR1 and R1. British Aerospace[6] was responsible for the subsequent addition of the SCP duct in the MR2. The 'acceptance' of the aircraft or modifications by the RAF at the time does not absolve either company from their responsibilities as the Design Authority for poor design.

[4] Subsequently Defence Standard (Def-Stan) 00-970.

[5] Hawker Siddeley became part of British Aerospace on 29 April 1977.

[6] British Aerospace became BAE Systems Plc in November 1999 on the merger with Marconi Electronic Systems.

Introduction

Cross-Feed/SCP duct system

Original Cross-Feed duct in MR1 and R1 (1969-1975)

4.1 All 46 Nimrod MR1s and three Nimrod R1s originally delivered (1969-1975) came fitted with the same "bleed-air" system and Cross-Feed duct.

4.2 The hot bleed-air from the engines is fed through a substantial three inch (internal diameter) steel duct, called the "Cross-Feed duct", which runs transversely across the aircraft hull, through the bomb bay (just forward of the aileron bay) and is routed *via* the port and starboard No. 7 Tank Dry Bays (see Figure 4.1). The majority of the ducts are insulated with Refrasil insulation, a 12mm thick glass fibre blanket, protected by an outer dimpled stainless steel jacket. Where components, such as expansion bellows cannot be insulated by this method, they are covered by two-part metallic shrouds. I discuss this in more detail below.

4.3 When starting engines on the ground, the first engine is started by using either pressurised air from an external ground unit or air from the aircraft's Auxilliary Power Unit (APU) in the tail. Air from either source is fed to the Cross-Feed duct and thence to the engine to be started; the remaining engines are then started using air bled from running engines. In-flight, hot air "bled" from any of the engines embedded in the port and starboard wings could be used to start any of the other engines, should they fail or have been shut down (the APU cannot be used in flight). Depending primarily on the engines' power settings, the Cross-Feed duct could contain hot bleed-air at up to 470°C during flight.[1]

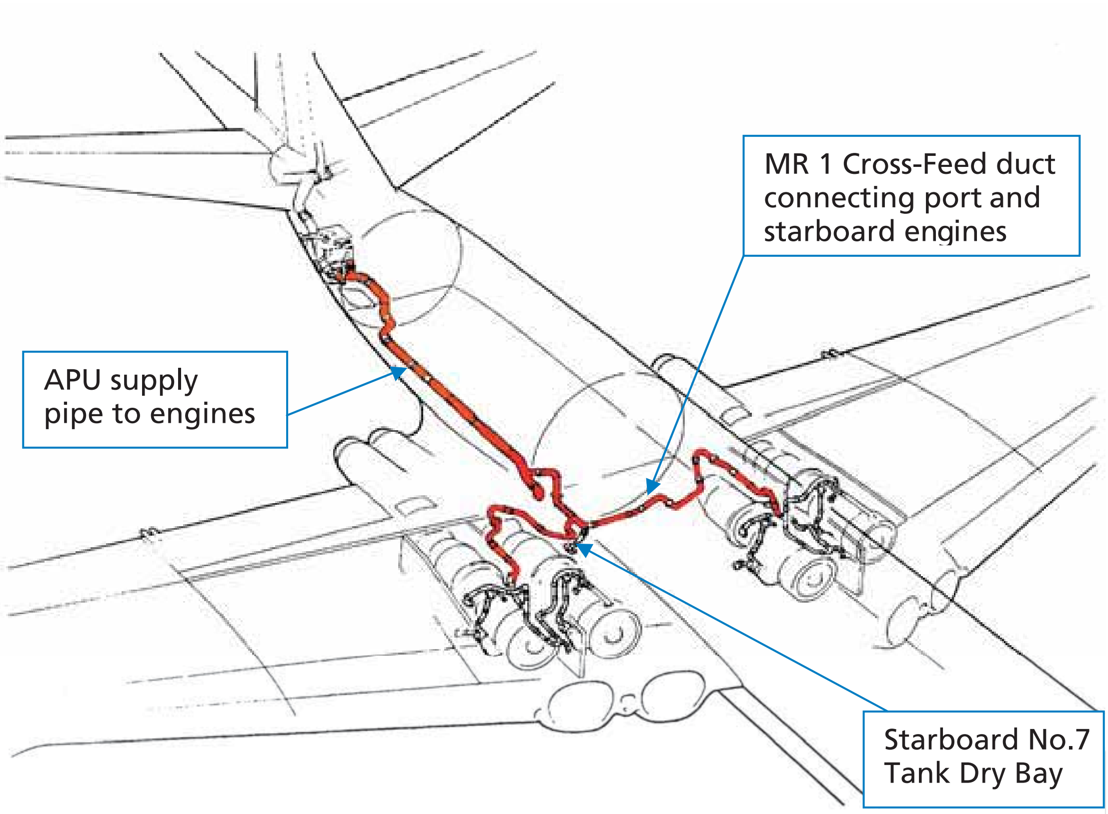

Figure 4.1: Nimrod MR1 Cross Feed Ducts

[1] BOI Report, Exhibit 12, Page 111 (A Rolls Royce report provided to AAIB). This would be true for an aircraft flying at low-level in the European environment; however, at, for example, 20,000 feet in the Middle East the temperature would still be approximately 428°C.

Addition of SCP duct to MR2 (c. 1979)

4.4 When 35 of the Nimrod MR1s were upgraded to MR2s (1975-1984),[2] they were all fitted with a Supplementary Conditioning Pack (SCP) to supply extra cooling air to the aircraft's upgraded electronic equipment. The SCP increased the mass flow of conditioned air to the cabin by supplementing the original two conditioning packs located in the wings. The SCP incorporates a pre-cooler in a fairing aft of the bomb bay and a tail pack in the APU compartment, which includes a two-stage heat exchanger and a Cold Air Unit (CAU). Space did not allow the SCP expansion bellows to be covered by the type of shrouds used on the Cross-Feed duct and so flexible muffs were used instead (see further below).

4.5 To power the SCP, it was decided to off-take bleed-air from the Cross-Feed duct and run the bleed-air aft to the tail where the SCP was located. To do this, a five-way junction was fitted to the pre-existing Cross-Feed duct, immediately below the entrance from the bomb bay to the starboard side No. 7 Tank Dry Bay. Adjacent to this off-take, the new SCP bleed-air duct was routed through the very lowest section of the starboard No. 7 Tank Dry Bay and then aft (see below). With the air supply to the SCP switched on, hot, high-pressure air bled from the Cross-Feed duct fed through the SCP duct to a combined Pressure Regulating and Shut-Off Valve (PRSOV), which reduced the extracted bleed-air from up to 280psi (the maximum working pressure of the Cross Feed duct) to approximately 56psi (the normal operating pressure of the SCP duct) and through a flow-limiting venturi to the pre-cooler. Bleed-air for the SCP was routed along the outside of the starboard fuselage from the PRSOV to the pre-cooler and along the outside of the port fuselage from the pre-cooler to the tail pack itself.[3]

4.6 This combined duct now to be found in MR2s is referred to collectively in this Report[4] as the "Cross-Feed/SCP duct" (see Figure 4.2 – a cross section shown with the bomb bay doors open).

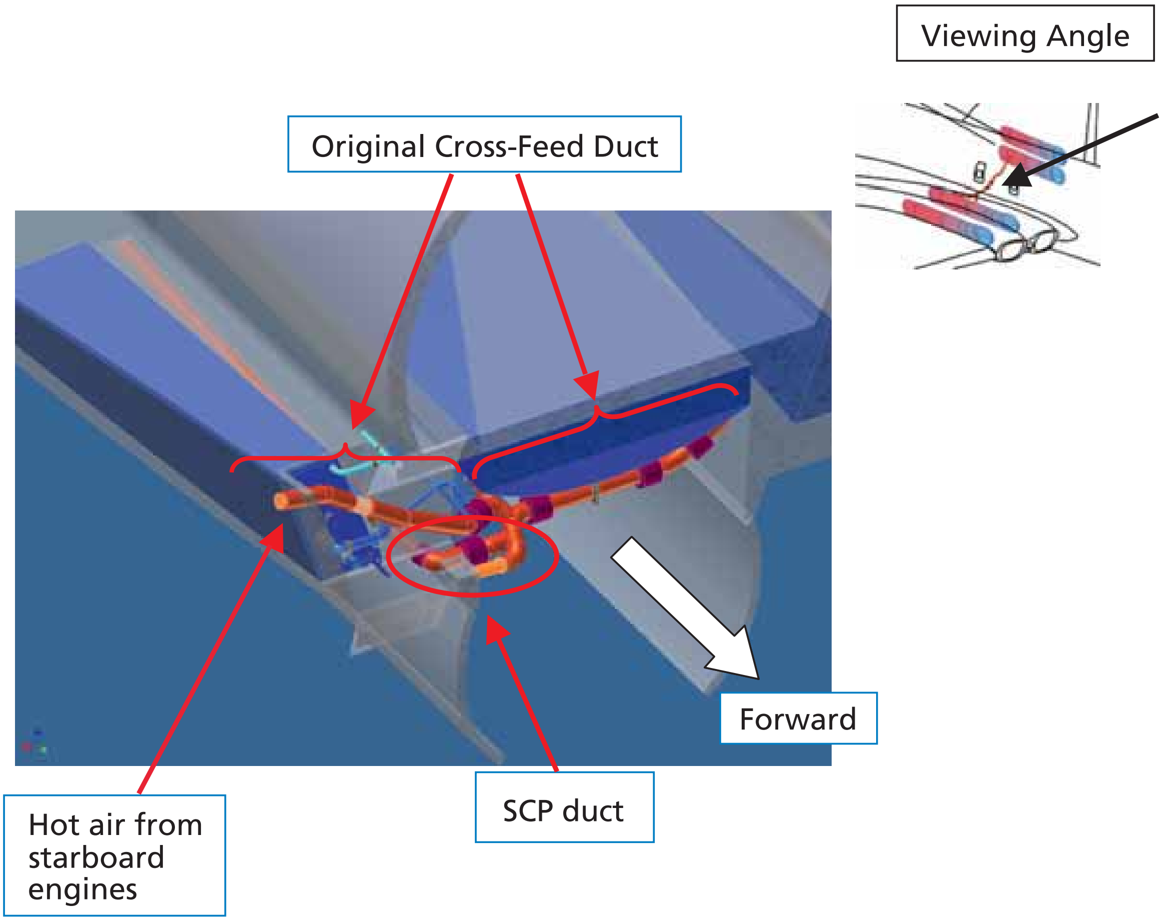

Figure 4.2: Nimrod MR2 Cross Feed Ducts

[2] The RAF took delivery of 35 upgraded MR2s between 1978 and 1984. XV230 was one of those upgraded.
[3] See also BOI paragraph 38 [2-27].
[4] And the BOI.

Regular in-flight use of bleed-air system

4.7 It is important to note that it was always intended, and well understood, that the bleed-air system would be regularly used by Nimrod crews in-flight. Indeed, in-flight use was the *raison d'être* of both the Cross-Feed duct and the SCP duct.

4.8 The Cross-Feed duct was fitted to the MR1 and retained on the MR2. It allowed crews to shut down individual engines in-flight to save fuel and thereby extend flight endurance; and then to re-start them again quickly using bleed-air from other running engines. This meant that the Cross-Feed duct would be open and hot in-flight. This fact is substantiated by the earliest Nimrod documentation. The Aircraft Specification for the Nimrod MR1[5] makes reference to the aircraft's ability to patrol on only two engines and to the need for an immediate re-light to be possible in the event of an engine failure. Furthermore, the configuration of two of the Nimrod's hydraulic systems ('Blue' and 'Green') was modified from the Comet 4C design to include additional pumps on the inboard engines, which prevented loss of a hydraulic system should an engine fail in the two-engine flight configuration.

4.9 Thus, at the very earliest stage, the aircraft designer was aware of the requirement for airborne operation of the Cross-Feed duct. Nimrod MR2 documentation refers to the fact that the *"aircraft may be using four, three or two engines depending on the AUW*[6] *and height"*[7]; that *"range and/or endurance can be enhanced under certain conditions by shutting down one or two engines"*[8] and the aircraft's Flight Reference Cards give parameters within which air assist start (i.e. using the Cross-Feed system) is recommended and specifically quotes its use with *"an engine failure when on 2 engines".*[9]

4.10 The SCP duct fitted to the MR2 enabled crews to ensure that sufficient cooling air was always available for the considerable amount of sophisticated electronic equipment carried. There were no instructions limiting the SCP to ground use only; Nimrod documentation provides guidance on the use of the SCP while airborne[10] and there were no instructions preventing its use during AAR[11]. The Nimrod Release to Service notes that *"the SCP may shut down automatically when…at low-level" and "may shut down …when the bomb bay doors are opened"*[12] Indeed, the very purpose of the SCP was to increase the flow of cooling air to the MR2's new electronics and this was a function whose primary utility lay while the aircraft was airborne and particularly at low level. Significantly, the addition of the SCP meant that the temperature of the air in the MR2's Cross-Feed duct was greater than that on the MR1, because of the continuous flow of hot air to supply the SCP.

4.11 Even when the SCP was not operating, standard procedure was for the engine Cross-Feed duct to remain pressurised (*i.e.* hot) whenever engines were shut down for fuel economy, in order to effect an immediate air-assist engine start should an emergency make it necessary[13] (in the same manner as the MR1). The Nimrod MR2 Aircrew Manual specifies the use of air assist start in the event of engine failure at low level, clearly requiring the Cross-Feed duct to be active.[14]

4.12 In summary, therefore, in-flight use of the Cross-Feed duct was always intended and understood from the inception of the Nimrod MR1; and in-flight use of both the Cross-Feed and SCP was intended and understood from the inception of the Nimrod MR2.

[5] Aircraft Specification No. MR 254 D&P for HS 801 Maritime Reconnaissance Aircraft dated 13 April 1965.

[6] All Up Weight, *i.e.* the weight of the aircraft, plus the fuel.

[7] AP101B-0500-15S 3rd Edition August 2002 Paragraph 0221 Low-Level Flying.

[8] MR2 RTS Issue 7 Amendment 26, 6 March 2006, Page C3.

[9] AP 101B-0503-14A (Issue 2) July 1994 (AL 7 March 2001) Card 13.

[10] AP 101B-0503-15C 3rd Edition, Part 2, Chapter 1, paragraphs 15, 21 and 36.

[11] BOI Paragraph 40(d)(4).

[12] MR2 RTS Issue 7, Amendment 26, dated 6 March 2006, page C3.

[13] Paragraph 4(b) of Comments on BOI Report by the Station Commander.

[14] AP101B-0503-15C Aircrew Manual Book 3 – Flying, Part 3, Chapter 4, paragraphs 8 and 9.

No. 7 Tank Dry Bays

4.13 The aircraft's No. 7 Tank Dry Bays are located immediately in front of each of the forward faces of the port and starboard No. 7 fuel tanks, adjacent to the aileron bay, and underneath the after end of each wing root. (see Figure 4.3).

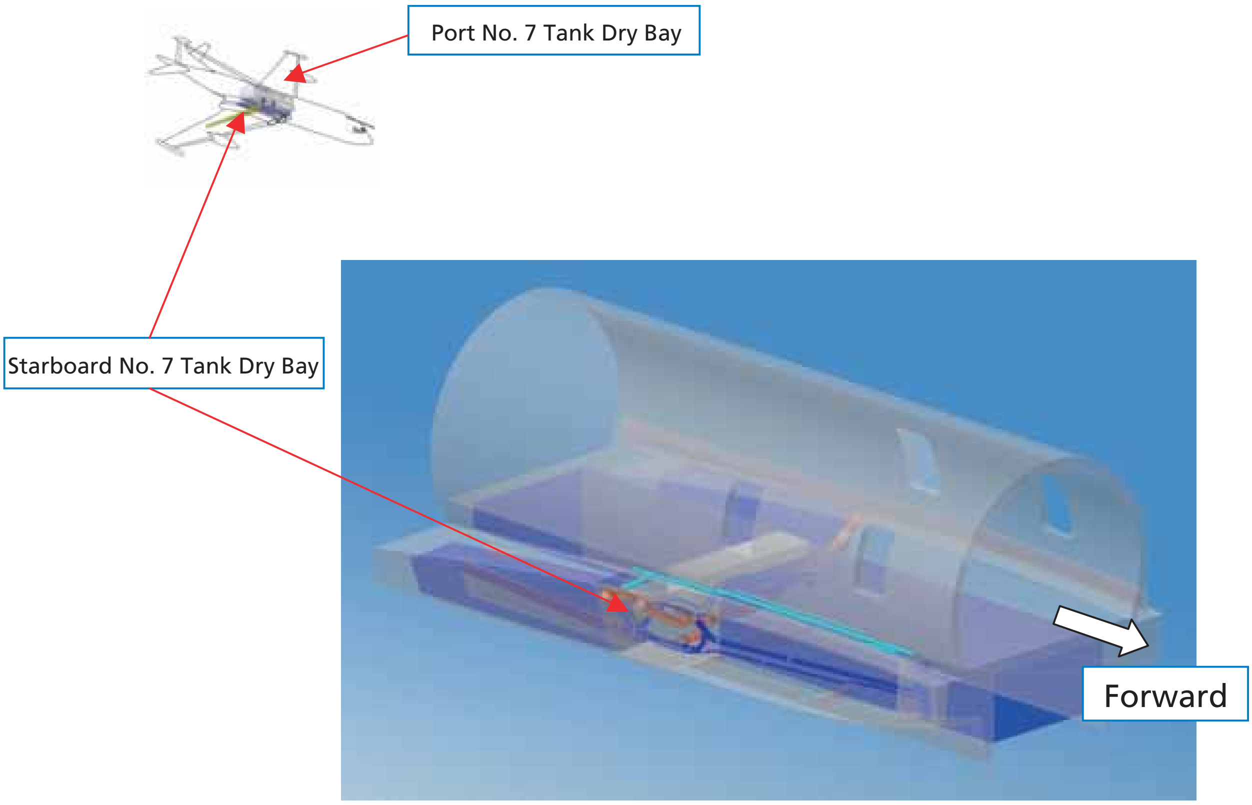

Figure 4.3: Location of No. 7 Tank Dry Bay

4.14 The No. 7 Tank Dry Bays house the wing rear spar-to-fuselage attachment points and a considerable number of fuel and other systems in close proximity to each other:

Running fore-to-aft in the starboard Dry Bay are:

- the No. 7 fuel tank feed pipe;
- the Nos. 6 and 7 tank de-fuel pipes;
- the Nos. 6 and 7 tank vent pipe;
- the tail anti-ice duct; and
- the numerous hydraulic pipes (primarily fore to aft).

Running across and between these pipes is:

- the Cross-Feed/SCP duct.

Starboard No. 7 Tank Dry Bay on MR2

4.15 The starboard No. 7 Tank Dry Bay on all MR1s was modified, on conversion to MR2, to house the SCP bleed-air duct. The SCP duct was routed from the five-way junction on the Cross-Feed duct into and through the bottom of No. 7 Tank Dry Bay and then to an elbow joint outside the existing line of the fuselage. For this purpose, a special fuselage fairing was fashioned, the forward element of which was attached to the internally-ribbed horizontal panel, which formed the lower access panel to the No. 7 Tank Dry Bay (see Figures 4.4 and 4.5).

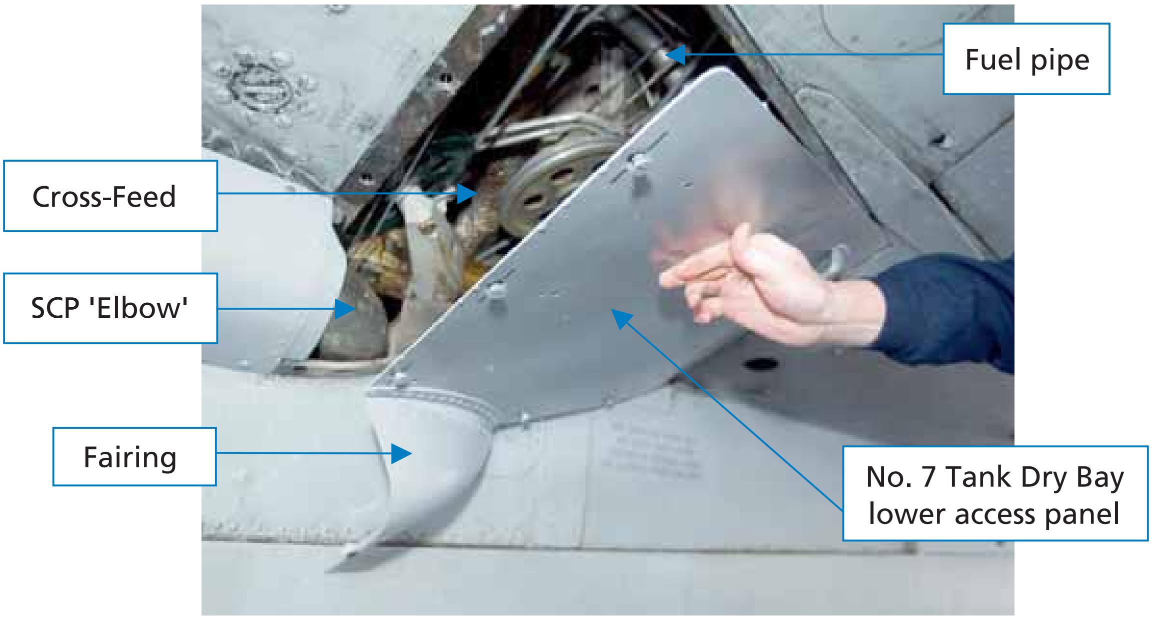

Figure 4.4: No. 7 Tank Dry Bay (Lower Panel)

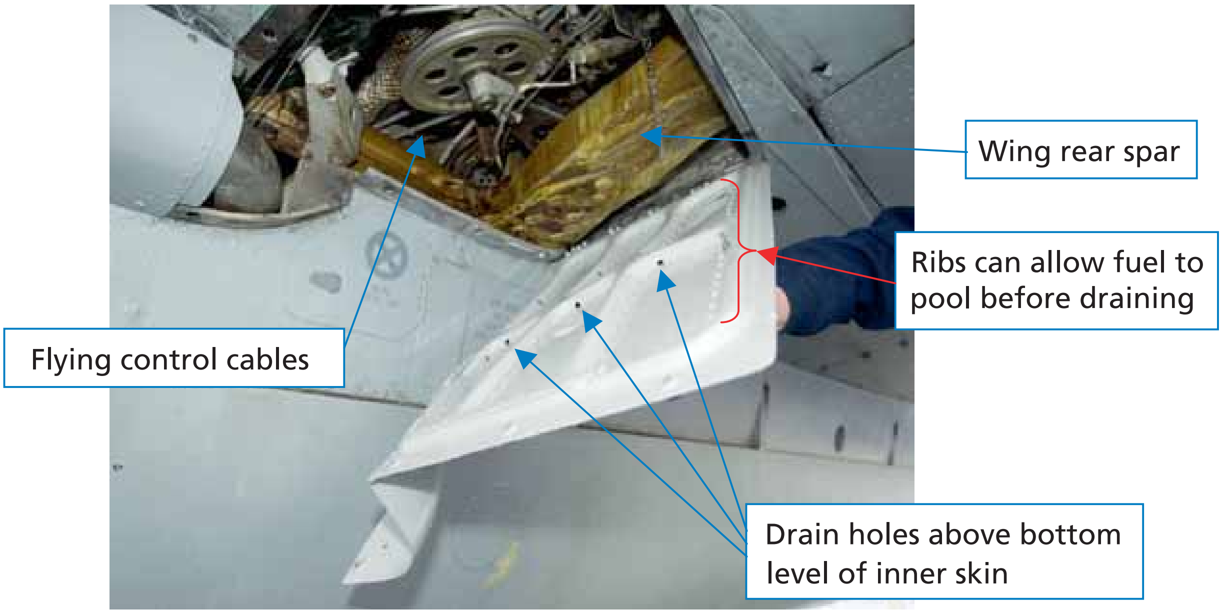

Figure 4.5: No. 7 Tank Dry Bay (Internal Drain Holes)

Temperatures

4.16 The BOI's theory for the initiation of the fire on XV230 relied on fuel reaching its spontaneous ignition temperature, or auto-ignition temperature (AIT),[15] on the hot SCP duct. Certain conditions have to be present for auto-ignition to occur; the surface has to be hot enough and the fuel has to remain in contact long enough for it to reach ignition temperature before it evaporates or runs off. The hotter the surface, the shorter the contact time required, but contact time will also be affected by the shape of the surface. Flat surfaces require lower temperatures than, for example, curved pipes, because fuel does not run off so easily. Other variables also have an effect on AIT, such as altitude and the temperature of surrounding air. AIT increases with altitude, but decreases as the ambient temperature increases.

[15] The terms 'spontaneous ignition' and 'auto-ignition' are used in a number of sources to explain the same phenomenon, and for the purposes of this Report, are considered to be synonymous.

4.17 Trials conducted as part of the BOI showed that the exposed surfaces of the Cross-Feed/SCP duct reach temperatures of between 344ºC and 399ºC at 98% power.[16] However, these trials were conducted on the ground, following the prohibition on the use of the SCP in the air after the loss of XV230. The time that the SCP can be run on the ground is limited and it is likely that higher surface temperatures would be recorded while airborne in a hot environment at high power (as XV230 was). Indeed, figures quoted by the AAIB indicate that the temperature of the duct surfaces (non-insulated) could have been 420°C or higher.[17] However, the highest suggested temperature for the SCP duct comes from a BAE Systems document,[18] which shows that the temperature of the SCP duct will be 435ºC. At these temperatures, in the environment provided by the SCP duct and its insulation, ignition of AVTUR[19] is likely to occur within seconds.

4.18 Hot air ducts are encased in different types of insulation which are intended to protect the aluminium frame of the aircraft and other structures from being affected by the heat of the ducts and to reduce the insulated outer surface to temperatures well below the AIT of AVTUR. The nature of the various types of insulation, and whether they provide a comprehensive barrier to liquid ingress, is discussed further below. It should be noted that the SCP duct at the proposed ignition location has a section which is insulated by a flexible muff. The potential exists for this muff to absorb fuel and thereby ensure the AIT contact time required to ignite aviation fuel. I am therefore satisfied that the Cross-Feed/SCP duct in the No. 7 Tank Dry Bay represents a highly credible ignition point; indeed no other has ever been proposed.

Recent incidents – XV249 and XV255

4.19 There have been two recent incidents which provide empirical evidence that fluids can penetrate the duct insulation potentially leading to ignition on hot ducts within the Nimrod. First, on 28 January 2008 evidence was discovered of a short-lived fire on the Cross-Feed duct of Nimrod R1 XV249. At the time, the aircraft was in the process of a series of investigations into a number of fuel leaks which it had suffered. The ignition caused understandable concern as it should have been prevented by restrictions placed on the use of the Cross-Feed duct following the loss of XV230.[20] The clear physical evidence proved that the Cross-Feed duct's temperature could ignite fuel. The subsequent investigation[21] determined that the most likely reason for the fire was ignition of an accelerant on the Cross-Feed duct during ground runs, which allowed the ducting temperature to reach the AIT for the accelerant; the most likely accelerants were AVTUR and/or OX-87 hydraulic fluid. Second, in January 2009, a flexible muff from the SCP expansion bellows was removed from XV255 at Kinloss to facilitate work as part of the hot air duct replacement programme (see further **Chapter 15**). There was a clear indication of blackening and scorching on the muff. Analysis and study suggested that the discolouration of the muff did not occur as a result of a fire but was caused, or contributed to, by pyrolysis[22] of OX87 hydraulic fluid or OX7 engine oil.[23] There is, therefore, hard evidence confirming that the Cross-Feed/SCP duct reaches temperatures within the range of auto-ignition of aviation fuel and that fluids can gather under the muff.[24] Both the XV249 and XV255 incidents are discussed further later.

Insulation

4.20 The majority of the Cross-Feed/SCP duct is encased in a Refrasil glass-wool insulation blanket protected by an outer steel jacket.

[16] QinetiQ Combustion Analysis of Nimrod MR2 XV230 Accident, paragraph 2.2 (BOI Report, Exhibit 30).

[17] BOI Exhibit 12, page 30.

[18] Report MBU-DES-R-NIM-210565 dated September 2003 "Removal of Asbestos Insulation Muffs in the APU Bay PDS Task 16-3381", page 5.

[19] Aviation Fuel.

[20] The three Nimrod R1s do not have SCPs. See the full discussion of this incident in **Chapter 8**.

[21] WAD/9155/3/FSWHQ/8/08 signed by the investigating officer on 19 May 2008.

[22] "The chemical decomposition of a substance either when heated to a high temperature in the absence of oxygen or when heated at lower temperatures in air over prolonged periods". QINETIQ/09/01371/D, dated 18 June 2009.

[23] QINETIQ/09/01371/D dated 18 June 2009.

[24] QINETIQ/09/01371/D dated 18 June 2009.

4.21 The original 1967 design specification for the Refrasil blanket thermal insulation for High Temperature (HT) ducts provided for a layer of fibreglass wool insulant ½ inch thick, protected by a thin dimpled stainless steel skin or sheath.[25] It was designed as insulation capable of providing a thermal barrier at internal temperatures up to 550°C, allowing an external temperature of no more than 165°C. The 1967 specification clearly indicates that the blanket insulation was intended to have a dual function: both (a) inhibiting heat radiating out; and (b) preventing fluids seeping in, and therefore onto, HT ducts. [26] The specification stated, *"[b]ecause of its stainless steel skin it is useful in places where there may be a risk of spillage of fluids"*. [27] The specification also provided: *"[w]hen the dimpled s/steel sheath is assembled and welded in place it should present a neat sealed casing which will prevent the ingress of moisture or fluids"*.[28]

4.22 When brand new Refrasil should be as shown in Figure 4.6.

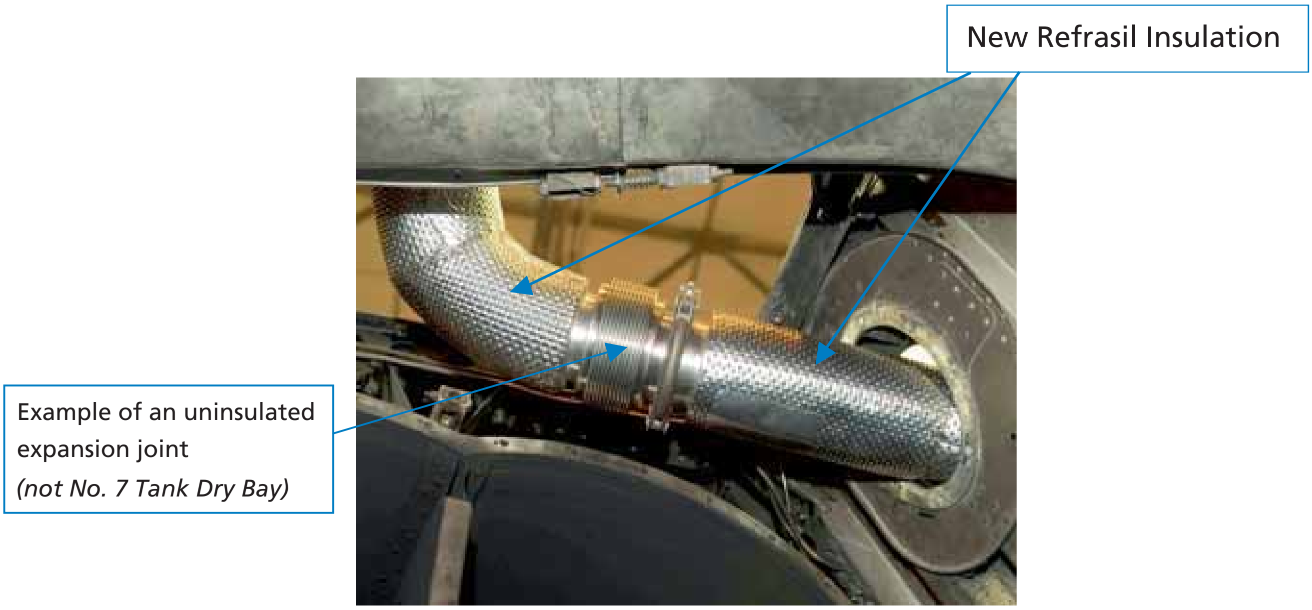

Figure 4.6: Newly Installed Section of Cross Feed Duct

4.23 Old Refrasil insulation was found on many Nimrods, however, to look as shown in Figure 4.7. The outer stainless steel covering is compressed almost uniformly around the circumference, has a distinct 'ribbed' pattern, and can no longer perform its function of maintaining the outer surface temperature at 165°C maximum (see Figure 4.7).

[25] *"The design consists of a layer of fibre glass wool, acting as a light weight insulant wrapped around the duct, retained and protected by a skin of dimpled stainless steel of very thin gauge which is welded to retaining rings on the ducts"*. (Spec, Ibid, page 1).

[26] Hawker Siddeley Aviation Ltd Spec DHA 567 dated 13 September 1967 (BOI Report, Exhibit 63).

[27] Spec, Ibid, page 1.

[28] Spec, Ibid, paragraph. 2.2.5)

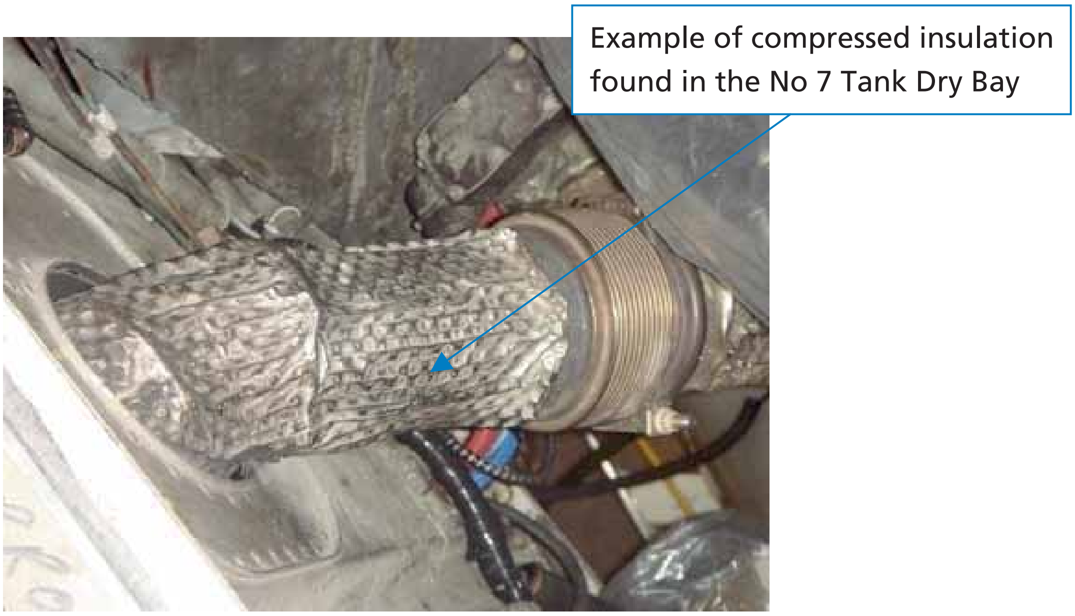

Figure 4.7: Old Section of Cross Feed Duct

4.24 Although, in theory, the Nimrod's hot air duct insulation was intended to be liquid-proof, there were a number of weaknesses in its design. These weaknesses stemmed from the fact that the Refrasil was not continuous and did not cover every inch of the ducting; therefore, parts of the duct, in particular some expansion bellows, were left unlagged or covered in 'shrouds' or 'laced muffs', which were vulnerable to fluid ingress (see further below).

Unlagged Bellows

4.25 There are a number of un-insulated bellows within the Cross-Feed/SCP duct system. The BOI was unable to determine any recorded reason for leaving the bellows in the upper No. 7 Tank Dry Bay un-insulated. Trials conducted by the BOI recorded that these bellows reached a temperature of between 343°C and 399°C when the Cross-Feed duct was open.[29] As noted above, these trials were limited by restrictions placed on the operation of the SCP after the loss of XV230 and full operating temperatures could not be reached. The temperature of the bellows when the SCP operated in the air would be higher. Indeed, from the BAE Systems and AAIB evidence quoted previously, the duct could have reached temperatures in excess of 400°C.

4.26 BAE Systems has been unable to trace a positive design decision to leave the No. 7 Tank Dry Bay bellows un-insulated. This is perhaps not surprising in view of the passage of time since the original design was completed. BAE Systems submitted to the Review, however, that the decision not to insulate the bellows was an *"understandable and a reasonable engineering judgement"*.[30] This was based on five main assertions:[31]

(1) As the bellows are situated above the fuel pipework in the No.7 Tank Dry Bay leaking fuel is unlikely to impinge on them;

(2) Although the bellows are below elements of the aircraft's vent system, this system will only hold limited amounts of fuel in the event of a system 'abnormality';

(3) The AIT for AVTUR is likely to be higher than the surface temperature of the bellows;

(4) Any leak of fuel reaching the bellows would be unlikely to be sufficient for a sustained fire; and

(5) Fitting a detachable insulating muff would have added a potential loose article hazard to an area crowded with flight control cables and pulleys.

[29] BOI Report, Exhibit 36.

[30] BAE Systems written submissions to the Review.

[31] BAE Systems written submissions to the Review.

4.27 The BOI determined that, whilst the un-insulated bellows were a possible source of ignition, it was much less likely than the SCP bellows for very similar reasons to BAE Systems' points at (1), (2) and (4) above. The BOI did, however, note a greater risk of fuel leaking from the vent system, because of a poorly designed vent connection and the potential for overflow during AAR.[32] As to point (5), I would have expected that if insulation had been required, a product which would not form a 'loose article' hazard would have been used, *i.e.* it would be fastened in such a way that it could not detach from the duct, fall onto the floor of the bay and/or potentially become entangled in flying controls *etc.* The better point, in my view, is that had a muff been fitted, it might have given rise to just the same risk of leaking fuel being held in contact with a hot duct that we can see in the case of XV230's SCP muff at a lower level in the No. 7 Tank Dry Bay.

4.28 Point (3), however, requires closer examination: would the AIT for AVTUR be above the surface temperature of the duct? The surface temperature of the duct is quoted in a BAE Systems paper[33] as 435°C, which corresponds to the figures quoted by the XV230 BOI and the Air Accident Investigation Branch (AAIB). The BAE Systems paper was produced as the result of the need to replace the insulation muffs around the SCP (and other) ducts, because they had a high asbestos content. It considered whether the aircraft could be operated without muffs fitted to these areas whilst replacements were manufactured. The paper stated that the muffs could only be removed if duct temperatures were 100°C below a *"worst case ignition temperature of 305°C"*.[34] This 'worst case' temperature was calculated for a hydraulic fluid contacting a three inch diameter pipe within a chamber having an ambient temperature of 79°C to 90°C.[35] The only possible difference between these criteria and the situation of the unlagged bellows is that the ambient temperature around the bellows might be lower. However, even allowing for a significantly reduced ambient temperature of 35°C, the AIT would be 420°C. Thus, by BAE Systems' own criteria (admittedly produced many years after the bellows were initially left unlagged) these bellows should actually have been insulated.

4.29 Nonetheless, it is worth considering whether, in absolute terms, the unlagged bellows actually could reach AIT for AVTUR. In the 1960s and 1970s the Royal Aircraft Establishment (RAE) conducted laboratory experiments[36] in an attempt to determine the AIT of a number of fluids in differing circumstances. In some of these experiments, pipes of known temperature were placed in spheres of uniform temperature. This arrangement will *"quite closely approximate to real situations"*, but is *"a more severe condition than is often met in practice, where a more open environment of forced ventilating flows can give additional relief"*.[37] Nonetheless, one of the papers notes that *"the extent of such relief is extremely difficult to assess and unless directly applicable data is available it may be considered safer to use the relevant limiting ignition temperature as quoted"*.[38] In other words, the laboratory experiments provide a 'worst case' and it is best to use these, unless data specific to a given situation shows the figures to be too pessimistic. This is, of course, exactly what BAE Systems did in its paper discussed above.

4.30 The RAE experiments conducted in controlled environments indicate that the AIT of AVTUR aviation fuel vapour on a 76mm diameter pipe (the approximate diameter of the SCP pipe) is 325°C,[39] while that of AVTUR liquid is 390°C[40] (using 'worst case' examples as noted above). The graphs from which these figures are obtained are the same as those cited in the BAE Systems' report above and the ambient temperatures used are the same.

4.31 Although BAE Systems apparently provided a logical rationale and explanation for the lack of insulation on the bellows within the No. 7 Tank Dry Bay, it appears clear that, on occasions, the temperature of the exposed ducting could reach the AIT for AVTUR (the BOI noted that temperatures in the order of 420°C would only

[32] BOI Report, page 2-33, paragraph 40(d)(i), and page 2-49, paragraph 65f(3).

[33] MBU-DES-R-NIM-210565 Issue 1 dated September 2003. The temperature is for the hot air duct within the SCP external fairing. The unlagged bellows will, if anything, be of a higher temperature as they are closer to the engines.

[34] Ibid, page 5.

[35] Both pipe diameter and ambient temperature can have a significant effect on the AIT for a given liquid.

[36] Royal Aircraft Establishment Technical Report 72059, dated May 1972 and Royal Aircraft Establishment Technical Report 67162, dated July 1967, Figure 41. Some of the data from these form the basis of the BAE Systems report discussed above.

[37] Royal Aircraft Establishment Technical Report 72059 dated May 1972, page 11.

[38] Ibid.

[39] Interpolated from Royal Aircraft Establishment Technical Report 67162, dated July 1967, Figure 7.

[40] Interpolated from Royal Aircraft Establishment Technical Report 67162, dated July 1967, Figure 41.

be reached with high power settings).[41] The chance of fuel actually reaching and remaining on this potential point of ignition in sufficient quantity to cause a fire is, however, relatively low. During a test to determine the potential leak paths for fuel, should it leak from the aircraft vent system couplings above the unlagged bellows, none touched the bellows.[42] This was, of course, a static test and could not reproduce the variations in pitch and bank that would occur during flight. There is no doubt though, from the information calculated by RAE and subsequently utilised by BAE Systems, that the unlagged bellows could reach the AIT for AVTUR and, therefore, by BAE Systems' own criteria, should have been lagged. As discussed below, however, the addition of an insulation muff or shroud could have exacerbated the risk of fire in the event of leaking fuel making contact with the bellows. Whether or not the risk was properly considered at the Nimrod 'acceptance conference' during August 1968 is a moot point (see further below).

Shrouds

4.32 There are two metal shrouds covering the Cross-Feed expansion bellows in the fuselage centre section; these shrouds appear to be the device used within the MR1/R1 design to insulate expansion bellows. They consist of two half-shells, each comprising two layers of stainless steel, separated by a layer of insulation. One of these shrouds was involved in the (fortunately short-lived) fire discovered on Nimrod XV249 on 28 January 2008. An accelerant[43] had entered the shroud (thus it is clearly not liquid-proof) and been ignited; the ignition process was complex, but it is believed that fuel soaked into a Cross-Feed duct mounting block, ignited and in turn ignited fumes emitting from the fluid in the shroud.[44] The investigation suggested that the accelerant had pooled within the shroud because it had been closed such that the join between its two halves was in a horizontal alignment; it was postulated that, if the shroud had been rotated through 90 degrees, the accelerant would have drained out between the join. However, prior to this incident, there was no requirement to fit the shrouds in this manner and no indication that not doing so could prove a fire hazard; furthermore, there are no drain holes in the shroud to allow drainage.

Laced flexible muffs

4.33 During the conversion process from MR1 to MR2, the addition of the SCP also brought with it the need to insulate the new duct from the surrounding structure, including the external fairing aft of the No. 7 Tank Dry Bay. The majority of the insulation on the SCP pipe is Refrasil but the expansion joints were covered by flexible muffs laced up with wire along a longitudinal seam (see Figure 4.8 below). The selection of the laced muff was driven by the need to minimise its surface area to allow it to fit into the cramped confines of the (new) SCP fairing.[45] Produced initially by Bestobell, the specification of these muffs describes the end finishing as *"draw wire or cord in the hem"*, *"to prevent the ingress of fluid"* and that *"all external unproofed stitching or cloth is sealed against fluid contamination"*. The muffs are faced with a metallic lacquer, which provides resistance against absorption. BAE Systems' understanding was that these muffs would provide a liquid-proof barrier. In a BAE Systems document discussing the need to remove or replace some of the muffs, which had asbestos content, a Chapter is entitled: 'Lagging and Insulation Muffs Design Philosophy.'[46] This Chapter notes that: *"If flammable liquids were not contained and drained, then the hot ducts would require lagging to bring surface temperatures below the ignition point of any possible leaking flammable fluids or vapours. The latter design philosophy applies in the APU and pannier bays on the Nimrod aircraft"*.[47]

4.34 In an obvious contradiction of the design philosophy expressed above, the muff immediately aft of the SCP elbow is not long enough both to cover the exposed section of duct and to fit over the end of the Refrasil, to form a liquid tight seal (see Figure 4.8 below). In any event, the rear end of the muff abuts against a clamp which is not insulated. Moreover, the movement of the expansion bellows relative to the aircraft will always

[41] BOI Report, paragrapth 42(c) [2-38].

[42] NAEDIT/1505/09/14/Task, dated 1 September 2009.

[43] The investigation was unable to determine whether the accelerant was aviation fuel or hydraulic fluid.

[44] QinetiQ report /08/01561/5.0 dated 29 January 2009. An additional report is being compiled but was not available at time of publication of the Review.

[45] Evidence from Martin Breakell of BAE Systems, May 2009.

[46] Report MBU-DES-R-NIM-210565 dated September 2003 "Removal of Asbestos Insulation Muffs in the APU Bay PDS Task 16-3381", page 3.

[47] Report MBU-DES-R-NIM-210565 dated September 2003 "Removal of Asbestos Insulation Muffs in the APU Bay PDS Task 16-3381", page 3.

mean that any attempted seal between the muff and the Refrasil will not remain complete. Even in its 'as designed' state, the muff cannot form a completely liquid-proof seal between the Refrasil sections.[48] This is apparent to the eye and when one pours water from a glass over it. Furthermore, the design of the SCP muff is such that, even if the laces are facing downwards, an internal flap or 'tongue' prevents fuel escaping once it has entered. The BOI noted a number of aircraft in which there was a gap between the Refrasil insulation and the edge of the muff (as seen below); this left a small area of ducting surface exposed, which would have been at a temperature of over 400°C when operating.[49] In some of these aircraft, the wire holding the muff was also loose, further increasing the possibility of liquid ingress (see generally Figure 4.8).

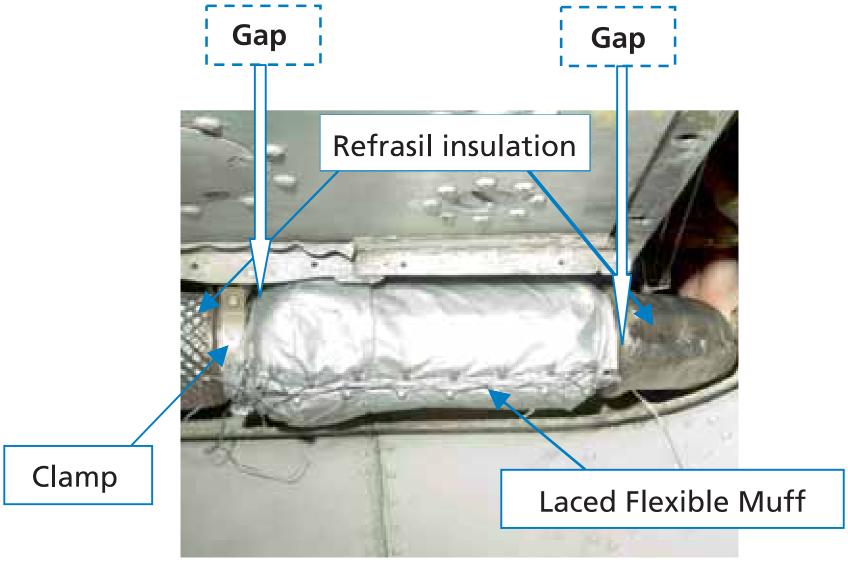

Figure 4.8: SCP Expansion Bellows – Flexible Muff (new)

Flexible muff on XV255

4.35 In January 2009, during work on the 'Hot Air Duct Replacement' programme, a flexible muff removed from the SCP elbow of XV255 at RAF Kinloss showed signs of scorching/combustion; from its smell, it had also clearly been contaminated by fuel (AVTUR). Subsequent analysis by QinetiQ[50] has proved that the marks indicate 'pyrolysis'[51] rather than complete combustion of an accelerant; the most likely accelerants were identified as OX87 hydraulic fluid and OX7 engine oil (it was considered likely that the fuel had contaminated the muff shortly before its removal and after the pyrolysis had taken place). The OX7 had probably escaped from a small leak in the V-band clamp at the joint in the pipe and been transported there by engine bleed air; this would be normal for a Spey engine. The original source of the OX87 was not proven, however, there is no internal route within the engine for hydraulic fluid to reach this location; it must have leaked from an external source on to the muff. A consequent risk of ignition was identified within the report:

> *"The low auto-ignition temperature of one of the OX87 marker compounds found on the discoloured muff ... indicated that there would have been a consequent risk of ignition occurring within the muff if sufficient reactive mixture had been present. This risk was not realised."*

[48] Of note, as explained in **Chapter 8**, the RAF lost a Tornado, attributed to the leakage of fuel into the gap between two sections of Refrasil insulation.

[49] BOI Report, page 2-38, paragraph 42.

[50] QinetiQ/09/00792/DRAFTvC. An interim report – final report not available at time of Review publication.

[51] *i.e.* decomposition brought about by high temperatures.

4.36 This confirms that combustible fluids can gather under the muff; both hydraulic fluid and fuel in this case. Since the SCP has not been used since September 2006, it is difficult to determine when this incident may have occurred. Regular maintenance checks of the SCP on the ground were carried out until July 2008 and would only have used low engine power settings consistent with the results of the chemical analysis. It remains a possibility that, under the normal operating temperatures of the SCP pipe experienced before September 2006, the hydraulic fluid could have been ignited, as indeed would fuel. The precise sequence of events will never be known but, in my view, it is powerful corroboration of the BOI's finding on likely ignition point and proof that fluids can, and do, enter the SCP elbow muff (see Figures 4.9 and 4.10).

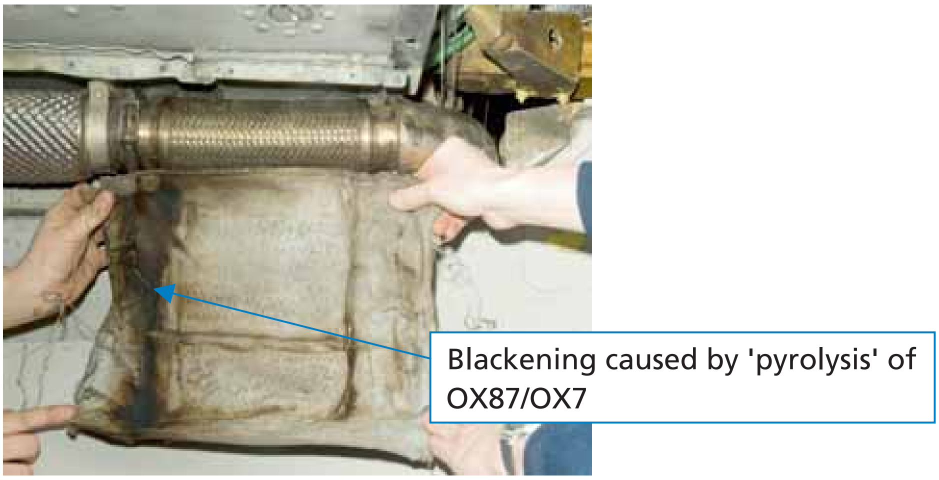

Figure 4.9: XV255 Flexible Muff

Note: the muff shown on the photograph was the item taken off XV255 and shows the scorching. The part is, however, not the correct muff for this bellows and is in fact 6cm longer then the correct part. Thus, it may give the incorrect impression that the muff is designed to cover the gap between sections of Refrasil.

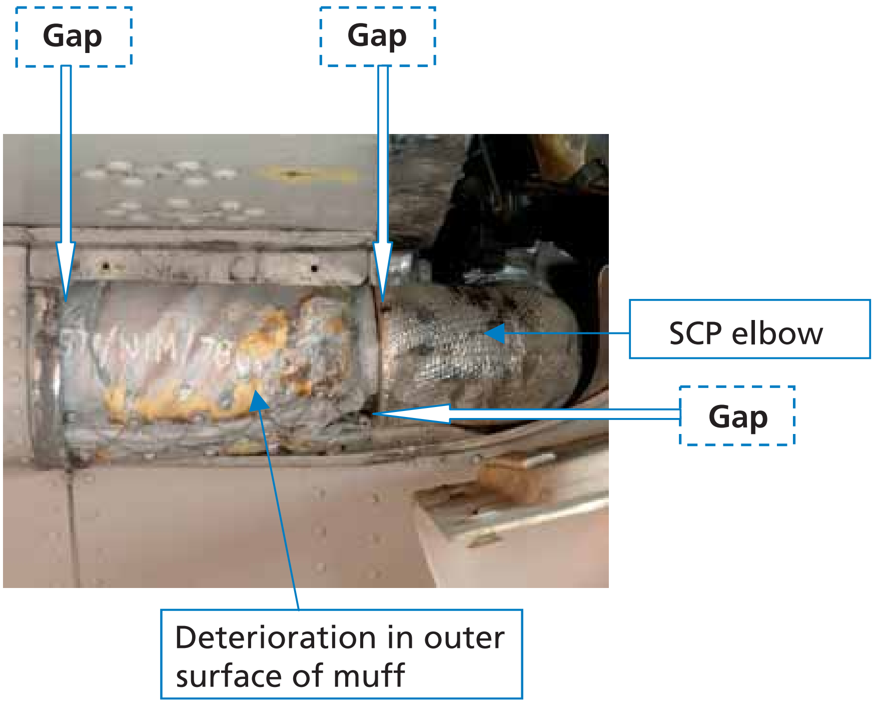

Figure 4.10: SCP Expansion bellows/flexible muff (showing deterioration)

Insulation gave false sense of security

4.37 The insulation may have led to a false sense of security by giving the impression that the Cross-Feed/SCP duct was somehow impregnable to fluid and did not pose any, or any significant, risk as a source of ignition in the event of fuel or hydraulic oil leaks. Many skilled and experienced Nimrod engineers may have failed to realise the dangers lurking in starboard No. 7 Tank Dry Bay because of a false sense of comfort given by the insulation.

4.38 As mentioned above, BAE Systems' engineers investigating the possibility of removing insulating muffs from hot ducts (because the muffs contained asbestos)[52] determined that the muffs had to remain on the ducts within the SCP pannier bay, as their temperature exceeded the "ignition temperature for DTD 585"[53] and AVTUR vapour. However, no consideration was given to the adequacy of the duct insulation, because it was believed that it was adequate.

4.39 In drawing up the Nimrod Safety Case, BAE Systems appears to have assumed from looking at the photographs used in its Phase 2 analysis that the insulation obviated any risk of fuel ingress: *"[A]ll hot bleed-air system piping ducting in vicinity and outside the fire zones is appropriately lagged with non flammable insulation material encased within a stainless steel foil covering (to prevent an exposed high duct/duct surface temperature as an ignition source.)",*[54] The author(s) wrongly assumed that the insulation covered the entire duct system and would prevent the ignition of flammable liquids against such ducts: *"the ducting is insulated and analysis has shown that the surface temperature of the insulation in all cases will be below that required for spontaneous combustion of the fuel"*[55] (see further **Chapters 10** and **11**).

Condition of insulation

4.40 Inspection of the Refrasil insulation on the Cross-Feed/SCP duct of other Nimrod aircraft showed many areas to be visibly compressed, and in some places, the outer jacket to be cracked. The poor condition of the insulation would have reduced its effectiveness in preventing the radiation of heat from the Cross-Feed/SCP duct. Experiments conducted by the Nimrod Aircraft Engineering Design Investigation team (NAEDIT) on behalf of the BOI *"indicated only a 16°C temperature difference between an exposed section of hot air duct and the exterior of the insulated blanket"*. Refrasil removed from Nimrod MR2 XV246 was observed to be damaged and to exhibit possible *"baked on"* deposits. Analysis by BAE Systems[56] determined that the deterioration meant that the exterior of the insulation would have reached temperatures between 200°C and 300°C. The Refrasil damage was considered by the BOI as *'likely to have occurred over time during maintenance activities'.* While maintenance may have contributed to some damage, the regular, circumferential nature of the compression may also indicate a long term physical process at work, such as thermal expansion and contraction[57] or changes in atmospheric pressure. Nonetheless, recent experiments by BAE Systems in which sections of Refrasil covered ducts were subjected to cyclic pressure changes have been unable to reproduce the observed degradation. However, the degraded Refrasil may well have been in place for in excess of 35 years and the long term affect of cyclic pressure changes and thermal expansion would require a longer-term investigation. Despite these facts, it would be more difficult for auto-ignition to occur on the outside of the Refrasil as fuel would tend to evaporate quickly before ignition could take place.

4.41 In addition to the Refrasil, many of the muffs fitted to the aircraft have been observed by the BOI and the Review to have degradation of their metallic external covering, which would make them prone to liquid ingress/absorption (see above). The poor state of the Refrasil insulation and the muffs is attributable to differing interpretations of the maintenance policy. There were no maintenance limitations or allowances on the condition of Refrasil. Although the Air Member for Materiel, in his comments on the BOI,[58] stated that this meant that *"no acceptable damage limits are defined"* and that a concession should have been sought for any damage, this was clearly

[52] Report MBU-DES-R-NIM-210565 dated September 2003 "Removal of Asbestos Insulation Muffs in the APU Bay PDS Task 16-3381".

[53] DTD585 is an obsolete hydraulic fluid used by BAE Systems to represent a 'worst case' ignition risk.

[54] BAE Systems Baseline Safety Case Fire/Hazard (August 2004) Report, see pages 100 and 106.

[55] Mechanical Systems Zonal Hazard Response Pro-Forma, Hazard NM/H73, paragraph 6.

[56] BAES-WMAT-RP-NIM-CHM-303359, Issue 1, dated May 2008.

[57] BOI Report, Exhibit 30 page 8 paragraph 2.1.6.

[58] BOI Report, Air Member for Materiel Comments, paragraph 11.

not the interpretation of the maintainers, both military and civilian, in a variety of ranks, over many years. The Refrasil in poor condition is not confined to a few isolated areas, but is relatively widespread throughout the fleet. It is probable that the gradually deteriorating condition of the Refrasil became accepted as normal, over a period of years, by those charged with its maintenance. There is no evidence that this view was ever challenged by any supervisory organisation – civilian or military. The deteriorated condition of the ducting appears to have been the accepted norm. There were very few, if any, brand new ducts manufactured with which comparison could be made.

4.42 The deterioration in the Refrasail should, in my view, have been observed and corrected. There is no doubt that, under the Corrective Maintenance policy for the hot air system, the Refrasil condition deteriorated. I thus agree with the observation of the BOI that a *"lack of guidance"* on the allowable condition for hot air duct insulation contributed to its gradual deterioration in some areas. [59]

Gaps

4.43 Whilst the deteriorated condition of the insulation did present a potential ignition risk, in my view, the most significant risk of ignition, as demonstrated by incidents following the loss of XV230, was the presence of gaps within the insulation associated with the muffs, which could allow fuel to enter the muff and be effectively trapped between the surface of the duct and the inner surface of the muff. These gaps were there as a result of inadequate design. It is design which is the predominant factor which allowed the ignition of fuel on XV230. Nonetheless, as noted above, the maintenance policy for the hot air system did not prevent a significant deterioration of the hot air duct insulation, inured personnel to its worsening condition, and may have prevented a more questioning attitude to the effectiveness of that insulation.

No fire detection and suppression system

4.44 Despite the fact that fuel reaching the outer surface of the metal ducting is likely to ignite, there is no fire detection or suppression system in either port or starboard No. 7 Tank Dry Bays.[60] There is a heat probe[61] in both No. 7 Tank Dry Bays close to the point where the Cross-Feed duct exits the bay. There is also a fire detection wire (fire-wire) which runs round the bomb bay past openings between the No. 7 Dry Bays and the bomb bay. But in no sense can either be considered a fire detection system in starboard No. 7 Tank Dry Bay, still less a fire detection and suppression system.

Cross-Feed/SCP duct posed a serious fire risk

4.45 The Cross-Feed/SCP duct posed a serious fire risk on the Nimrod MR2 for four reasons: (1) location; (2) design of the No. 7 Tank Dry Bay; (3) inadequate insulation; and (4) lack of fire protection (see Figures 4.11-4.13 below).

(1) Location

4.46 The location of the Cross-Feed/SCP duct across the centre section of the fuselage and within the No. 7 Tank Dry Bays made it a potential ignition source for any fuel which might escape from the numerous fuel, hydraulic and vent systems all around:

- its location in starboard No. 7 Tank Dry Bay was very close to fuel pipes and couplings (there are several fuel couplings within 12 inches);
- the location of the SCP duct at the lowest point of starboard No. 7 Tank Dry Bay made it particularly vulnerable to fuel either leaking from above or tracking along the fuselage; and
- the location of the SCP duct in an external fairing only 2.1 metres aft of the No. 1 tank blow-off valve made it particularly vulnerable to fuel tracking back from the blow-off valve during AAR.

[59] BOI Report, paragraph 31(b) [2-22].
[60] BOI Report, paragraph 43 [2-39.]
[61] A Kiddie-Graviner temperature sensitive switch (part of the centre section overheat detection system).

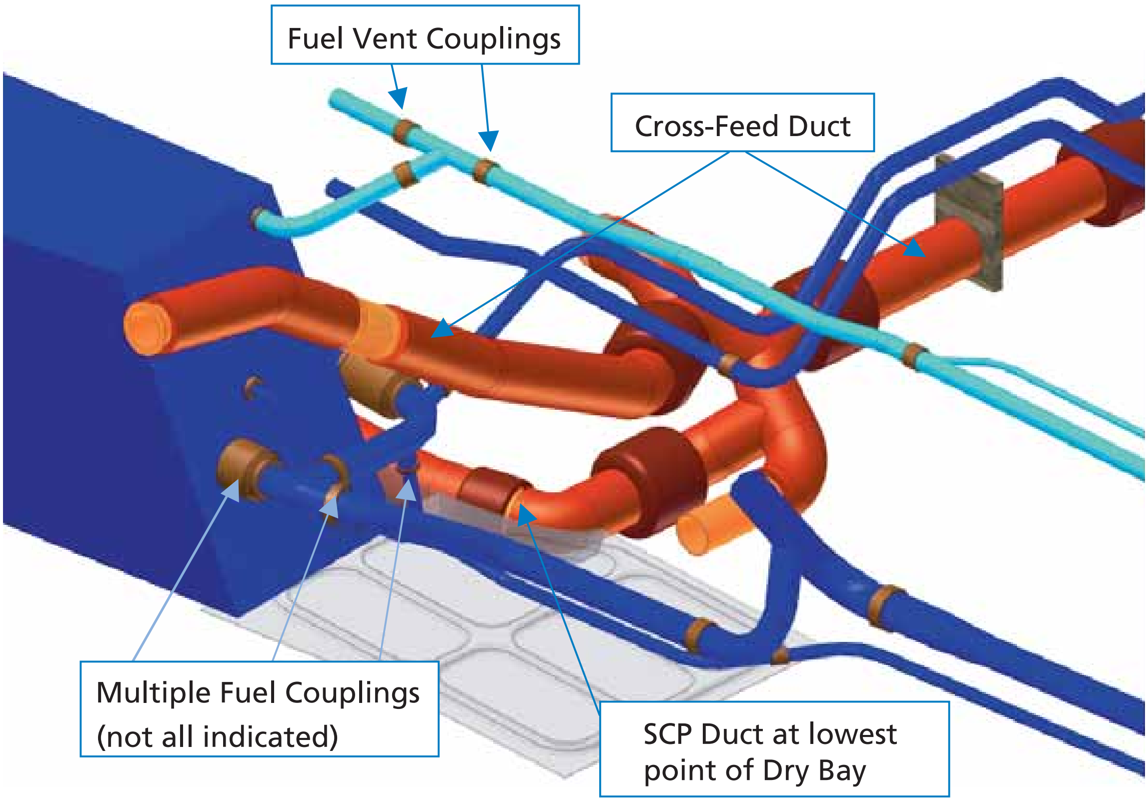

Figure 4.11: No. 7 Tank Dry Bay

(2) Design of No. 7 Tank Dry Bay

4.47 The design of starboard No. 7 Tank Dry Bay increased the likelihood of fuel coming into contact with the SCP duct:

- the design of the lower fairing panel was such that it could act as a receptacle for leaking fuel to pool close to the SCP duct elbow. The drain holes are located such that about 300ml of fuel could collect between the ribs of the panel before spilling over to reach the drain holes;[62] and
- the design of the fairing (covering the SCP duct as it left the No. 7 Tank Dry Bay) was such that any fuel or liquid tracking along the side of the fuselage hull could enter the SCP fairing and, potentially, the bottom of starboard No. 7 Tank Dry Bay.

[62] Following a BOI recommendation, drainage is now improved.

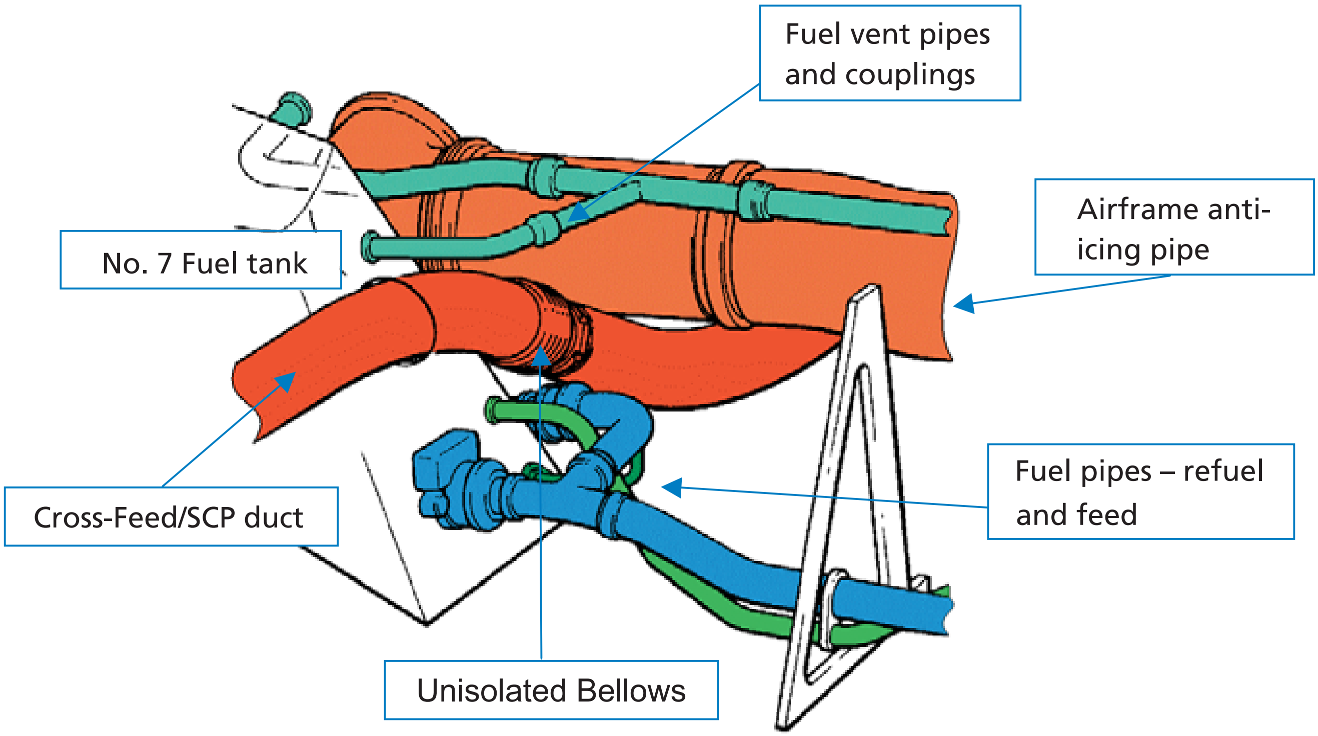

Figure 4.12: No. 7 Tank Dry Bay (Main Components)

(3) Inadequate insulation

4.48 The Cross-Feed/SCP duct was inadequately protected from contact with fuel and hydraulic fluids:

- its insulation arrangements were inadequate: there were sections with no insulation at all and gaps between different types of insulation;
- the muffs and shrouds used to insulate for example, expansion bellows, can allow fuel to enter and touch the duct surface. They may then effectively hold the fuel against the surface, promoting a combustion environment;
- there was no other significant form of protection from leaks of inflammable fluid;
- the understanding that the Refrasil acted as a perfect barrier against liquid may have led to a lack of focus on both its real effectiveness and its deteriorating condition; and
- the insulation was allowed to deteriorate over a period of time with no attempt at remedy.

(4) No fire protection

4.49 There was no fire protection in the starboard No. 7 Tank Dry Bay:

- there was no fire detection and suppression system protecting the Cross-Feed/SCP duct;[63] and
- there was no fire-wall around it.

[63] It would be unlikely that an attempt to introduce a fire detection and suppressant system to an area such as this would be made. It is more likely that the hazard would be removed – as it now has been.

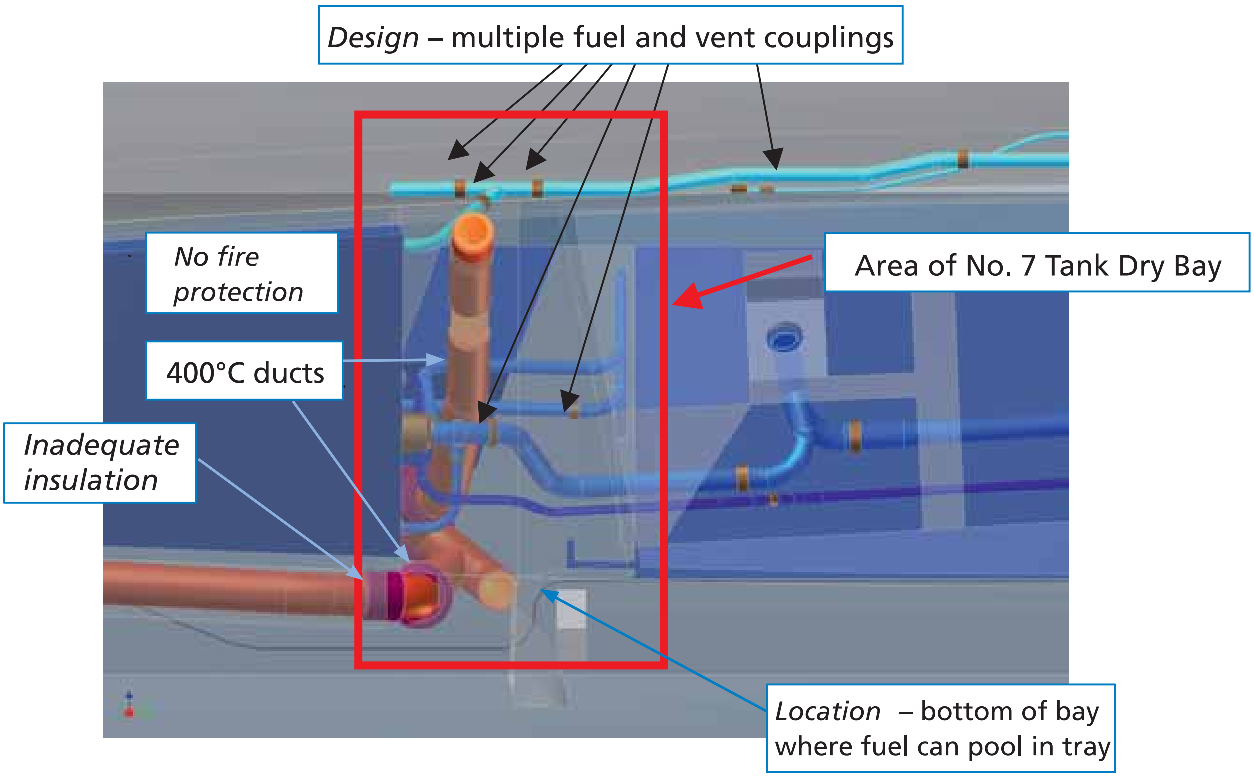

Figure 4.13: No. 7 Tank Dry Bay (Design Features)

Breach of design standards applicable in 1969 and 1979 – AvP 970

4.50 In my view the original Nimrod designs for the MR1 and MR2 were in breach of design standards applicable in 1969 and 1979.

4.51 As explained in **Chapter 2,** the Nimrod MR1 was a derivative of the Comet 4C airliner and was designed and certificated to MOD Specification No. MR254 D&P dated 13 April 1965, which accepted the same certification base as the MR1. The underlying design specification of the Comet 4C was accepted as being valid, having been certified in accordance with British Civil Airworthiness Requirements (BCARs), Section D Issue 3, dated 1 July 1956. The changes to the original design were required to comply with AvP 970, the military equivalent of BCARs. Derogation from AvP 970 was not allowed unless *"… the requirements are obviously inapplicable or are over-ridden by the requirement of the Aeroplane specification."*[64]

4.52 Those elements of the Nimrod MR1's design which were specific to the Nimrod (such as the Cross-Feed system and the bomb-bay empennage) were required to conform to the military AvP 970 issued on 1 May 1958.

4.53 As a matter of good engineering practice, it would be extremely unusual (to put it no higher) to co-locate an exposed source of ignition with a potential source of fuel, unless it was designated a fire zone and provided with commensurate protection. Nevertheless, this is what occurred within the Nimrod.

4.54 It will come as no surprise that the design of the Nimrod Cross-Feed/SCP system was contrary even to the design standards and regulations applicable at the time of the original design and modifications in 1969 and 1979, respectively:

[64] AvP 970, 1965 Edition, Volume 1, paragraph 1.2.

(1) Breach of original general fire safety design standards

4.55 In my view, the original Nimrod MR Mk1 and Mk 2 designs were in breach of general fire safety standards applicable in 1969 and 1979 because of the juxtaposition of the Cross-Feed/SCP duct and fuel pipes in the No. 7 Tank Dry Bays. These bays had the characteristics of a *"fire zone"*, but had none of the safety features mandated by AvP 970, *viz*: fire walls; a fire detection system; a fire suppression system; and fire-proof fuel pipes.

4.56 AvP 970 Chapter 715[65] defined a fire zone as *"Any region in which a single failure of an installation or any part of it could result in a fire or break out of existing controlled fire (e.g., combustion chamber) into the aeroplane"*.[66] AvP970 also made it clear that the responsibility for identifying fire zones rested with the designer: *"The decision as to which regions must be regarded as fire zones is clearly one which, initially at least, can only be taken by the designer. To provide a basis for this, the general requirement of Chapter 715 and paragraph 3.1 has been formulated"*.[67]

Scenario A: Leak from fuel coupling onto Cross-Feed/SCP duct

4.56.1 The numerous fuel pipes and couplings, and their juxtaposition to the high temperature Cross-Feed/SCP duct, represented just such *"single failure"* points which were potentially catastrophic. Fuel could leak from any one of the nine couplings in starboard No. 7 Tank Dry Bay onto the Cross-Feed/SCP duct and, by reason of the gaps in and around the insulation and the laced 'muffs', such leaking fuel could gain access to the very hot surface of the ducting itself and ignite. BAE Systems' Chief Airworthiness Engineer, Chris Lowe, said in interview with the Review that such muffs probably *"would not* [provide a complete seal against fuel ingress] *and neither is it meant to"*.[68] He said that they were designed to allow fuel to drain out. Their shape and construction, in particular the 'tongue', would, however, give rise to a real risk of fuel 'pooling' and being held against the hot metal surface of the ducting for a sufficient period to ignite.

Scenario B: Failure of Cross-Feed/SCP duct

4.56.2 Further, the Cross-Feed/SCP duct, by virtue of the high temperature and pressure of the air they contained, and their proximity to vulnerable fuel couplings, clearly represented just such *"single failure"* points which were potentially catastrophic. A failure of the duct would allow the escape of hot bleed-air which was likely to impact upon, and destroy the integrity of, adjacent rubber fuel coupling seals leading to leakage of fuel onto very hot duct surfaces, either through pre-existing gaps in the insulation or through new gaps caused by damage occurring during the original failure. This is the scenario that nearly befell XV227 on 22 November 2004, when it suffered a major hot air duct failure in a section of the Cross-Feed/SCP just aft of the elbow at the bottom of No. 7 Tank Dry Bay due to corrosion.[69] The hot air leak of gases up to 420°C caused serious damage *inter alia* to numerous proximate fuel seals in No. 7 Tank Dry Bay. XV227 was fortunate not to have been lost entirely (see further **Chapter 7**).

(2) Breach of original design safety standards on accumulation of flammable liquids

4.57 The Nimrod designs were in breach of the safety standards regarding the accumulation of flammable liquids applicable in 1969 and 1979 because fuel could pool in No. 7 Tank Dry Bays.

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[65] AvP 970, Volume 1, re-issue, 1 June 1960.

[66] AvP 970, Chapter 715, paragraph 3.1.

[67] AvP 970, Chapter 715, paragraph 2.1.3.

[68] Chris Lowe's subsequent remarks about the liquid draining out through the lace holes fail to take account of the fact that (a) the muff might be laced with the holes uppermost and (b) in any event, the inner lining of the muff would act to hinder any liquid draining out.

[69] At point in the duct between the Pressure Regulating and Shut Off Valve (PRSOV) and the Flow Limiting Venturi.

4.58 AvP 970 Chapter 715 (paragraph 2.2.2) required that *"Any compartment in which inflammable fluids may be liable to accumulate accidentally or from a drain on or in the aeroplane shall either drain automatically in flight or be capable of being drained as a servicing operation."* Fuel leaking from one of the numerous fuel pipes and couplings in starboard No. 7 Tank Dry Bay was liable to accumulate in the lower (corrugated) panel tray at the bottom of the bay because the design and placement of the drainage holes in the panel was ineffective, in that it was possible for fuel to pool on the upper surface of the panel, between stiffeners, in volumes of up to 300ml (these drainage holes have since been rectified).

(3) Non-conformity with design safety standards regarding the use of absorbent lagging

4.59 The Nimrod designs were arguably not in conformity with the original safety standards of 1969 and 1979 regarding the use of absorbent lagging for the protection of flammable liquids.

4.60 AvP 970 Chapter 715 (paragraph 6.4.1) required that *"Heat insulating material shall be non-inflammable and preferably non-absorbent"* The laced muffs in the No. 7 Tank Dry Bay were unable to prevent fluid ingress at their ends and seam, were liable to retain liquid, and were, therefore, on this basis 'absorbent'. (The capability of such laced muffs to absorb and retain fluid is demonstrated by the XV225 incident in which the muff was found to be soaked in fuel).

Design Handbook

4.61 It should be noted that the Design Handbook at the time provided as follows:

> *"Section 3:...leakage or drainage of combustible substances such as fuel, oil, hydraulic fluids etc, near a heat source is a fire hazard ... lines should, therefore, be placed as remotely as possible from heat sources and away from or below other equipment to avoid leakage on to controls, components (especially electrical equipment) or absorbent materials. The use of protective shrouding or trays (with adequate drainage) should be considered to protect vital equipment or contain the fluid from a coupling failure."* (emphasis added)

BAE Systems' denial of breach of original design standards

4.62 In its submissions and evidence to the Review, BAE Systems denied there was any breach of any of the original design standards. The Review heard from two senior BAE Systems executives: the Military Airworthiness Solutions (MAS) Chief Engineer¸ Martin Breakell, and BAE Systems MAS Head of Airworthiness, Tom McMichael. They accepted the fact that fuel could access the muff, but sought to argue on behalf of BAE Systems that the single point failure scenarios postulated above were *'incredible'* because: (a) very large volumes of fuel would be required to create the conditions for soaking and ignition and the required catastrophic fuel pipe failure of this nature was not *'credible'*; and (b) a failure of the Cross-Feed/SCP duct would *'blow the fuel away'* and that ignition was, therefore, not *'credible'*. In my view, both arguments were grasping at straws.

4.63 First, it is clear *e.g.* from the recent videos of leaks on board XV250 and XV229 (see above and further **Chapter 5**) that fuel couplings could suddenly spring significant fuel leaks which could provide a substantial and continual fuel source feeding any fire. Second, it is clear from the configuration of starboard No. 7 Tank Dry Bays that fuel from such leaking couplings might well find its way onto the Cross-Feed/SCP duct and into the gaps and crevices in and about the Refrasil insulation and muffs and pool in the lower panel tray. Third, it is clear from the QinetiQ fire study that only a *very* small quantity of fuel is required to start the initial fire which, if fed, would quickly lead to a catastrophic conflagration in the bay. Fourth, it is clear from the XV227 incident that, if the SCP duct rupture had occurred earlier in the sortie when the No. 7 tank had been full, the result could have been catastrophic.

4.64 BAE Systems also raised a series of other arguments regarding the improbability of a fire starting in either of the No. 7 Tank Dry Bays. These were, frankly, weak. The problem BAE Systems faced is the incontrovertible fact that it is clear that XV230 *was* lost as a result of a serious fire on board and the fact that all the evidence points to the origin of the fire being in starboard No. 7 Tank Dry Bay. Further, the QinetiQ study commissioned by the BOI shows a clear and entirely plausible causal ignition scenario, namely an initial source of fuel igniting on the Cross-Feed/SCP duct which set fire to a pool of fuel on the lower panel leading to further damage to fuel system components and causing the fire to become self-sustaining. In these circumstances, I deal briefly with three further particular suggestions made by BAE Systems on this topic.

4.65 First, BAE Systems suggested that the muff on the SCP elbow was itself shrouded by panelling above it and any fuel dropping down from a failed fuel coupling above would not affect it. This is obviously wrong. Fuel dripping or pouring onto the SCP elbow would easily find its way into the gap between the Refrasil and the muff. This is obvious to the naked eye. It is also obvious when one pours a bit of water onto the elbow.[70] Further, the videos amply demonstrate that fuel goes everywhere in the event of a significant fuel coupling failure in this area. Second, BAE Systems suggested that fuel finding its way into the bottom of the SCP fairing would simply pour into the bomb bay. This ignores, however, the ½ inch lip which runs between the fairing and the bomb bay and would enable fuel to pool in the lower section of the fairing. It also ignores the risks of fuel pooling in the ribbed panelling above. Third, BAE Systems suggested that the distance between the No. 7 Tank Dry Bay lower panel and the elbow and muff was too great to allow a fire to propagate. However, the QinetiQ combustion experts, with significant experience in such matters, believed that the wetting of many areas by leaking fuel would provide a relatively simple path for the fire to spread (see Figure 4.14).

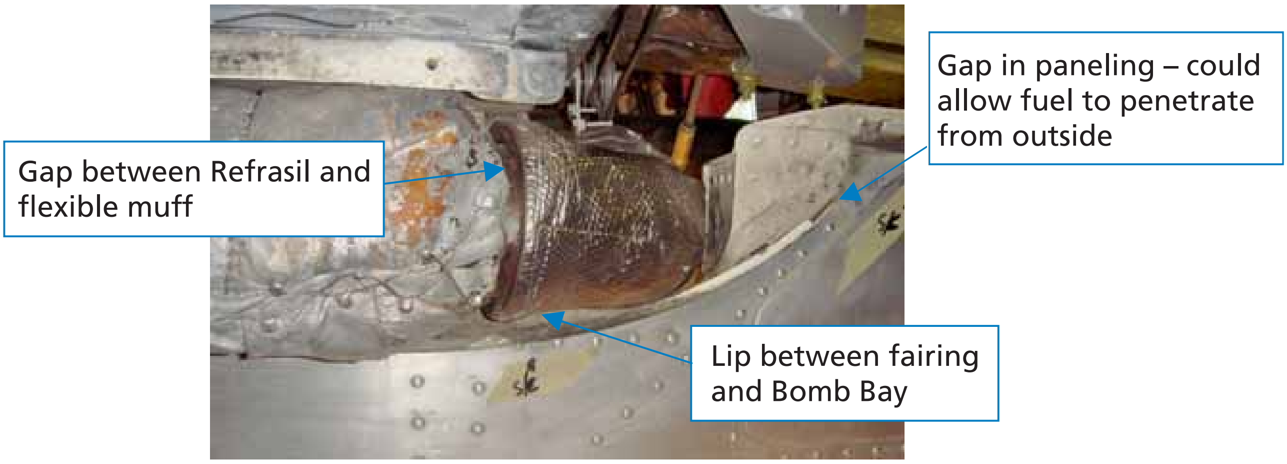

Figure 4.14: SCP Elbow

4.66 In my view, the potential for a single failure of a system containing flammable fluid causing a fire existed in the MR1, *i.e.* even before the addition of the SCP to the MR2. This is illustrated by the fire on Nimrod R1 XV249 (which was fortunately short-lived). The addition of the SCP simply added another single point of failure, arguably more potent because of the location of the SCP at the bottom of the bay and its unsatisfactory casing in a muff. BAE Systems' explanation for routing the SCP duct through the No. 7 Tank Dry Bay is that this was *"the optimum available structural corridor"*.[71] However, even if this were the case, in my view the designer should have given due consideration to the risks involved in the solution and either provided protection commensurate with a fire zone, or redesigned the system to remove the risk. Unfortunately, the passing of time means that, some 30 to 40 years after the events described, the thought processes of those involved are impossible to recreate.

[70] As the Review did during the course of its interview with Tom McMichael and Martin Breakell on 29 April 2009.

[71] BAE Systems Inquest statement, May 2008, paragraph 20.

The terms of the Aircraft Specification

4.67 BAE Systems advanced a further argument, that the terms of MOD Specification MR286 D&P did not require any assessment of whether the No.7 Tank Dry Bay constituted a fire zone under AvP 970 to be carried out for the MR2 upgrade. In support of this argument, BAE Systems referred to paragraph 15.2.3 of Specification MR286 D&P which provided as follows:

> *"Bomb Bay, Fuel Tank area and Ordnance area - The fire protection requirements of these areas shall be to the standard of the Nimrod MR Mk1 aircraft."*

4.68 BAE Systems sought to interpret this provision as providing that the fire protection requirements of the specified areas, *i.e.* the bomb bay, fuel tank area (which would include No. 7 Tank Dry Bay) and the ordnance area, were to be exactly the same as those for the Nimrod MR Mk 1. I do not accept that contention. In my view, the reference to the *"standard"* of the Nimrod MR Mk 1 aircraft is a reference to just that, *i.e.* the relevant standard to which the fire protection requirements of the MR Mk 1 were designed, namely AvP 970. In my view, therefore, British Aerospace (as it then was) was obliged under the terms of the Specification to assess whether the No. 7 Tank Dry Bay, with the newly introduced SCP duct, constituted a fire zone under AvP 970.

4.69 In any event, it must not be forgotten that, taking AvP 970's definition of a fire zone, the No. 7 Tank Dry Bay as designed for the MR Mk 1 was already non-compliant with AvP 970, and hence the original MR1 Specification (MR254D&P), in that it contained a single point failure mechanism that could result in the outbreak of a fire in flight. The introduction of the SCP under Specification MR286 D&P compounded this problem by introducing a new ignition source to an unprotected zone of the aircraft containing fuel lines, fuel couplings, and a fuel tank. In my view, there is no escaping the conclusion that Hawker Siddeley, as the designer of the aircraft, was under a clear responsibility to ensure that the proposed modification met the requirements of AvP 970 and that the company identified any fire zones and took the necessary precautionary design measures.

'Acceptance' of MR1 and MR2

4.70 BAE Systems also sought to argue that the design of the MR2, and in particular the potential for ignition in the No. 7 Tank Dry Bay area, was in any event 'accepted' by the MOD when the type was accepted. The background to this argument resides in the fact that the Nimrod MR1 was tested by a branch of the MOD called the Aircraft Armament and Experimental Establishment (AA&EE) in 1968 and 1969,[72] at Boscombe Down.[73] During development, a resident MOD/RAF team undertook a number of design and acceptance reviews, including a final 'Acceptance Conference' during August 1968. A similar process took place as regards the development of the MR Mk2, in that evaluation of the aircraft, including recommendation for service release, was undertaken by AA&EE and a series of Acceptance Conferences for the modifications introduced by the upgrade were held in October 1978 at Woodford. The participants at the Acceptance Conferences included representatives from British Aerospace (as it had by this time become), AA&EE, the RAF and the MOD.

4.71 It is correct to observe that the minutes of the Acceptance Conferences held at Woodford include express statements such as *"Modification to engine cross feed ducting - Accepted"*[74] and *"Ducting to rear hinged fairing – Accepted"*.[75] BAE Systems argued in submissions to the Review that *"the aircraft design was authoritatively inspected, reviewed, and accepted by the MOD for service with the RAF"*.[76] BAE Systems relied further, in this respect, on the notes of a series of meetings between British Aerospace and RDI Fires[77] in relation to the Nimrod Mk3 Airborne Early Warning aircraft (AEW3)[78] held in May 1977 and January 1978, which record a number of discussions regarding the fire protection in the pannier (equivalent to the MR2 bomb bay) and external fairing (SCP fairing) of the AEW3 aircraft and which, BAE Systems contended, demonstrated that the potential

[72] BAE Systems Inquest statement, May 2008, paragraph 12.

[73] The Boscombe Down facility now forms part of QinetiQ.

[74] Paragraph A1.1(a) of the minutes to Conference No. 1.

[75] Paragraph A1.2(a) of the minutes to Conference No. 1 under the heading "External Piping".

[76] BAE Systems Inquest statement, May 2008, paragraph 15.

[77] Understood to be the MOD's fire expert at the time.

[78] It should be noted that the design of the SCP installation on the AEW was identical to that on the MR Mk2.

hazard of fuel coming into contact with the hot SCP ducting was specifically considered and addressed by British Aerospace and the MOD. In particular, BAE Systems submitted, the potential hazard from fuel coming into contact with the SCP ducting in the external fairing below the No. 7 Tank was specifically discussed with RDI Fires, following which action was taken to fill in the tooling holes.[79] However, as regards the latter point, it is clear that the discussion with RDI Fires refers specifically to this one item, *i.e.* the tooling holes. There is no evidence that the more obvious route for fuel to enter the SCP fairing from No. 7 Tank Dry Bay was discussed.

4.72 Having carefully reviewed the relevant documentation, I entirely agree that the potential hazard of fuel coming into contact with the SCP duct was specifically considered by British Aerospace and RDI Fires. What I do not accept, however, is that this in any way absolves BAE Systems of its responsibility in respect of the poor design of the aircraft. On the contrary, in my view, what the documents establish is that British Aerospace did actively consider whether No. 7 Tank Dry Bay presented a fire hazard (somewhat contrary, it must be said, to its argument as set out above that it was under no obligation to consider this), but erroneously concluded that there was no, or at least no unreasonable, level of risk.

4.73 It should also be noted, in this respect, that the notes of the meeting of 19 May 1977 between British Aerospace and RDI Fires[80] record:

> *"RDI Fires queried the soundness of the soft lagging installation on the hot air supply to the precooler and they stated that while under hot running conditions any fuel leaks dripping on the lagging would evaporate; under cold duct conditions the lagging if NOT impervious to fuel could absorb it and this would reduce the spontaneous ignition temperature. Although it was considered that the lagging was impervious to fuel, H.S.A. would have this checked."*

4.74 This issue (together with other concerns raised by RDI Fires) was addressed by British Aerospace in a *"Pannier Fuel Tank Bay Fire Protection Study",* the final version of which (Issue 3) was issued in December 1978, although it is clear from the notes of the meeting on 19 May 1977 that an earlier draft of the report was available at that meeting. The report stated as follows:

> *"1.2 This report assesses the degree of fire hazard in the bay, and concludes that there is no necessity for a fire protection or fire extinguisher system ...*

4.2 Bleed Air Ducting and Precooler

> *4.2.1 The hot air supply to the precooler is taken from the existing engine air crossfeed pipe at the rear spar, and routed out of the pannier on the starboard side ...*
>
> *4.2.2 The following precautions have been taken in order to minimise the possible hazard from this piping.*
>
> *(a) The greater proportion of the pipe is ducted outside the pannier.*
>
> *(b) The tooling holes in the outer shield of the piping beneath Tank 7, are blanked off to prevent contact from leaking fuel on the hot piping.*
>
> *(c) The APU fuel pipe has been re-run to pass below the hot air duct on the port side, to obviate the possibility of fuel dripping onto the hot surface.*
>
> *(d) The soft lagging over the control valve is sealed with aluminium foil to prevent the absorption of fuel.*
>
> *(e) Lagging of the inlet and outlet pipe of the precooler ensures that the temperature of the outer face is maintained below 300° and hence below the spontaneous ignition temperature of fuel on a 3" duct, which is in the region of 360°C at an ambient temperature of 25°C*[81]

[79] Believed to be small holes introduced to aid the manufacturing process of the fairing.

[80] HSA-MPP-V-AEW-0013, paragraph 5.3.3.

[81] An interesting statement in view of BAE systems contention to the Review that the unlagged bellows could not reach the AIT for AVTUR.

5 CONCLUSIONS

5.1 The results of the investigation have shown that in spite of the presence of fuel in the pannier bay, sufficient precautions have now been taken to reduce the possibility of ignition to an absolute minimum. In fact, the pannier bay on the A.E.W. is probably safer than the bomb bay of Nimrod Mk. 1 and Mk. 2 with its combination of fuel pipes, hydraulic pipes and explosive stores."

4.75 In light of the above, and whilst it must be a matter of conjecture in the absence of any detailed notes of the discussions that took place at the Acceptance Conferences, it would seem to me to be a reasonable inference that any 'acceptance' of the MR2 design by the MOD was at least in part informed by British Aerospace's work in relation to the AEW and its conclusion that there was no necessity for a fire detection or suppression system in the vicinity of No. 7 Tank Dry Bay. Even if this were not the case, in my view, 'acceptance' of the aircraft by the MOD/RAF does not absolve the Design Authority from fundamental responsibility for the design.

4.76 In conclusion, the Cross-Feed/SCP duct represented a clear breach of good design standards and was contrary to design regulations applicable at the time (1969 and 1979). In particular, the SCP adjunct to the Cross-Feed duct was a manifest breach of the standards of AvP 970.[82]

Causation

4.77 The Cross-Feed/SCP duct represented a fundamental flaw in the design of the Nimrod aircraft and was the primary physical cause of the accident.

Responsibility

4.78 Hawker Siddeley[83] was responsible for the original design flaws in the MR1 and R1. British Aerospace[84] was responsible for the design flaws in the MR2. As stated above, the 'acceptance' of the aircraft by the MOD does not absolve the Design Authorities from their responsibility for poor design. British Aerospace were responsible for designing, manufacturing and installing the SCP installation to the Nimrod but failed properly to assess the risks inherent in its design. BAE Systems' denial of the breach of the applicable design standards is surprising. I discuss these issues further in **Chapter 6** (in relation to the incorporation of the AAR capability pursuant to Mod 715) and further in **Chapter 11** (when dealing with BAE Systems' overall approach to the matters raised by the Review).

[82] Subsequently Def-Stan 00-970.

[83] Hawker Siddeley became part of British Aerospace on 29 April 1977.

[84] British Aerospace became BAE Systems Plc in November 1999 on the merger with Marconi Electronic Systems.

Section Two: Fuel source

CHAPTER 5 – LEAK FROM FUEL COUPLING

"Fuel tends to seek out an ignition source if it can."
(An Aviation Safety Engineer, 2009).

Contents

Chapter 5 addresses the fuel source for the fire on XV230. It answers the following questions:

- What was the in-service history of fuel leaks in the Nimrod fleet?
- What was the maintenance regime for the Nimrod fuel system?
- Did it comply with regulations and good practice?
- Did a leak from a fuel coupling cause the loss of XV230?
- Who was responsible for any failures?
- Do fuel seals age and deteriorate and, if so, why?
- Should seals be lifed?

Summary

Description of Fuel System

1. The Nimrod fuel system is complex. It comprises 13 tanks, interlocking pipework and approximately 400 fuel couplings,[1] most of which are 'FRS' couplings and 66 are 'Avimo' couplings.

2. The starboard No. 7 Tank Dry Bay is a spaghetti junction of fuel pipes, pulleys and ducts. It contains eight 'FRS' fuel couplings and a single 'Avimo' fuel coupling, all within inches of the Cross-Feed/ Supplementary Conditioning Pack duct.

Maintenance

3. In common with other military and civilian operators, the RAF do not 'hard life' fuel seals. Nimrod fuel seals were replaced when observed to be faulty under a Corrective Maintenance policy. Dismantling during Major maintenance, however, meant that almost half the aircraft's fuel seals were replaced every five years.

4. Maintenance of the Nimrod Fuel System is not straightforward. Replacing seals is made more difficult because the aircraft was not designed for ease of access and maintenance. Nimrod was not put on the 'LITS'[2] data collection system because of its perceived impending Out-of-Service date.

[1] Fuel pipe couplings are used to connect pipes to other pipes, and pipes to fuel tanks.

[2] Logistics Information Technology Strategy (LITS).

Prevailing Approach

5. There was, and remains, a prevailing belief that: (a) fuel couplings leaks are 'inevitable' but seals should generally be left undisturbed because prophylactic replacement might actually increase the number of fuel leaks by disrupting the system and/or because of high failure rates of recently fitted seals; and (b) there should be a concentration on eliminating ignition sources. This is a not an uncommon approach amongst civilian and military operators.

Increased leak trend

6. The Nimrod fleet experienced a four-fold increase in fuel coupling leaks during the period 1983-2006.[3]

Warnings

7. There were a number of incidents in the years before XV230 which should have raised awareness of the fire risks inherent in fuel coupling leaks (see **Chapter 8**).

Maintenance regime unsatisfactory

8. The RAF's maintenance regime of the Nimrod fuel system prior to the loss of XV230 in September 2006 was unsatisfactory because: (a) there was insufficient emphasis on analysing fuel leak trends and, as a result, the four-fold increase in leak rates went unnoticed; (b) fuel system tests were not done under pressure; (c) there was no system of sampling seals; (d) there was a lack of proper guidance in Maintenance Manuals as to how properly to replace seals; and (e) the RAF failed to address the apparent discrepancy between the manufacturer's original recommendation in 1968, namely, that the FRS seals should be inspected every five years, and actual practice.

Avimo seals

9. A serious manufacturing defect has been found in Avimo seals: Avimo seals fitted to Nimrods after 2000 have been found to contain 50% less carbon black filler than earlier seals. This has made them prone to swelling and splitting and reduced their fatigue life.

10. From 2000 manufacture of the seals was subcontracted to a new small general rubber manufacturing company, Cellular Developments Ltd, who was not told that it was an aviation part and was given a 1947 specification drawing which was unclear and had also never been updated. In my view, Cellular Development Ltd was not to blame for using a British standard Neoprene material which complied with the 60/65 hardness requirement. There was a lack of effective quality control because of the convoluted and inappropriate procurement chain.

11. A warning sign regarding the quality of Avimo seals was missed in 2005. In July 2005, maintenance personnel at RAF Kinloss observed abnormal "*swelling*" and "*splitting and blistering*" in some Avimo seals. The Nimrod Integrated Project Team (IPT) requested BAE Systems to test them for "*conformance to specification*". In September 2005, BAE Systems reported that its limited test showed results which were "*typical*" for Neoprene and gave "*no indications of non-conformance to...specification*". Given the earlier observations, the Nimrod and Aircraft Support IPT should not have let the matter rest there.

[3] BOI Report, Part 2, paragraph 39(b).

12. The fact that a non-conforming part found its way into the Nimrod fleet raises serious concerns about the MOD procurement chain for such parts and whether it is wise for specialist aviation parts to be sourced by the non-specialist Medical and General Stores IPT.

Causation

13. I am satisfied that the Board of Inquiry was right to find that a leak from one of the fuel couplings in starboard No. 7 Tank Dry Bay is one of the two most likely sources of fuel to have caused the XV230 fire. The refuel system within the No. 7 Tank Dry Bay would have been pressurised and full of fuel at the relevant time as a result of Air-to-Air Refuelling. The evidence shows that significant quantities of fuel can leak from faulty couplings within the refuel system.

14. I have concluded, on balance, that if a fuel coupling was the source of fuel, it is more likely to have been one of the eight FRS couplings in the starboard No. 7 Tank Dry Bay, rather than the single Avimo coupling, for three reasons: (a) recent evidence captured on video shows that FRS couplings can, and do, suddenly spring major leaks; (b) despite the rubber manufacturing defects, no Avimo seal has actually been found leaking (they tend to be held together by the outer metal flange); and (c) numerically, the probabilities favour an FRS coupling being the culprit on this occasion.

Responsibility

15. The MOD bears responsibility for the fact that a leak from a fuel coupling may have been the source of fuel causing the fire on board XV230 and is open to criticism for the shortcomings in the maintenance system referred to above and in particular for: (a) failing to do enough to monitor fuel leak rates over the years, and (b) failing to give better guidance for the fitting of couplings and elimination of fuel pipe leaks. RAF maintenance personnel expended considerable efforts over the years in curing individual leaks, but it appears that no-one in the Nimrod IPT or elsewhere was consolidating the history of leaks, nor making sufficient efforts to analyse the underlying causes of leaks, nor providing guidance that might have reduced the leak rate.

Post accident

16. The loss of Nimrod XV230 has now placed sharp focus on fuel coupling leaks. The Nimrod Fuel Seal Replacement Programme undertaken in 2008-2009 has resulted in the replacement of many centre section fuel system seals, and also addressed issues of misalignment of couplings due to previous incorrect assembly and lack of proper guidance on how to fit couplings. The need for such a programme should have been considered prior to the loss of XV230 as a result of: (a) the (unobserved) increase in the fuel leak rate; and (b) the incremental slippage in the retirement of the Nimrod MR2 with the consequent increase in its service life.

Inconvenient truth

17. The inconvenient truth is that elastomeric fuel seals do deteriorate. This can be due to: (1) age; (2) misalignment; (3) pressure; (4) vibration or airborne stresses; (5) temperature; (6) drying out; and (7) manufacture. Fuel coupling leaks are difficult to predict and hence any catastrophic consequences of their failure should be mitigated by design. Elastomeric seals are widely used in military and civilian aircraft around the world. Many legacy aircraft may contain seals which have been in place for decades. Not enough is known about elastomeric fuel seal behaviour. More international research is required in this area (see **Chapter 23**).

18. Targeted fuel seal replacement programmes such as that recently undergone by the Nimrod fleet, teardowns, and seal sampling, are useful tools in the management of fuel seal reliability (see **Chapter 23)**.

19. It is important in the future that *active* thought is given to the appropriate management of all fuel seals.

Alternative theories

20. The alternative fuel source theories are not realistic and can be discounted.

Introduction

5.1 A distinction needs to be drawn between three types of fuel leak: (a) fuel leaks from integral wing tanks; (b) fuel leaks from main fuselage tanks; and (c) leaks from fuel couplings and pipes located in the main body of the aircraft. Wing leaks (a) are rarely a threat to an aircraft, as fuel readily disperses into the airflow behind the aircraft. The Nimrod's fuselage tanks (Nos. 1, 5 and 6) are, at a minimum, double skinned[1] and designed such that any fuel leaks are vented to atmosphere. However (b) and (c) leaks from fuselage tanks, fuel pipes and couplings within the main fuselage are potentially a much greater problem: their leak path is difficult to predict and they can drip and/or run through the fuselage allowing fuel to reach many areas of the aircraft and accumulate in hidden voids. Such leaks, therefore, present a potential fire risk in the event that they contact an ignition source. For these reasons, aircraft are required to be designed such that any potential single-point ignition risks are mitigated by *inter alia* fire detection and protection systems.

5.2 I set out first a description of the Nimrod fuel system and the various couplings used within it.

Description of Nimrod Fuel System

5.3 The Nimrod has 13 fuel tanks and can carry over 85,000lbs of fuel. There are three integral tanks in each wing (Nos. 2, 3 and 4 – port and starboard) and a wing pod tank (No. 4A port and starboard), three tanks in the central fuselage (Nos. 1, 5 and 6), and two tanks located in each trailing edge fillet adjacent to the fuselage (No. 7 tank port and starboard). The interior surface of the wings is covered in a sealant and fuel is contained within the wing structure; the wings' surfaces effectively form the fuel tank. The fuel tanks within the fuselage have a more complex structure. The No. 1 tank, outside the pressure hull, was part of the original Comet design and consists of a metal structure divided into four cells, within which the fuel is held in rubber bags attached to the cell walls. The Nos. 5 and 6 tanks are within the aircraft pressure hull and, for this reason, they have double skins. They are divided into three cells and, again, the fuel is held in rubber bags. The No. 7 tanks (in the port and starboard wing fillets) are also of metal construction, although rubber bags are not used to contain the fuel. Refuelling is controlled by high-level float switches in the tanks, which automatically curtail refuelling when the tank is full.[2] Fuel is pressure fed round the fuel system by immersed booster pumps in each tank. The tanks are ventilated by ram air taken from the wing inlets and vented to atmosphere. Blow-off valves are fitted to each tank except the No. 4A tanks; these are safety devices to prevent damage to the structure of a tank if the high-level float switches fail and a full tank continues to be refuelled.[3]

[1] Fuel is held in a rubber bag, which in turn is contained within a metal structure.

[2] Although it is important to note, as the XV230 BOI pointed out, the fitting of two independent float switches in No. 1 tank meant that the tank was prone to asymmetric filling (XV230 BOI Report, Annex N).

[3] No. 5 tank had the blow-off valve blanked off on fitting of AAR Mod 715 in 1989 and a restrictor fitted in the fuel line to limit pressure build-up. This was because of concern that a blow-off from that fuel tank might allow fuel to be ingested by the aircraft engines.

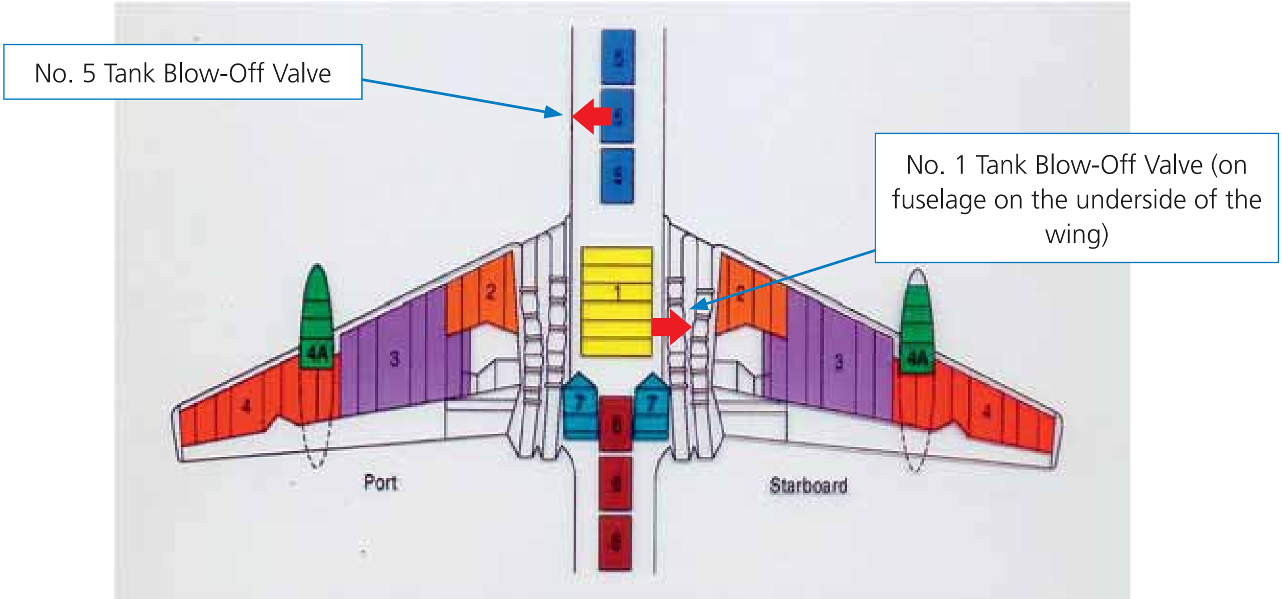

Figure 5.1: Location of Nimrod Fuel tanks

5.4 The fuel pipework system is necessarily complex. It comprises overlapping refuel, fuel feed, and fuel venting pipework. The refuel system conveys fuel to the tanks, either on the ground from a bowser, or a tanker during Air-to-Air Refuelling (AAR).[4] The fuel feed lines are those used to convey fuel to the engines (in some cases via other fuel tanks), while the vent pipes provide a head of pressure and fuel tank ventilation.

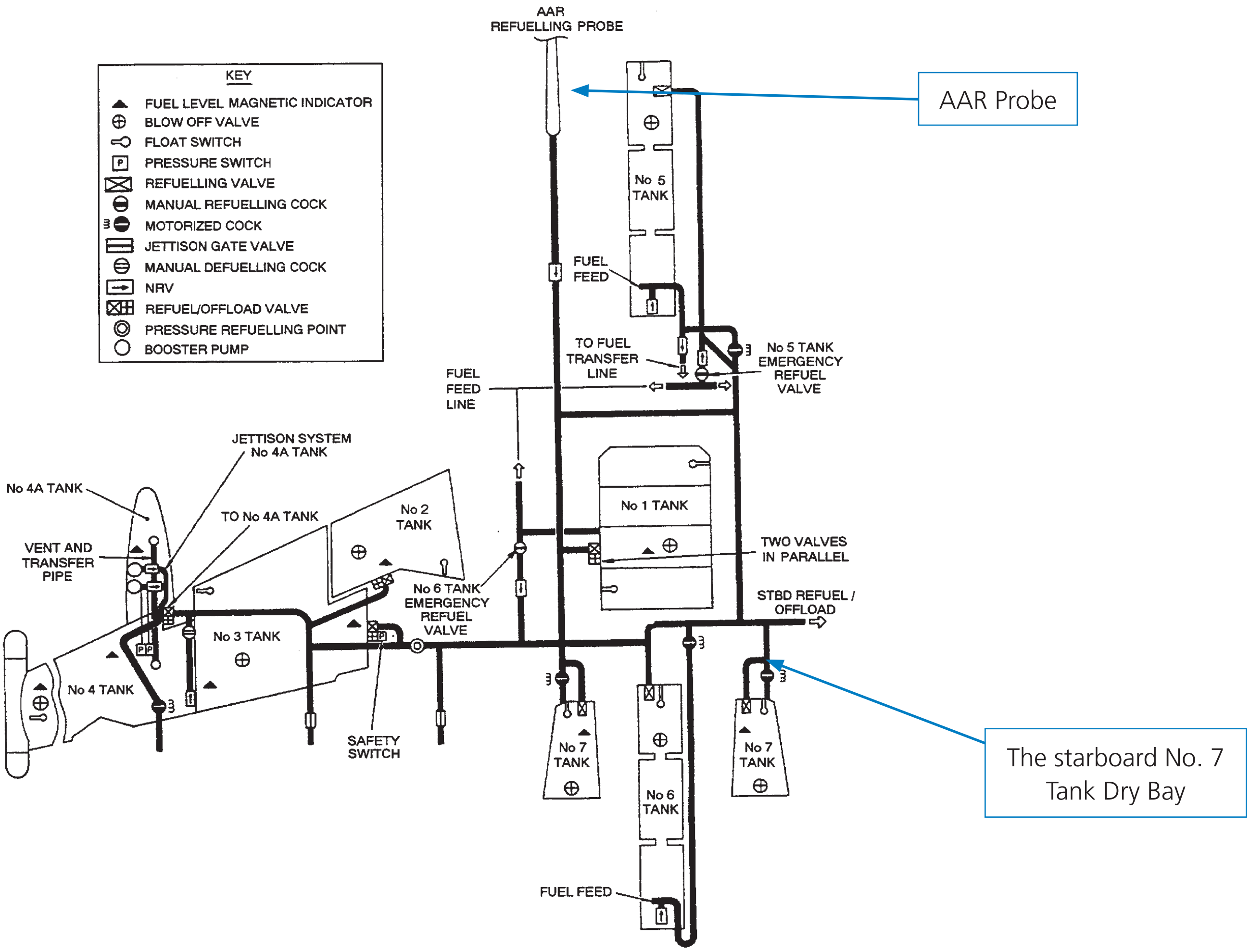

Figure 5.2: Nimrod Refuel System

[4] The Nimrod no longer undertakes AAR.

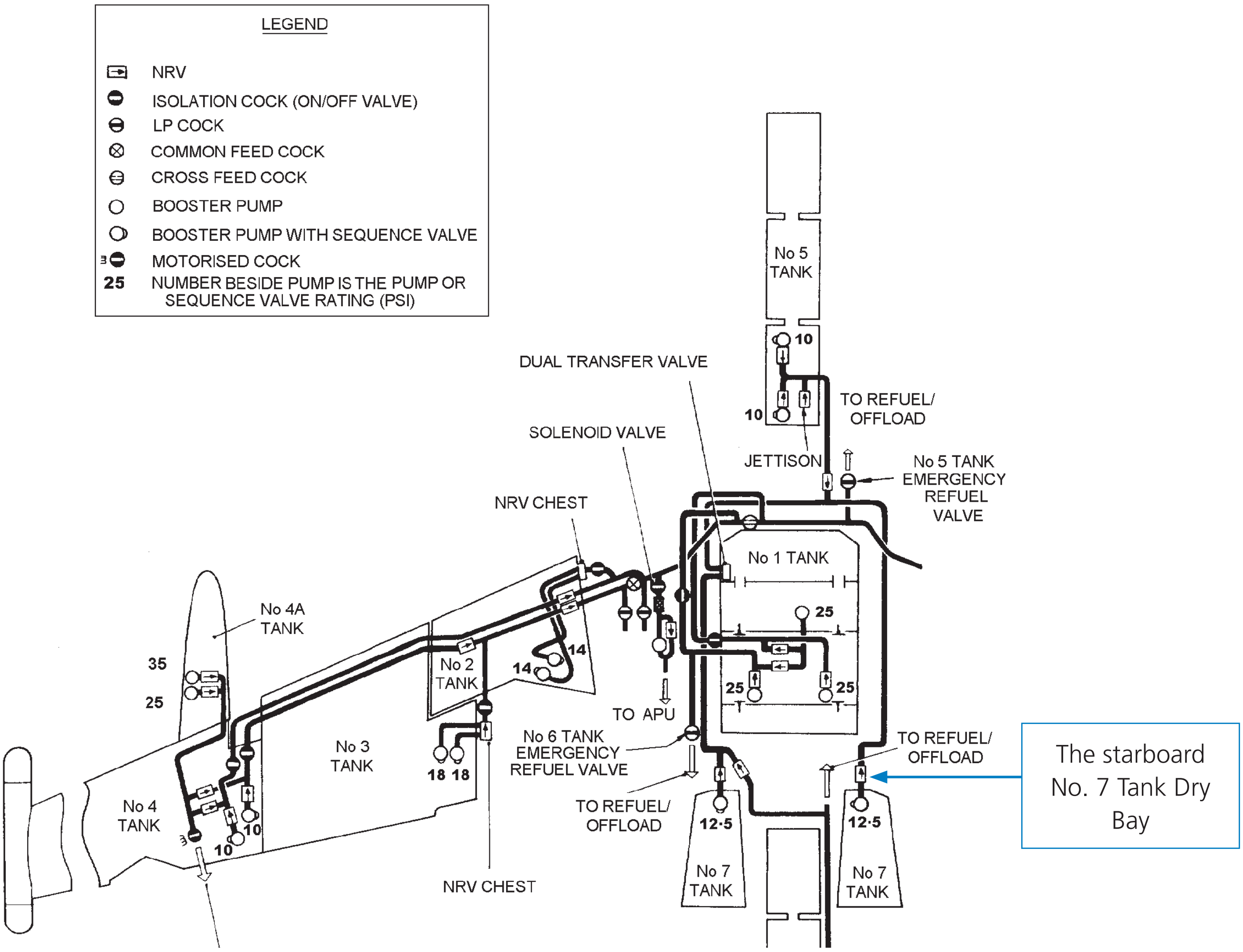

Figure 5.3: Nimrod Fuel Feed system

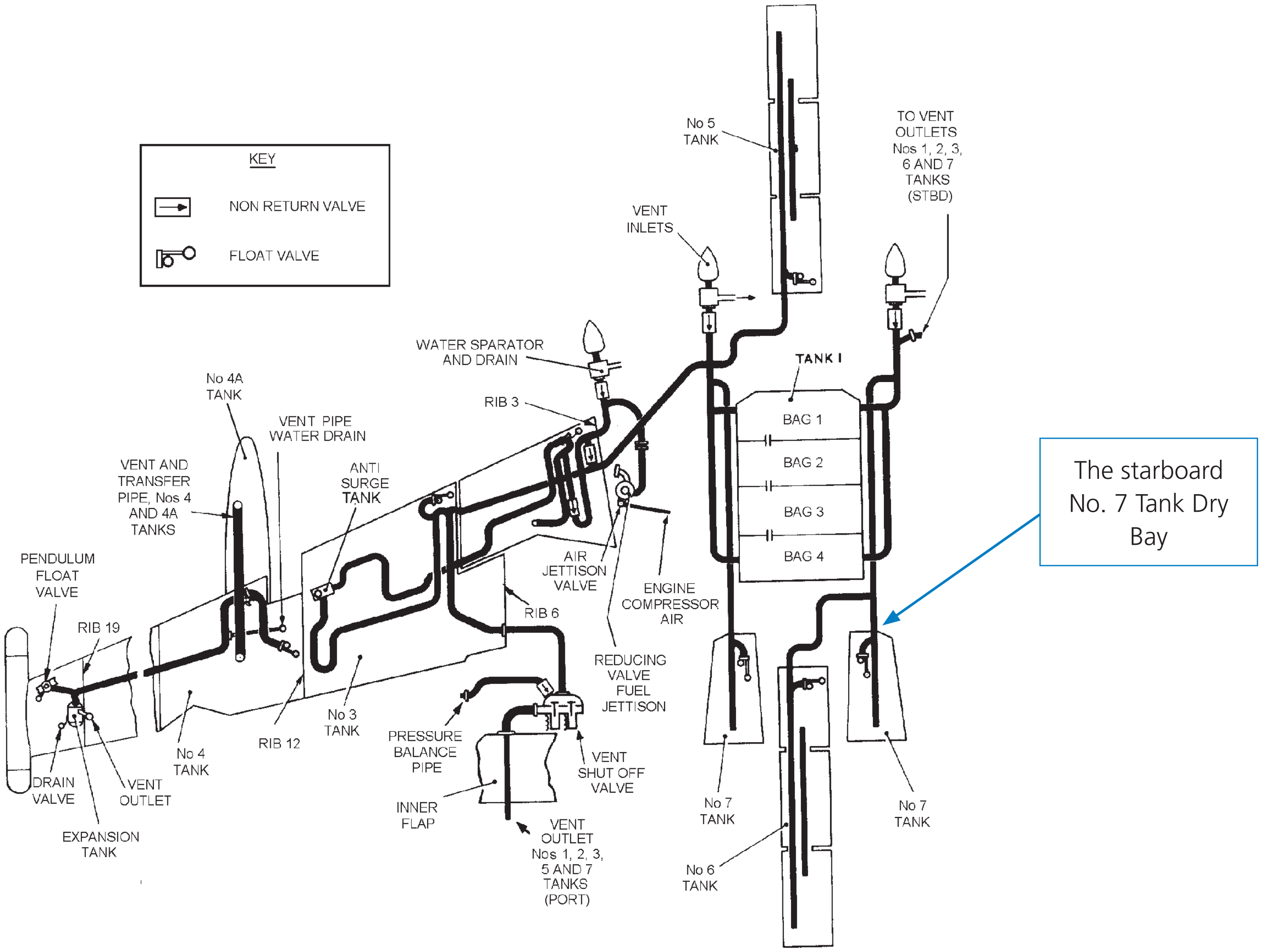

Figure 5.4: Nimrod Fuel Venting System

Description of Fuel Couplings

5.5 The Nimrod fuel system contains approximately 400 fuel couplings,[5] of which the majority are of the FRS type. The remaining 66 are Avimo couplings. Both FRS and Avimo couplings have been in existence for many years and are widely used in aerospace applications.[6]

FRS coupling

5.6 An FRS coupling is shown below (see Figure 5.5). It consists of an inner and outer metal sleeve, a flexible rubber seal, two split collars, two circlips and a locking wire (not shown in the diagram). The elastomeric seal is used to create a pressure-tight seal between two pipes. The seal is chamfered at each end and has moulded grooves which fit over a bead formed near the end of each fuel pipe. The split collars are fitted at each end of the seal and retained by circlips. Assembly is completed by screwing together the inner and outer metal sleeves, after which the locking ring is applied. Each sleeve has a shoulder formed at one end, which abuts the outer face of the adjacent split collar, thus applying pressure to the split collar (and hence the elastomeric seal) to ensure an effective joint. The most recent Declaration of Design and Performance for the FRS 110 coupling notes that the maximum pipe angle deflection for the installation is 1°.[7] Figure 5.5 shows an FRS coupling prior to assembly, while Figure 5.6 portrays an FRS coupling assembled. The elastomeric seals are currently manufactured from a Nitrile Series 4 compound (Series 1 Polysulphide rubber "Thiokol" was used until 2004,[8] but this material is now obsolete).

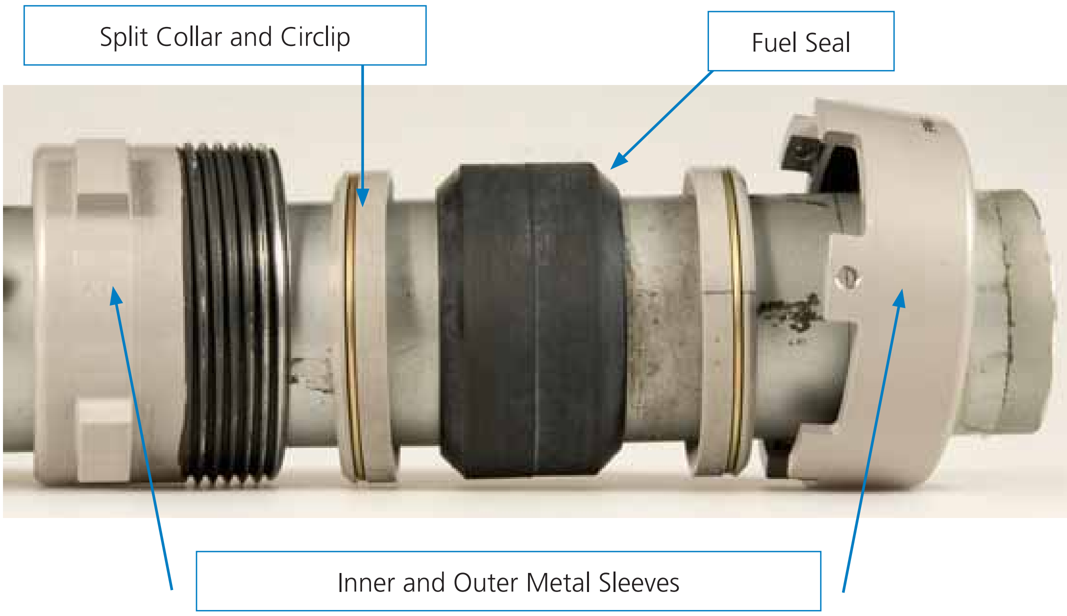

Figure 5.5: FRS Coupling Assembly (parts shown separated)

[5] Used to connect pipes to other pipes, and pipes to fuel tanks.

[6] FRS couplings were fitted to Spitfires, Lancasters and Vulcans; and the original patent for the Avimo Original coupling dates back to the 1930s.

[7] Eaton DDP-FRS110-Series-1, dated 7 June 2007. The original Declaration of Design and Performance issued in 1968 likewise stated under the heading of 'Special Limitations' *"Maximum pipe deflection 1° in any direction with or without axial pipe restraint."* See XV230 BOI Report Exhibit 75.

[8] Change of material notified at FR-HiTemp Service Information Letter SIL/CS/1/03 9.

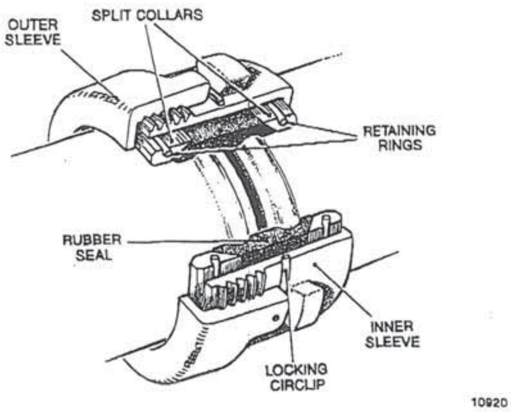

Figure 5.6: FRS Coupling Technical Diagram

5.7 Research by the manufacturers of FRS seals, Eaton Aerospace, has shown that large numbers and types of RAF and civilian aircraft have been, and are, currently fitted with the same kind of elastomeric fuel seal as used on the Nimrod fleet. In total, an estimated 13,000 aircraft have been fitted with FRS110 couplings, of which over half are still in service.

Avimo couplings

5.8 Two types of Avimo couplings are used within the Nimrod: the Avimo 'Original' and the Avimo 'O' ring Type MR8610. Prior to fitting an Avimo original coupling, grooved sleeves are welded or brazed onto the pipe ends. The Avimo Original coupling comprises a rubber seal fitted over the pipe ends and retained by two semi-circular metal shells held in place by a jubilee clip. The seals used in the Avimo Original couplings were manufactured from polychloroprene (often referred to as Neoprene). In 2008, however, it was discovered that, since 2000, the Avimo seals have been made from a Neoprene compound which does not match exactly the required material specification, provoking early degradation (discussed later in this Chapter). As a result, the seals are now manufactured from a Nitrile material similar to that used in the FRS coupling.

Figure 5.7: Avimo Coupling Assembly

FRS and Avimo couplings in the starboard No. 7 tank dry bay

5.9 There are eight FRS couplings and one Avimo Original coupling in the starboard No. 7 Tank Dry Bay. They are all located higher than the Cross-Feed/Supplementary Cooling Pack (SCP), ducts.

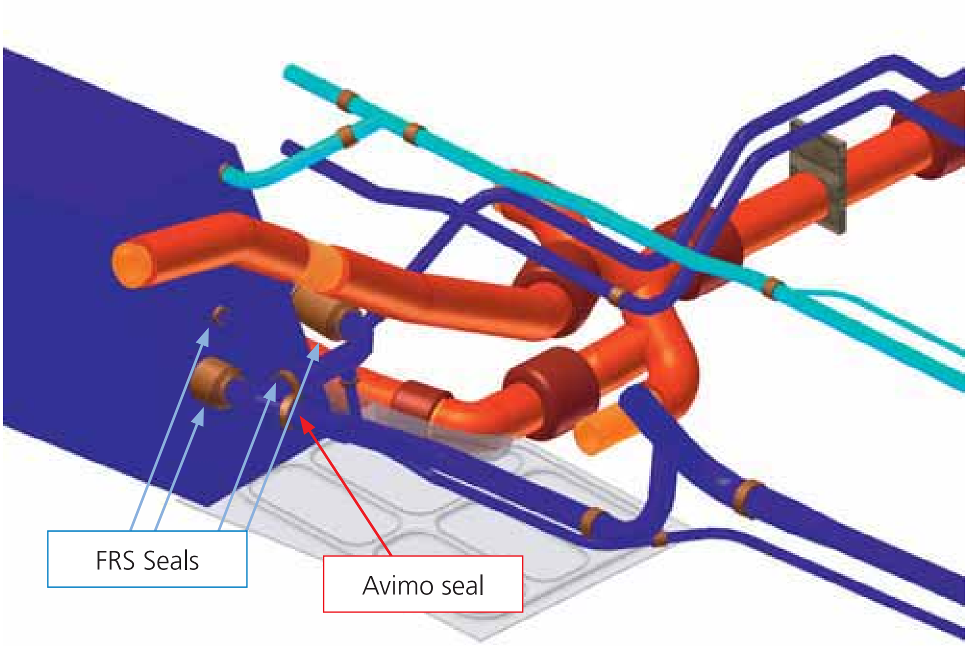

Figure 5.8: Fuel Seals in the No. 7 Tank Dry Bay (NB: not all couplings are visible in this diagram)

Maintenance Policy and Regulations

'Corrective' Maintenance

5.10 The majority of the Nimrod fuel system is maintained under a policy of Corrective Maintenance. Corrective Maintenance is defined as: *"...all those maintenance activities required to return an aircraft or equipment to a serviceable state following an unscheduled arising"*.[9]

5.11 In the case of the Nimrod fuel system, Corrective Maintenance has meant that items such as pipes, couplings and seals were only replaced if they were observed to be faulty, either due to visible damage or corrosion, or because they were actually leaking. Also, the MOD, in common with other operators, operates a strict 'one use only' policy for seals, *i.e.* when a coupling is removed for any reason the used seal is discarded and replaced with a new one. Elements of the fuel system are dismantled during Major maintenance to allow access to other systems; as a result, almost half of the aircraft's fuel seals were, in practice, replaced every five years.[10] Since the loss of XV230, however, and following the results of a Fuel System Safety Review undertaken by QinetiQ,[11] the Nimrod Integrated Project Team (IPT) decided to replace 42 fuel seals on each aircraft in the Nimrod fleet, being those seals which are not disturbed during Major maintenance, but which are located primarily in the centre section of the aircraft where any leak is deemed to be particularly undesirable.[12]

What is the military and civilian practice worldwide regarding fuel seal replacement?

5.12 My researches and inquiries have found that the Nimrod fuel system maintenance and seal replacement policy (which reflects the maintenance policy throughout the RAF) is little different to that of other military and civilian operators worldwide. The United States Air Force (USAF), Royal Australian Air Force and Canadian Defence Forces do not 'hard life' fuel seals.[13] I have found no overarching policy for routine seal replacement within the civilian world.

[9] JAP 100A-01 Issue 17, Chapter 5.4, paragraph 1.1.
[10] Once a coupling is dismantled, its seal is always discarded and replaced.
[11] Nimrod Fuel System Safety Review Report (Q/CHC/1/2/N1), dated October 2007.
[12] Known as the Fuel Seal Replacement Programme (FSRP).
[13] BOI Report Exhibit 77, DE&S(WYT)/366/8/2/CASD dated 22 November 2007 and USAF Air Force Response to Questions From the Nimrod Review.

5.13 I have, however, learned of two instances where the general approach has been modified. First, by the RAF following the loss of a Harrier GR3 in August 1988 as a result of a fire, when the Harrier IPT decided that Harrier FRS couplings should be changed during each Major Maintenance (see **Chapter 8** where this incident is discussed further). Second, within the civilian aviation industry, I have found one instance of a manufacturer mandating regular seal replacement: following reports of leaks from fuel seals within the engine struts on Boeing 747 aircraft in 1998, it was recommended that fluorosilicone and Nitrile seals should be replaced either during certain maintenance operations, or after *"five years regardless of flight hours"*.[14] Thus, as these two exceptions to the general approach show, operators can, and do, modify maintenance policies if, and when, they feel it appropriate to do so. And, as noted in the previous paragraph, this has now happened for the Nimrod fleet. An issue arises as to whether the Nimrod policy could and should have been modified earlier.

Trend Analysis to inform Maintenance Policy

5.14 The RAF's maintenance policy document makes it clear that trend analysis should be carried out to inform maintenance policy:

> *"It is important that corrective maintenance trends are analysed and, where appropriate reflected in changes to preventive maintenance*[15] *schedules. To achieve this, the IPT should define in the relevant SPS*[16] *the extent and method of corrective maintenance data reporting. This should be reviewed when the SPS is reviewed in accordance with Chapter 5.1. In formulating a data collection policy, IPTs should endeavour to use existing or emerging Information System applications."*[17]

Nimrod Maintenance policy review in 2001

5.15 A maintenance policy review was conducted for the Nimrod in 2001 using Reliability Centred Maintenance methodology in order to determine the suitability of the maintenance policy. The review examined data for the fuel system between 1995 and 2000, with a view to identifying failure trends in order to confirm the appropriate level of maintenance required for the Nimrod. Unfortunately, this review did not detect the trend of increase in leaks from the fuel system subsequently identified by the Board of Inquiry (BOI). This was because only a five year period was under consideration and the analysis did not discriminate down to the level of individual components within the fuel system. Even if a trend had been identified, however, it is questionable whether this would in fact have led to a change of maintenance regime in any event. As pointed out by the Air Member for Materiel in his comments on the BOI Report, the leak rate detected by the BOI *"would not have been considered to have been a high leak rate in an absolute sense"*.[18] The four-fold increase in fuel coupling leaks should nevertheless have been a cause for concern (see below).

Lifing of Components

5.16 JAP 100A-01 Chapter 5.3.1 on Lifing of Aerosystem Components notes that: *"most failures of aerosystem components occur in a random manner that is not related to usage; such failures can only be dealt with by replacing components as and when they become unserviceable"*. This is the rationale behind the policy of Corrective Maintenance for most of the Nimrod fuel system. However, the same chapter also notes that for some components the probability of failure increases with 'age and usage'. Two groups of such components justify replacement, or removal, for maintenance on a pre-determined basis. One of these is: *"Components for which safety considerations require that in-use failure should be minimized or eliminated."* If the failure rate of the Nimrods' fuel seals was determined to increase with 'age and usage', as suggested by the BOI analysis of fuel leaks, then it could be argued that safety considerations should mandate their replacement at a pre-

[14] Boeing 747 Service Letter, 747-SL-28-052-B dated 30 August 1998.

[15] JAP 100A-01 states that 'Preventative maintenance' is *"systematic, with prescribed work undertaken at pre-determined intervals to reduce the probability of failure, to restore the inherent level of equipment reliability and to ensure that performance is not degraded by time or usage"*.

[16] Support Policy Statement.

[17] JAP 100A-01, Chapter 5.4, paragraph 10.

[18] BOI Air Member for Materiel Comments, paragraph 10.

determined age. Following the impetus given by the BOI, research was undertaken on the proclivity of seals to leak. The results have suggested, however, that whilst there are a number of factors influencing leak rates, 'age and usage' may not be the primary factors.

5.17 Components which are not lifed are maintained 'on condition' on the basis that: (a) the safety and operational consequences of failures are 'acceptable', *i.e.* not catastrophic; and (b) it is reasonable to assume that the non-lifed components are fit for purpose for the assumed life of the aircraft. It follows, therefore, that even where there are no apparent assessed safety or operational reasons to life seals, it is essential to re-evaluate previous lifing assumptions when a fleet is extended in service. The numerous delays to the Nimrod MR2 replacement programme are a matter of public record (see **Chapter 14**). It is clear that the year-on-year delays to that programme have extended the life of the Nimrod MR2 aircraft by many years. In these circumstances, therefore, it is particularly disappointing that the MOD failed at any stage to observe the trend of an increase in the fuel leak rate and failed to properly consider whether the previous lifing assumptions and maintenance policy for fuel seals remained valid. An appreciation of the increasing trend of fuel leaks may have given pause for thought by those responsible for compilation of the Nimrod Safety Case (NSC) when they came to consider the risk posed by the Cross-Feed/SCP duct (see **Chapter 10**).

Categorisation of Leaks

5.18 Leaks are not simply noted and ignored. Leaks from wing tanks are regarded as far less of a problem than leaks within the fuselage or in the vicinity of the aircraft's engines. This is because leaks from wing tanks are not near a potential heat source and will disperse into the airflow. While there is a zero-tolerance policy for fuel leaks from pipes and couplings, which are always rectified as soon as they are discovered, the rectification of leaks from integral fuel tanks may be deferred, based upon a categorisation system.

5.19 Leaks in integral wing tanks are categorised in increasing order of seriousness: [19]

> *"STAIN. Where fuel wets an area around the leak source not over 50mm (2 inches) in diameter in 2 hours".*
>
> *"SEEP. Where fuel wets an area around the leak source not over 160mm (6 inches) in diameter in 2 hours".*
>
> *"HEAVY SEEP. Where fuel appears to spread very slowly to cover an area larger than 160mm (6 inches) in diameter. However, it does not flow or drip".*
>
> *"RUN. Where fuel is running and dripping at a rate less than 10 drops per minute. Alternatively, an area where fuel appears immediately to flow or run, following the contour of skin where the area is wiped dry."*
>
> *"UNACCEPTABLE LEAK. Where fuel is running or dripping at a rate greater than 10 drops per minute. Repair or exceptional limitation action must be undertaken."*

5.20 In summary:

- *"Stains"* and *"Seeps"* in wing tanks are termed *"minor leaks"* and require recording and documenting *"during pre and post scheduled maintenance fuel leak mapping",* and will not necessarily require rectification at the next tank opening or scheduled maintenance unless there is a *"large concentration"* of them.
- *"Heavy Seeps"* and *"Runs"* in wing tanks require rectification at the next tank opening or scheduled maintenance and must be fully documented in the aircraft's F700, F704 Acceptable Deferred Fault Register.
- Immediate repair of *"Unacceptable leaks"* may only be deferred *"in exceptional circumstances"*.

[19] See AP101B-0500-2(R)1 Part 1, Leaflet 013, Annex 1, page 6-10 (BOI Report, Exhibit 50).

- Leaks of any category *"in the vicinity of the Engines and Jet Pipes"* or *"from the fuselage tank cell, enhanced leak detection pipes or interspace drains"* are unacceptable.

Wing 'seeps' on XV230 irrelevant

5.21 There were seven wing tank *"seeps"* detected and recorded in XV230's F700 during Primary Maintenance.[20] Since they were from the outer wing tanks, in my view, the BOI rightly dismissed them as not playing any part in the accident.[21]

Fuel Seals – causes of failure

Introduction

5.22 The limited information available to the BOI did not allow it to discriminate between the different types of fuel coupling on the aircraft, *i.e.* FRS couplings and Avimo "Original" couplings and Avimo 'O' ring type MR8610 couplings. The absence of wreckage meant that it would be impossible to prove categorically which coupling, if any, had provided the fuel to initiate the fire on XV230. Thus, the Board understandably focused its efforts on the type of coupling which was in the majority within the aircraft fuel system, namely the FRS coupling, but recommended that lifing should be looked at for all types of seals.

5.23 The Review, however, has had the opportunity to consider the issue of the causes of fuel seal failure in more detail (see below). The Review has also had the opportunity to investigate a quality problem regarding post-2000 Avimo seals (again see below).

General causes of in-service seal failure

5.24 There has been surprisingly little research done worldwide on the life of fuel seals and the behaviour of seal materials. It appears, however, that a variety of different factors can affect seal integrity and performance, including: (1) ageing and condition; (2) misalignment; (3) pressure; (4) vibration or airborne stresses; (5) temperature; (6) drying out; and (7) manufacture. I consider factors (1) to (6) directly, and turn to (7) further below.

(1) Ageing

5.25 The BOI was very careful when considering whether the 'age' of fuel seals was a factor in the loss of XV230. It did not state that age *was* a factor, but that it could not rule it out, in view of the increase in seal leaks over time. When using the word 'age', it was considering it in its widest term, *i.e.* not simply the effect of internal chemical change over time, but also the effect of external influences over time as well. The term 'condition' could equally be used.

5.26 The original 1968 Declaration of Design and Performance (DDP) for the seals used in FRS couplings examined by the BOI gave them an indefinite life (subject to a five yearly inspection).[22] Following the loss of XV230, Eaton Aerospace (the FRS seal designer) issued a revised DDP dated June 2007 (revised further in October 2007) in which they recommended a seal life of 25 years after fitting, subject to five year inspections. The revised DDP further stated: *"Should the End User decide to continue to use beyond the 25 year recommendation, it is for the customer to determine scope, serviceability and suitability of use. Consideration of more frequent/additional coupling inspection intervals and risk assessment should be made by the End User."* This revised recommendation, however, arose as a result of Eaton Aerospace's work with the BOI; the decision was based on a concern to set a safe limit following the loss of XV230, based on the designer's generic experience of elastomeric seals, but not on any specific studies of FRS Nitrile material. Although, as I have mentioned elsewhere there have been instances of some fuel seals being lifed, the prevalent MOD view (reflected by other nations' air forces) appears

[20] XV230 underwent a Primary Maintenance between 21 November and 24 March 2006 (at 18,445 flying hours): BOI Report, paragraph 3 [2-2].

[21] BOI Report, paragraph 39(d) [2-30].

[22] BOI Report, Exhibit 75.

to have been that, once fitted, fuel seals could be left in place indefinitely. For example, the Defence Equipment & Support *"Review of Lifing and Maintenance Policy for Aircraft Systems Seals"* dated 22 November 2007 refers to anecdotal evidence of 55-year old Nitrile seals which had remained in oil for their fitted life being *"in perfect condition."*[23] Whilst this may be true, it must be balanced against the equally valid fact that clearly some fuel seals do not last anything like 55 years. The focus of any concern should be on early and medium failures, not just those that survive to a ripe old age.

5.27 RAPRA Technology Ltd conducted research in 2000 into the effect of age on elastomeric material performance, but only up to the age of 40 years.[24] Although this paper concluded that: *"none of the materials (elastomers exposed to differing climates over a period of 40 years) has deteriorated to such a degree as to be totally unusable"*,[25] it also noted that: *"many rubbers aged in the compressed condition, particularly in the hot climates, have set to such an extent after less than 40 years that their ability to act as an efficient seal is very doubtful".*[26] A study by QinetiQ[27] in 2007 of the relevant literature concerning Thiokol (the material used in the FRS Series 1 fuel seals before its replacement with Nitrile) suggested that it could suffer temperature-related degradation; the DDP for FRS110 Series 1 seals specifies a maximum temperature of 70°C.

5.28 This conclusion was reiterated by QinetiQ in its later report in 2007 into the *"Removal and Examination of Fuel Seals from Nimrod XV236"*.[28] QinetiQ considered that two different ageing mechanisms were likely to occur during the life of a polysulphide seal: the first being ambient temperature ageing, such as will occur in store or when used in benign temperature conditions; and the second being elevated temperature ageing, which will occur when the seals are exposed to high temperature environments. QinetiQ's conclusion was that ageing effects and thermal degradation initially cause hardening and lack of resilience, and that continued exposure to heat (especially to temperatures above 70°C) can cause significant softening of the seal.

5.29 Work by the US Defence materials experts, Advance Materials Manufacturing and Testing Information Analysis Center (AMPTIAC)[29] in 2003 on the service life of elastomeric seals, also suggests that the chemical structures, and thus the physical properties of elastomers, degrade over time. Ageing can be inhibited or accelerate, depending on the environmental conditions surrounding an elastomer. Ageing usually takes place under such conditions as heat, sunlight, oxygen, ozone, moisture or stress; and the rate of ageing is dependent on the amount of exposure to these factors. Such conditions will degrade the properties either by causing additional cross-linking or by chain scission. Ageing is an irreversible process.[30]

5.30 The inconvenient truth is thus that elastomeric seals do age. The problem is that this process is not yet well enough understood.

(2) Misalignment

5.31 A number of leaking seals from Nimrods have been subject to detailed analysis since the loss of XV230.[31] In the case of the FRS Thiokol and Nitrile seals, the principal cause of degradation appears to be stress relaxation (*i.e.* where the stress required to subject a material to a fixed deformation decreases with time), possibly caused by a combination of high temperature and coupling misalignment. Specific limitations are detailed for the angular displacement between pipes connected by couplings and for the distances between pipes and the coupling assembly.[32] In many instances where couplings have been observed to leak, the assembly has been found to be outwith the specified limits.

[23] DE&S(WYT)/365/8/2/CASD, page 7.

[24] Natural Ageing of Rubber, RAPRA Technology Ltd, 2000.

[25] Ibid, page 8.

[26] Ibid, page 10.

[27] Nimrod Fuel Seals, Literature Survey, Issue 1, September 2007.

[28] QinetiQ/EMEA/S&DU/CR0703772/2.0 dated November 2007.

[29] AMMTIAC Report dated April 2003: pages 21 to 25 deal with the service life of elastomeric seals.

[30] Ibid, paragraph 5.12: Ageing.

[31] QinetiQ Reports: Examination of Fuel Seal from Nimrod XV260, dated August 2007; Removal and Examination of Fuel Seals from Nimrod XV236, Issue 2, dated 2007 ; and Examination of Original Avimo Fuel Seals from Nimrod XV240, Issue 1, dated June 2008.

[32] Chapter 41-20 of Air Publication (AP) 101B-0503-1DK dated August 2002 and AP 106D-4402-13A. See also the revised DDP published by Eaton Aerospace after the XV230 incident dated 18 October 2007.

5.32 Following the loss of XV230, Headquarters No. 2 Group recognised in an internal document that: *"recent anecdotal evidence has highlighted a potential shortfall in the training of fitment of fuel couplings"*.[33] The Review was also informed during a trip to RAF Waddington that, when seals were removed, pipes were often found to be misaligned and had to be remanufactured. The available evidence in this regard, however, now goes well beyond the mere anecdotal. A detailed forensic examination of the failure of a fuel coupling and its seals was undertaken following a significant fuel leak on Nimrod MR2 XV229 at the end of December 2008.[34] The principal objective of the investigation was to determine the cause of fuel leaks in both the port and starboard dry bays. In my view, the report is a considered, detailed and thorough examination of a complex problem. It concluded that the port leak was caused by *"poor assembly of the FRS coupling"*. The assembly included an *"oversize cast split-ring collar"* which migrated into the female connector, causing an off-set in the coupling which led to the leak. The report also noted that the condition of the fuel pipe was poor and that, in contravention of the requirements, there was no gap between the two pipe elements. The starboard coupling probably leaked because of stresses imposed by the method of assembly, which displaced the fuel pipe within the coupling. The assembly method mandated required all couplings to be fixed prior to connecting the fuel pipe to the aircraft; this procedure has now been changed to reduce the stress on the assembly. Both couplings had been in place, with no record of disturbance, since at least July 2006; one seal was a FRS 54 K Series 1 seal, which must have been fitted since (at the latest) 2002, when they were declared obsolete. Thus, it is clear that misaligned couplings, *i.e.* those which have been assembled outside tolerance limits, may not leak immediately: one of XV229's couplings had been in place for at least six years before beginning to leak.

5.33 The difficulties of fitting and assembling fuel couplings within the complex, cramped environment of the Nimrod fuselage, the manual dexterity required and the paucity of clear guidance to ground crews as to the best methods of assembly of these coupling, make it not altogether surprising that some of the 400 fuel couplings fitted in each Nimrod over the years may not have been assembled in accordance with the strict criteria required, *i.e.* within a 1° tolerance. From a practical perspective, as QinetiQ noted in its 2007 report (see above), it is clear that building a pipe system of the type contained in the Nimrod, and ensuring repeatability of pipe positioning and alignment, would not be easy, especially when taking into account the 'hand built' nature of the aircraft and the complexity of the pipe system.[35] The difficulties are exacerbated by the fact that the replacement of a single seal or pipe often requires further seals and pipes to be disturbed in order to gain access to the original item.

5.34 I have been impressed in my many meetings and discussions with the ground crews at RAF Kinloss and RAF Waddington by their dedication and I have no doubt that they have done their best in the circumstances. Nonetheless, some couplings have undoubtedly been assembled outside tolerance over the years,[36] either in error, or through following procedures that induce stresses to the system. The result being that the individual coupling components undergo greater stresses than that for which they were designed; this can cause physical movement of components and early degradation of elastomeric seals, resulting in leaks.

(3) Pressure

5.35 Much consideration has been given to the effects of the pressures induced by AAR on the Nimrod fuel system. The normal pressures to be expected on the fuel system during AAR of 30psi to 40psi are well within the system's limits.[37] Nonetheless, pressures, albeit transient, of up to 80psi have been observed during AAR. A QinetiQ report makes reference to 'anecdotal evidence' of a surge up to 120psi, but the source of this information cannot be traced. These 'surges' appear to occur in all aircraft types undertaking AAR and are probably caused by the closing of the fuel system valves. With the sole exception of the single QinetiQ report, no pressures above the Nimrod's proof pressure have been reported. However, the slow response characteristic of the Nimrod's probe pressure transducer is such that pressures higher than those observed may in fact have occurred. Most pressure surges are transient in nature with an early peak followed by a slow reduction in pressure. With a response time

[33] Reference: 20071129-Fuel.

[34] RAF Form 765B Ground Incident Serial No. Kin 067/08, dated 29 December 2008.

[35] QinetiQ/EMEA/S&DU/CR0703772/2.0, dated November 2007: Removal and Examination of Fuel Seals from Nimrod XV236.

[36] Ibid, page 18. QinetiQ calculated from witness marks on two of the seals removed from XV236 that the pipes had probably been about 6° to 7° out of alignment.

[37] 75psi maximum working pressure and 112.5psi proof pressure.

of one second, the pressure gauge may only be displaying the later portion of a 'spike' as it reduces in pressure. Also, the transducer is located at the probe, whereas the maximum values are likely to be felt further down the refuel gallery closer to the shut-off valves.

5.36 Consultation with the United States Air Force Safety Centre (AFSC) has confirmed that *"surge pressures can impact the integrity of the fuel system and fuel system components* *<u>if the proof pressure for the fuel system is exceeded</u>"* (emphasis added). The AFSC reported that during testing of the Chinook helicopter system, excessive surge pressures caused: *"a fitting to loosen (discovered by leaking fuel)"*. However, the significant point is that surge pressures need to be above proof pressure to trigger a leak. Aside from one 'anecdotal' report, excessive surge pressures have not been observed on Nimrod.

5.37 BAE Systems presented evidence to the Review of a fluid 'hammer' effect which is a pressure wave which occurs when a fluid in motion is forced to stop or change direction suddenly, such as happens when a valve in the AAR system closes. They calculate that if fluid with an input pressure of 70psi was affected it could have a fluid hammer pressure of up to 153psi. This pressure would be only momentary and thus the excess energy would be small. Nonetheless, there is a potential to expose the refuel system to pressures, albeit briefly, in excess of the proof pressure. Additionally, the maximum working pressure of the seals currently used in FRS couplings is 110psi. This theory appears to have risen from the evidence presented at the Inquest that a bowser in Theatre had briefly delivered fuel to an aircraft at 70psi. However, subsequent investigation into the fuel leaks discovered on Nimrod XV229[38] proved that the bowser could not in fact have delivered fuel at 70psi as it was governed to 50psi. The BAE Systems theory rests on the proposition that fuel was delivered at a steady rate of 70psi; it was not, and there is no evidence that it ever has been, from either bowser or airborne tanker; thus, BAE Systems' contention has no basis in fact.

5.38 What practical evidence is there of AAR-induced fuel leaks within the Nimrod? The Nimrod R1s of No. 51 Squadron have flown significantly more AAR sorties than any Nimrod MR2s. The Squadron examined its records for a period of intensive AAR sorties for two of its aircraft and noted that neither aircraft had suffered a single fuel leak.[39] Statistically, this is a small sample upon which to build any conclusion. Nonetheless, if AAR in itself was the primary cause of fuel leaks, it might be expected that those aircraft with the highest number of AAR sorties would display the greatest number of leaks. It has been suggested that a comparison between the Nimrod R1 and the Nimrod MR2 is invalid because of the different operational profiles of the two aircraft; however, when conducting AAR, the two aircraft operate the same flight regime. Furthermore, those aircraft which have displayed fuel leaks during AAR (particularly those which attracted considerable interest following the loss of XV230) have, with few exceptions, leaked in areas not subject to increased pressure during AAR. Increased pressure during AAR might affect a system already weakened, and it may well be a contributory factor in some leaks, but, on current evidence, is unlikely to be the principal cause of coupling leaks. In the case of XV230, however, given the proximity in time of the first fire warning and the cessation of AAR (approximately 90 seconds), it is likely that AAR played some part in the initiation of the fire.

(4) Vibration or airborne stresses[40]

5.39 During a 1999 investigation into fuel leaks on Nimrod R1 XV249, cameras showed that one fuel pipe assembly actually moved in flight. In November 2007, AAR was prohibited on the Nimrod when it proved impossible to reproduce a known airborne fuel leak on Nimrod MR2 XV235 whilst on the ground. In December 2008, the investigation into the leaks on XV229 also considered this issue and noted that on another aircraft (XV241) a leak assessed as a 'run' with the aircraft jacked became a drip every three seconds when the aircraft was resting on its undercarriage. It thus appears that the stresses of the airborne environment can induce leaks, but it is not yet clear whether these leaks are simply manifestations of pre-existing weaknesses caused by misaligned couplings.

[38] 20081127-XV229 F765B Report-U16.

[39] BOI Report, Exhibit 51.

[40] *i.e.* aerodynamic loading causes wings to flex.

(5) Temperature

5.40 The RAPRA studies previously mentioned indicate that high temperatures can affect the performance of elastomeric seals. The Nimrod has been exposed to elevated temperatures during its recent Gulf operations and this may have had an effect on seal performance. In a recent report,[41] QinetiQ state in relation to in-service environment and temperature:

> *"The actual service temperatures experienced by the seals under test is not known but information from the Nimrod IPT on measurements taken on an aircraft operating in desert climates gives typical internal temperatures of about 43°C. In addition, it was noted that internal temperatures did not exceed 50°C. Measurements were also made of ground temperatures and these recorded 68°C on the pan and 58°C in the shade. ... In addition, those couplings in close proximity to hot pipe work will also have experienced elevated temperatures, regardless of the geographical location. However, these temperatures are not known and should be measured."*[42]

5.41 QinetiQ refer to the effect of particularly large increases in temperature between 70°C and 80°C on stress relaxation and suggest that it is possible that these sort of temperatures could be reached if an aircraft is parked on the tarmac under a hot sun whilst on deployment. The DDP by Eaton states that Thiokol materials can be used with fluid temps between -45°C and +55°C and ambient temps between -65°C and +70°C. Therefore, there appears to be a possibility that seals in aircraft operating in desert environments may experience temperatures close to their specification limit. Furthermore, test results show significant softening occurs between 70°C and 80°C. Accordingly, temperature excursions above the specification limit for these seals could result in significant and rapid stress relaxation occurring.

5.42 The US Defence materials experts, AMMTIAC,[43] state that heat resistance is not one of an elastomer's great strengths. In fact, elastomers are very susceptible to high temperatures. Since most elastomers are organic, they usually chemically degrade under high temperatures, causing their physical properties to deteriorate. Elastomers will typically soften under increasing temperatures, eventually causing their properties to degrade and subsequently turn brittle. Thermal expansion can sometimes give seals better performance temporarily, but this swelling can result in stress relaxation, compression set, and reduction in strength. Fluid compatibility is also somewhat dependant on temperature. That is to say, higher operating temperatures tend to cause the elastomers to become more susceptible to fluids. Low temperatures cause elastomers to gradually become stiffer and eventually turn brittle. This causes their hardness to increase, which can adversely affect an elastomer's ability to maintain a seal.[44]

(6) Drying out

5.43 There was a considerable amount of evidence, both from maintainers and experts, that the incidence of fuel leaks from couplings went up following a period when a fuel system had been drained down, *e.g.* during Major maintenance. It was observed that when the system was pressured up again with fuel, a greater number of fuel coupling leaks was experienced. Expert opinion points to the deleterious effect that 'drying out' can have on elastomers.[45]

5.44 I now turn to consider the fuel system maintenance regime and leak history of the Nimrod fleet itself.

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[41] QinetiQ Report: "Removal and Examination of Fuel Seals from Nimrod XV236" dated November 2007.

[42] Ibid, page 37.

[43] AMMTIAC Report dated April 2003: pages 21 to 25 deal with the service life of elastomeric seals.

[44] Paragraphs 5.9 to 5.10.

[45] See, for example, pages 8 and 9 of QinetiQ's 2007 report (supra).

Maintenance regime for Nimrod fuel system 1969-2006

5.45 The maintenance regime of the Nimrod fuel system is, and was, hampered by a number of physical, practical and organisational factors.

Physical difficulties

5.46 The maintenance of the Nimrod fuel system is far from straightforward for a number of physical reasons:

5.46.1 First, the Comet fuel system has been extensively modified by the addition of fuel tanks, and the incorporation of AAR to extend the Nimrod's endurance. This has led to a complex and extensive system of fuel pipes (incorporating approximately 400 couplings) within a relatively small airframe;

5.46.2 Second, the Nimrod was not built with easy maintenance and accessibility in mind. This presents a particular problem with regard to the replacement and assembly of FRS couplings, which requires a degree of accuracy and manual dexterity;

5.46.3 Third, the design tolerances of the Nimrod reflect standards prevalent several decades ago: the aircraft were hand-built and the dimensions of each aircraft are slightly different. When replacing components such as lengths of pipe, the replacement part often has to be specially altered and fashioned to fit the dimensions and space available in the particular aircraft. This is not unusual in designs of the Comet/Nimrod era. In absolute terms, the differences are small. However, the requirements for the FRS fuel couplings are stringent: there is only a 1° maximum pipe angle deflection tolerance allowed. This imposes the need for accurate fabrication of individual components as well as equally accurate assembly; and

5.46.4 Fourth, defects and deterioration in fuels seals (unless made evident by fuel leakage) are not normally observable without dis-assembling the coupling, which would then require replacing.

Lack of guidance in maintenance manuals

5.47 The practical and perceived difficulties of maintaining the Nimrod fuel system were not eased by inadequate supporting documentation. The BOI noted that:

5.47.1 The Aircraft Maintenance Manual (Topic 1) was deficient in that it did not contain guidance for the correct assembly and fitting of the locking rings to fuel couplings. If the locking ring is incorrectly fitted, the two halves of the coupling could potentially loosen and allow it to leak.

5.47.2 The Aircraft Illustrated Spares Catalogue (Topic 3) did not comprehensively identify every coupling and its component parts, giving rise to the risk of incorrect parts being fitted.

5.48 An RAF investigation in 2008 into fuel leaks experienced by Nimrod MR2 XV229 reported continuing problems with Topic 1 and its supporting documentation, describing them as *"contradictory and ambiguous"*.[46] In particular, the report cites lack of guidance, missing instructions, incorrect references, a fuel pipe assembly procedure *"that is prone to build stress into a system"*, and an omission of any directions on *"how to carry out installation work to mount fuel pipes to the aircraft structure, the procedure to be followed if the pipe does not fit or guidance to review the relevant chapter of AP101B-0503-3A for alternate structural fitment procedures"*.[47] It is a matter of concern that, despite the focus on fuel coupling leaks since the loss of XV230 almost three years ago, and the specific recommendations made by the BOI, documentation specifying fuel system maintenance should still have been regarded as inadequate in 2008.

[46] RAF Form 765B Ground Incident Serial No. Kin 067/08, dated 29 December 2008.

[47] Ibid, page 20.

Lack of Trend Analysis

5.49 As required by Maintenance Policy, and as the BOI correctly emphasised:[48] *"...it is important that corrective maintenance trends are analysed and, where appropriate, reflected in changes to preventative maintenance schedules"*[49]. Unfortunately, as explained above, the maintenance data for the Nimrod fuel system was never subject to any trend analysis at a component level which would have allowed the increase in leak rates to be detected. In his comments on the XV230 BOI Report, whilst noting that fault trends had been analysed and that the direction contained within JAP 100A-01 had been followed, the RAF Kinloss Station Commander went on to note that: *"…the analysis was not effective as it did not identify the increase in fuel leaks that the BOI uncovered."*

5.50 Nimrod was not part of the Logistics Information Technology Strategy (LITS) because the Nimrod's (perceived) impending out-of-service date (OSD) was thought not to make this worthwhile. However, the data relating to the maintenance record of the aircraft did exist and it is regrettable that insufficient effort was applied to analysing fault trends to inform maintenance decisions. In order to analyse the trend of fuel leaks, the BOI was forced to sift through a database containing summaries of several thousand aircraft job cards, examining each record individually to see if it contained any relevant data. The inadequacies of the official Nimrod data recording systems are illustrated by the fact that the Nimrod Line Engineers at RAF Kinloss felt the need to develop their own database, which unfortunately fell into disuse when the individual Line engineer with the Information Technology (IT) skill to construct and maintain the system was posted elsewhere. From my discussions with personnel at RAF Kinloss, it is plain that it was regarded as a valuable asset and its passing is much regretted now.

5.51 Following the accident to XV230, the Nimrod IPT introduced mandatory reporting of fuel leaks using a form known as a Leaflet 70 from AP101B-0500-2(R1). These were to be sent to the IPT when completed to highlight any ongoing problems with fuel leaks. As a result of the F765B investigation into the fuel leaks on XV229 in December 2008, one of the observations made by the Investigating Officer, was that his review of a significant number of Leaflet 70s listed ambiguities, factual inaccuracies, and non-standard practices: "*It was concerning that there seems to be no follow up action by the IPT to address these anomalies ... it is considered that the robustness of the reporting and reviewing process is questionable and requires a process review."*

5.52 This lack of follow up is a matter of concern, particularly since Leaflet 70 was meant to serve as the primary monitoring tool for fuel leaks and the effectiveness of any new procedures to deal with them, such as the enhanced inspection regime.

Prevailing attitude that fuel leaks 'inevitable'

5.53 There was (and remains) a prevailing attitude that leaks in aviation fuel systems are an inevitable fact of life.

5.54 This is reflected in, *e.g.,* the DE&S *"Review of Lifing and Maintenance Policy for Aircraft System Seals"*,[50] dated 22 November 2007, which stated that: *"ultimately, leaks from seals are inevitable and the system design principles used for aircraft in both the civil and military environments to mitigate against leak hazards (sic)"*. The term 'leak tolerant' (a term which seems to have sprung up since the loss of XV230) appears intended to convey the sense that fuel leaks in themselves should not pose a significant hazard because aircraft should be designed and constructed such that leaks would never reach a point of ignition. This is undoubtedly true in theory: any competent designer should naturally do everything to eliminate the risk posed by sources of ignition. Nonetheless, as the *TWA 800* case[51] and XV230 have starkly illustrated, however careful you think you have been, you cannot be sure you have anticipated all potential ignition sources.

[48] JAP 100A-01, and BOI Report, paragraph 32(a)(5).

[49] As mirrored by civilian maintenance procedures: see Civil Aviation Authority (CAA) IP leaflet 1-7, BOI Report, Exhibit 12.

[50] DE&S(WYT)/365/8/2/CASD, page 18.

[51] *TWA 800* exploded on a flight from Paris to New York on 17 July 1996 over Long Island. Investigators determined that fuel vapour in the almost empty central fuel tank had been ignited by an unknown source, most probably an electrical short.

Ignition/Leak Equation

5.55 A maintenance approach which relies primarily on a belief that all potential ignition sources have been eliminated is, in my view, unsound. Further, it is not generally a good approach to tolerate recurrent defects, even minor ones; they might have unexpected, unforeseen, or cumulative consequences. It is also a well known adage that *'fuel will tend to find a source of ignition'*. Liquid paths are eccentric. Accordingly, as I state in **Chapter 23,** good practice, and the principle of As Low As Reasonably Practicable (ALARP), require that the risk of *both* parts of the ignition source/fuel sources equation be equally carefully addressed. One BOI witness said that leaks *"were seen more as an operational issue as opposed to a flight safety issue"*.[52] It is right to point out, however, that if crew detect a fuel leak in flight they are expected to file an Incident Report (IR). Significant leaks on the ground would also be reported in an IR and probably supplemented by a Serious Fault Report (SFR). Ground crews are required to do all in their power to identify and cure a leak and aircrew would not accept an aircraft to fly unless leaks were cured, or within limits and correctly recorded. Nonetheless, in the past, it appears that not enough was done to give thought to attempting to identify the underlying causes or patterns of leaks, or the potential risks flowing from them.

'Non-disturbance' philosophy

5.56 There has been a widespread philosophy in the MOD, and other air forces and the civil sector, that fuel seals should generally be left undisturbed. This stemmed from a prevailing belief that pro-actively replacing seals might actually increase the number of fuel leaks by disturbing the system and fuel couplings[53] up and down the line and/or because of 'infant mortality', *i.e.* early failures of newly assembled couplings. Whether this belief is justified in all circumstances is, however, not clear. The Nimrod Fuel Seal Replacement Programme (FSRP), whereby 42 fuel seals located in specific areas deemed to present a particular risk,[54] and the Nimrod teardown exercise have yielded potentially valuable results (see **Chapter 23**).

Lack of appreciation of leak rates

5.57 There was a lack of appreciation of Nimrod fuel leak rates in some quarters. BAE Systems stated repeatedly in the NSC: *"From in-service data the potential for fuel pipe leakage is given as Improbable".* The definition of *"Improbable"* is *"remote likelihood of occurrence during the operational life of a particular fleet"*.[55] For combat aircraft this equates to a figure of $1x10^{-6}$ or an occurrence of one in a million flying hours. As explained in **Chapter 11**, even a cursory examination by BAE Systems of IRs raised by Nimrod crews following fuel leaks would have shown this statement to be unsound. Any discussion with the aircrafts' maintainers as to the frequency of leaks detected on the ground would have shown the claim to be manifestly untrue. An experienced Nimrod engineer told the Review that, on average, he would estimate that there was a fuel leak (excluding wing tank leaks) about once a fortnight.

Limited pressure testing and 'leak mapping'

5.58 The approach to fuel leaks was, therefore, essentially re-active rather than pro-active. There were occasions, however, on which pro-active steps were taken to detect leaks. Prior to some Depth maintenance activities, aircraft were filled with fuel and left overnight. On the following day an inspection would be made to determine the location and extent of fuel leaks and any leaks 'mapped' (there is a page in the F700 for entering on a diagram the position of fuel leaks). Although this was effective at detecting external leaks in the aircraft's wing tanks, it was significantly less effective at detecting leaks elsewhere, particularly as the fuel system was not pressurised for this procedure. Pressure tests were, however, conducted on any element of the fuel system that was disturbed and rebuilt during or following Major maintenance.

[52] BOI Witness 33.

[53] It is entirely possible that what was perceived as 'infant mortality' was actually the failure of incorrectly assembled couplings.

[54] It is still too early to tell the medium and long-term effects of the FSRP.

[55] BAE Nimrod Task 06-3409 "Equipment Safety Management Nimrod MR2: Mk2 Equipment Safety Case Baseline Report" (J4-475), Appendix B, page 2.

History of leaks in Nimrod fleet 1983-2006

Introduction

5.59 The Nimrod fleet experienced a four-fold increase in fuel coupling leaks during the period 1983–2006.[56] Although, in absolute terms, the increase was not large, it should have been detected by reviews of maintenance policy. The relatively slow increase, over a period of decades, was, however, below a level at which it was immediately apparent to those operating the aircraft. Although the leak rate was broadly comparable with leak rates from some other RAF aircraft, no comparison appears to have been made until after the loss of XV230. No single cause for the increase in leaks has been determined. It is likely to be due to a combination of interlinked factors, including inaccurate alignment of couplings and fuel pipes, exposure to high temperature, and mechanical movement or vibration. Although seals manufactured after 2000 used in Avimo couplings were not of the correct specification, and were found to have degraded (see further below), none of the couplings from which they were extracted was itself found actually to be leaking.

Wing Tank Leaks

5.60 The Nimrod, as with other types employing similar design, suffers from leaks from the wing fuel tanks. The design of the Nimrod is based on the Comet. When the Comet was designed in the 1940s the ability to make large wing panels did not exist and a large number of joints were required for the Nimrod in order to fasten together the relatively small wing skin panels.[57] As fuel leaks are most likely to occur at structural joints, the susceptibly of the Nimrod to fuel leak incidents was seen as an 'inevitable' consequence of the basic design.[58] Because leaks from certain areas of the wings will enter the airflow and be dispersed behind the aircraft, as long as they are within prescribed limits, they can be accepted and the aircraft will fly with them. This is, however, subject to certain procedures: a careful engineering assessment and the recording of each leak in the aircraft's documentation (Form 700). Further, the aircraft captain will examine this document before deciding whether or not to accept the aircraft for flight. The addition of electric operational equipment to the hard points under the Nimrod's wings from the early 1990s meant that the areas of the wing in which leaks were 'acceptable' was reduced. However, in practice, ground crew found it difficult to prevent recurrence of leaks in these areas and this led to a reduction in aircraft availability: the aircraft were not allowed to fly until the leaks had been cured. Significant time and effort was devoted to this recurrent problem straining ground crew resources. In 2006, QinetiQ was tasked to investigate the issue and determine whether it was possible to reduce the leak rate from wing tanks, to improve aircraft availability. The subsequent QinetiQ report[59] highlighted that, although the tank repair work on the Nimrod MR2 examined at RAF Kinloss was to a 'high standard' there were a number of improvements that could be made. In particular, QinetiQ highlighted the following: *"The working conditions of RAMS[60] are ... less than ideal"* and *"the temperature and humidity variations are unlikely to be conducive to the correct curing of sealant materials"*; *"Finally, it was noted that the facilities and previous hangar environmental conditions were not fully conducive to working efficiently with fuel tank sealant ..." to allow the curing of tank sealant"; "the APs in use by both RAMS and NSG were found to be both out-of-date and of insufficient depth to be of practical value", "the bolt replacement has been a random process according to where the leaks occur and is not covered by preventative maintenance or inspection routines".* QinetiQ also noted that there was poor sharing of data between organisations, poor analysis of available data, the use of outmoded procedures and documentation and the use of particular sealants, when more appropriate sealants were available. This episode thus does not reflect very well on the then current processes and procedures for dealing with wing leaks. But it is right to point out that the report made it clear that, when faced with a wing tank leak that posed a threat to aircraft safety, the RAF simply did not allow the aircraft to fly. The QinetiQ report was prompted by the operational impact of unavailability of aircraft. Nonetheless, it is a matter of concern that these unsatisfactory aspects of maintenance were found.

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[56] BOI Report, Part 2, paragraph 39(b).

[57] "Nimrod Fuel Leak Study", QinetiQ/D&TS/AIR/RF051726/14, dated 17 March 2006, page 10.

[58] Ibid.

[59] "Nimrod Fuel Leak Study", QinetiQ/D&TS/AIR/RF051726/14 dated 17 March 2006.

[60] Repair and Maintenance Section.

Fuselage Leaks Trend

5.61 There had been an undetected but inexorable and significant increase in the leak rate in the Nimrod fleet in the 23 years before the XV230 accident. Whilst some integral wing tank leaks do not generally pose a potential problem, leaks within the aircraft fuselage are a different matter.

5.62 The BOI's Engineering Member, Squadron Leader Andrew Gransden, carried out a painstaking and meticulous analysis of several thousand records[61] held within the RAF's Maintenance Data System. This exercise took many weeks**.** It showed that there had been an increase in fuel leaks from couplings and seals between 1983 and 2006.[62] These had seen an increase from approximately 0.5 per thousand flying hours in the 1980s, to approximately 3.5 per thousand flying hours in the 2000s. Although, in absolute terms, this did not represent a significant number and the rate of leakage in the 1980s was particularly low, it did represent a significant growth in reported leaks. A subsequent report by DE&S[63] suggested that the rate of increase over the period 1997 to 2006 was very low. However, this report (compiled from BOI data) was over a much shorter timescale and utilised information for 2006 as representing the entire year, leading to a distortion of the analysis (notwithstanding that the BOI had clearly identified that this data represented only a portion of the year in question). In my view, if one compares like with like, the conclusions of the BOI are consistent with the DE&S report.

Comparative leak rates – other military aircraft

5.63 The DE&S study referred to above considered leak rates for a number of aircraft (Nimrod, VC10, Puma and Tornado IDS) over the period 1997 to 2006. Although the Puma had a much lower leak rate than Nimrod, the Tornado's leak rate was comparable. The VC10 experienced a much higher leak rate than any of the other aircraft, peaking at 16 faults per 1000 flying hours in 1998. This was attributed to a change of maintenance procedures for the VC10 fuel system, which had required significant disruption of the fuel system and provoked additional leaks. The rate of leaks for VC 10s had, however, fallen and in 2006 was only slightly higher than that of the Nimrod. Nonetheless, it would appear from the limited data available that the Nimrod has a comparable leak record with some other MOD aircraft.

Warning signs

5.64 There were a number of incidents over the years which indicated the potential for fuel leaks to cause significant problems. These incidents can be seen as lost opportunities. They were potentially serious events which should have highlighted the risks inherent in fuel coupling leaks interacting with patent ignition sources. They are discussed further at **Chapter 8**.

Post accident leak history

5.65 Following the loss of XV230, there was an increase in reported fuel leaks. This can probably be explained by an increased inspection schedule and the regular checks for leaks under pressure.

Shortcomings in fuel seal maintenance regime

5.66 It is important to place the issue of Nimrod fuel leaks in context. No Nimrod crew would knowingly accept an aircraft with a fuel leak (with the exception of minor leaks from the wing fuel tanks, which had been assessed as not presenting a threat to the aircraft and recorded as such in the aircraft documentation). The majority of detected leaks were, and still are, relatively small leaks, found by the ground crew during maintenance and immediately rectified. Nonetheless, in my view, there appears to have been an inadequate appreciation of the risks from fuel coupling leaks in the fuselage, unsatisfactory maintenance and no overarching direction to

[61] Approximately 46,000 in total.

[62] XV230 BOI Report Annex I, and Addendum A1-2. Where possible integral wing tank leaks were excluded from the analysis as, from the Board's knowledge of the Nimrod's systems and the reported location of the fire on XV230 it felt able to disregard fuel tank leaks as a potential source of fuel.

[63] "Review of Lifing and Maintenance Policy for Aircraft System Seals", DE&S(WYT)/366/8/2/CASD, dated 22 November 2007.

monitor the frequency or extent of fuel leaks generally: they were seen as essentially a routine maintenance issue preventing aircraft flying, but not necessarily as a threat to the aircraft. Each incident appears to have been treated in isolation, with no attempt to gather evidence of patterns or trends. As fuel represents the most unpredictable 'third' of the fire equation,[64] there should always be careful and unremitting focus on managing, tracking, monitoring and reducing fuel coupling leaks to ALARP.

5.67 In my view, the maintenance regime operated for many elements of the Nimrod fuel system prior to the loss of XV230 in September 2006, was unsatisfactory because:

5.67.1 Although the 'Corrective Maintenance' regime reflected common practice in the aviation field, it failed to detect an increase in fuel leaks, despite the conduct of the data reviews mandated to ensure the efficacy of the system. Perhaps the policy's greatest failing, though, is that it appears to have imbued a sense that fuel leaks were not an occurrence that required careful monitoring. Fuel coupling leakage was not perceived as a significant risk in itself, as the majority of leaks were considered to be extremely small and no one had realised the ignition threat posed by the Cross-Feed/SCP ducting.

5.67.2 Fuel leak mapping and zonal surveys of the fuel system, conducted prior to and during periodic maintenance, were of limited value in detecting fuel leaks as they were undertaken either with the fuel system empty, or full but not under pressure. The fuel system was not tested or inspected under pressure, unless a component was replaced under the Corrective Maintenance policy, or following scheduled maintenance to confirm correct reassembly of the fuel system. (The AAIB[65] report, produced as part of the investigation into the loss of XV230, highlighted that the maintenance regimes for some civilian aircraft included checking the fuel system for leaks while under pressure.)[66] Further, visual inspections were confined to external signs of damage, deterioration, corrosion, or leaks. Couplings were not dismantled to check the condition of their rubber seals; however, such a process would have involved the wholesale replacement of the seals as once disturbed they are automatically replaced. It is difficult to see, therefore, how incipient fuel leaks might be detected with any level of confidence.

5.67.3 There was no system of formal random 'sampling' of components such as seals to check their in-service condition, or any pro-active method to anticipate leaks.

5.67.4 There was a lack of guidance in the Aircraft Maintenance Manual (AMM) regarding the fitting of fuel couplings which meant that ground crew had no immediately available reference to ensure that the couplings were fitted correctly. Couplings have been found incorrectly assembled allowing some rotation of the coupling body. The Illustrated Spares Catalogue did not identify the part numbers of the couplings illustrated, such that maintainers had to rely on using the part number of the removed part to identify the necessary replacement – something which could perpetuate previous misidentifications.

5.68 The MOD was at fault in particular because:

5.68.1 Although Reliability Centred Maintenance was supposed to be used to determine fault trends, the MOD failed to detect the increase in fuel leaks, as it was not focused on individual fuel system components, nor was it directed to investigate fuel leak rates. The Maintenance Data System (MDS) managed through the Logistics Analysis and Research Organisation (LARO) captured maintenance work orders (MWO) but was not used to extract trend analysis for fuel leaks. The platform 'fault trend analysis' produced annually did not go down to component level. There was thus no means of investigating easily fuel leak rates, or indeed noticing increases over time; a fact illustrated by the BOI's need to interrogate several thousand records to produce their own analysis.

5.68.2 The system was reliant solely on IRs or SFRs, raised by air or ground crew, to reveal problems. However, unless a fuel leak was determined to have posed a threat to an aircraft, it would generally simply be recorded as a fault and rectified in the normal manner (although all leaks discovered whilst airborne

[64] A fire requires fuel, heat and oxygen to ignite.

[65] Air Accident Investigation Branch.

[66] BOI Report, Exhibit 12, page 48.

would generate an IR). The majority of fuel leaks were not detectable in the air and would thus be detected when ground crew examined the aircraft during post or pre-flight inspections, or during periodic maintenance. Thus, a simple examination of IRs and SFRs would provide only a narrow perspective on the true rate of fuel leaks within the aircraft.

5.68.3 There is no evidence that any of the previous incidents (see further **Chapter 8**) sparked any particular thought as to the risks inherent in fuel coupling failures.

5.68.4 There is no evidence that anyone had formally addressed the apparent discrepancy between the FRS coupling manufacturer's original recommendation in 1968 (that FRS Series 1 elastomeric fuel seals should be subject to a five-yearly inspection regime), and the actual maintenance regime operated in practice from 1969 to 2006.[67]

Avimo Seals – Quality problem: *post*-2000

5.69 I now turn to consider a major issue which has arisen in relation to Avimo seals. The Nimrod is fitted with 66 Avimo seals, of which one is located in the starboard No. 7 Tank Dry Bay immediately above the SCP elbow.

Avimo "Original" Couplings

5.70 The original patent for the Avimo coupling (obtained by the Review from the British Library) dates back to 1937 as a *"Resiliant Pipe Joint"* for pipes subject to vibration or small relative movements, such as those in internal combustion engines.[68] The patent was acquired by Avimo Ltd (a company formed in 1937) and apparently approved under CAA Airworthiness number E2594, although it has not been possible to locate this document. The couplings were used extensively on World War II aircraft[69] before De Havilland (later Hawker Siddeley) selected the coupling for use on the Comet airliner and then subsequently for the Nimrod R1 and MR2 aircraft, around 1969.[70]

5.71 In general terms, the Avimo coupling was selected to join pipe work in the Nimrod's refuel/de-fuel and fuel tank venting systems, *i.e.* (broadly) the larger diameter pipes in the aircraft's fuel system. More particularly, the Nimrod IPT confirmed to the Review in October 2008 that there are a total of 66 Avimo couplings fitted in the Nimrod R1 and MR2 fuel system, comprising: (a) 46 in the refuel/de-fuel system (no longer expected to be pressurised in flight now that AAR has ceased); (b) four in the vent system; and (c) 16 in the fuel feed system (which see a pressure of up to 28psi in flight, but all of which are contained within the wing fuel tanks). One of these couplings is located in the starboard No. 7 Tank Dry Bay.

[67] BOI Report, Exhibit 75.

[68] Patent Specification 465,724 accepted on 7 May 1937.

[69] Including the Spitfire.

[70] DG AS/WYT/3/2/NIM IPT & DG&S(Air)(Wyt)508324/120/1.

Figure 5.9: Avimo Seal

Seeds of Concern

5.72 Following the BOI into the loss of XV230, the Nimrod IPT initiated the Nimrod Sustainment Programme (NSP) to address the BOI's recommendations. This programme introduced a series of checks to determine the integrity of the Nimrod fuel system, including the promulgation of Special Technical Instruction (STI) 922 for a targeted replacement of fuel seals between Rib 3 port and Rib 3 starboard (the Nimrod FSRP). During the course of this programme, on 14 May 2008, Avimo seals removed from the refuel/defuel pipe in the No. 3 engine bay of XV240[71] were found to be degraded. In particular, the inboard seal was found to have extruded into the gap between the two pipe ends, suffering compression damage (deformation consistent with its surrounding components) to such an extent that it had split. Although there were no visible signs of fuel leakage from the coupling, there was perceived to be a risk that fuel could have leaked onto the ECU or the hot pipe situated below (although there was a fire suppression system in the relevant zone).

5.73 RAF Kinloss duly reported this finding to the Nimrod IPT in a Serious Fault Signal and the seals removed from XV240 were sent to QinetiQ for priority analysis, followed (in due course) by all the seals previously removed from XV244 and XV255 under STI 922.

5.74 In its report dated June 2008, [72] QinetiQ examined the Avimo seals removed from XV240. It concluded that the most probable cause of the damage to the seals was from mechanical loading effects, in that sustained compression and a sometimes warm environment probably caused deformation of the seals through stress relaxation or compression set. The inboard seal referred to above was found to have split through in two places. The split coupling did not leak because fuel could not pass between the seal and outer flanged packing. If, however, one of the splits had coincided with the gap between the two flanged pieces, a fuel leak would have been probable. QinetiQ accordingly recommended that all similar couplings in the engine bays and any other potentially hazardous locations should be examined for damage and/or fuel leaks and, where necessary, damaged seals replaced.

[71] The seals were removed from the inboard and outboard ends of refuel pipe 6M4P1477A/ND.

[72] "Examination of Original Avimo Fuel Seals from Nimrod XV240", QINETIQ/CON/AP/CR0800541.

Figure 5.10: Avimo Seal Damage

5.75 QinetiQ's subsequent examination of fuel seals removed from XV255 and XV244 confirmed the conclusions expressed in its June 2008 report. It found that one seal from each of XV244 and XV255 was split in a similar manner to that on XV240. As with the seals removed from XV240, none of the Avimo seals in the batch examined by QinetiQ had been observed to be leaking. They were merely replaced pursuant to STI 922 as a precautionary measure. Examination of the most damaged Avimo seal removed from XV255 (removed from the lower coupling joining the starboard Rib 1 Y-branch to the pipe that goes to tank 7, *i.e.* in a wing root location adjacent to the No. 7 Tank 7 Dry Bay), however, revealed that its inside surface had split open and it was *"very close to failure".* Although situated to the rear of the Rib 1 area, this seal is separated by a bulkhead from the No. 7 Tank Dry Bay and is thus unlikely to have been the source of fuel for XV230's fire (there is, though, one Avimo coupling within the No. 7 Tank Dry Bay). In QinetiQ's letter dated 25 July 2008 to Nim(ES)AWS, the lead scientist concluded that it was another case of progressive mechanical failure (fatigue) in the rubber seal and stated: *"As far as I am aware, most of the attention to date has focused on FRS couplings. We now have what appears to be an equally plausible fuel leak location in a branch pipe joined by Avimo couplings. Although both FRS and Avimo seals exhibit signs of material ageing and/or stress relaxation, in the Avimo seals, the primary mode of failure appears to be progressive mechanical failure (i.e. rubber fatigue). I know STI 922 is already replacing Avimo seals. However, I suggest you should review and consider whether sufficient attention is being given to the inspection and replacement of this type of fuel coupling across the fleet. Note that these are generic couplings probably also used on other aircraft."*

5.76 In a subsequent e-mail to the Nimrod IPT dated 28 August 2008, following a further examination of Avimo seals removed from XV236 and XV231, QinetiQ reiterated its view that: "*We clearly have a serious problem with the condition of this type of seal.*"

5.77 In the ensuing months, during further maintenance or as a result of the Nimrod FSRP, a further eight Avimo seals were found to have split in a similar manner and made the subject of an F760 (Narrative Fault Report) action. In the light of which, and acting on QinetiQ's advice, the Nimrod IPT ordered that all 23 seals from the Avimo couplings within the Rib 3 starboard to Rib 3 port area were to be replaced under STI 922, and that all Avimo seals (outside the wing tanks) were to be replaced by the end of March 2009[73]. It further tasked BAE Systems to take the QinetiQ investigation forward together with the Avimo coupling equipment manufacturer (who by this time, was Taunton Aerospace Limited (see below)), at an initial meeting on 23 September 2008.

Avimo seals now being replaced with new material

5.78 The seal compound was found not to conform to the original specification. Following the discovery of the non-compliant formula being used for the Avimo seals, the Nimrod IPT instigated a technical investigation and an urgent programme to find and manufacture new material for Avimo seals. I turn to consider this below.

[73] Annex A to Business Procedure (BP) 1301, dated 18 September 2008.

Composition of Avimo Seals

5.79 At the time of the loss of XV230, and indeed until very recently, the rubber seals used in the Avimo couplings were polychloroprene seals. Chloroprene was first synthesised in 1930 and the commercial manufacture of chloroprene started in 1932. One of chloroprene's many trade names is 'Neoprene'.

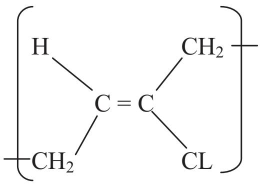
5.80 The Review was advised by QinetiQ that there are very many different possible formulations of chloroprene, using various base polymers, fillers, anti-oxidants, process aids, activators, curatives and process oils in different proportions. In consequence of which, the different properties of polychloroprene rubbers vary.

5.81 The original component drawing for the Avimo seal, drawing no. MR700D, dated 9 February 1947, entitled *"Rubber for Pipe Coupling"* (last amended 16 July 1962, Issue 12) (the Avimo Drawing) lists three categories of part numbers and gives detailed dimensions. The second category of part number specifies as its material *"Avon Rubber Co. Mixture No. 18 x 5"* or *"Spencer Moulton Mixture No. SH0/2"*. Note 1 to the Avimo Drawing provides as follows:

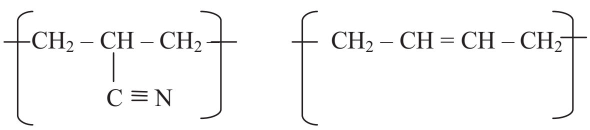
> *"MATERIAL: NEOPRENE WITH 100 PART LOADING CARBON BLACK PER 100 OF NEOPRENE.*
>
> *HARDNESS: 60/65% B.S.*
>
> *SPECIFIC GRAVITY 1.35"*

Formulae

5.82 A common formula for Polychloroprene or Neoprene is:



5.83 A common formula for Nitrile Co-Polymer is:



5.84 A common formula for Polysulphide Thiokol[74] is:

SH – R – S –(S-R-S) -S-R-SH

R – CH_2 CH_2 OCH_2 OCH_2 CH_2-

[74] Used for FRS seals until 2004.

The Manufacture of the Seals

5.85 On 20 July 1999, the Thales Group[75] acquired a minority stake in Avimo Group Ltd, Avimo Ltd's Parent Company. The Thales Group subsequently acquired the remaining shares between 6 February 2001 and 17 November 2001. Following the purchase, Avimo Ltd was renamed Thales Optronics (Taunton) Limited. In order to distinguish between the former and present guise of the company, I refer to its former and current names, 'Avimo' and 'Thales', respectively, for the remainder of this Chapter. It should be noted that, in November 2007, the aerospace component business of Thales was sold to a new company known as Taunton Aerospace Limited (Taunton), by way of a management buy-out and asset sale. Taunton is therefore the current manufacturer of the Avimo seals but had no involvement in any Avimo seals supplied to the MOD until 2007 (*i.e.* after the loss of XV230 on 2 September 2006).[76]

5.86 Given that the Thales Group did not acquire any interest in Avimo until 1999, it proved difficult for Thales to locate documents relating to the provision of the Avimo seals prior to that date. However, as a result of investigations by Thales and Taunton, the Review has learnt that, from an unknown date (but at least from 1994 until 1999) the material for the Avimo seals was sourced from Dunlop. The material formulation of those seals is unknown and Thales was unable to locate any contract relating to the supply of the seals by Dunlop.[77]

5.87 From about May 2000, the manufacture of the Avimo seals was sub-contracted by Avimo (later Thales) to a company known as Cellular Developments Limited (Cellular). Cellular is a very small rubber component manufacturing company based near Petersfield in Hampshire. The company started business in 1982 and is family-owned. It has some 22 employees and a modest turnover. It produces thousands of different lines each year, often with very small order quantities. It specialises in sponge and solid rubber mouldings and extrusions, rubber to metal bonded products, gaskets, and specialist rubber products used in a variety of different applications including lighting, domestic appliance and optical engineering products. It has been registered to British Standard ISO9002 since 1998.

Change in the compound used in Avimo Seals in 2000

5.88 Cellular first received an order from Avimo (as it then was) to supply the rubber component for 475 Avimo seals of varying sizes from 0.5" to 3" on, or about, 5 May 2000. The order was accompanied by a copy of the Avimo Drawing, discussed above, but Cellular was not informed of the intended use of the seals. Cellular explained to the Review that the information contained in the Avimo Drawing did not provide enough information from which to make a rubber compound. Cellular considered that the only material specification on the Avimo Drawing with any meaning was the hardness requirement of 60/65 and the choice of polymer, Neoprene. It therefore selected a standard, good quality Neoprene that it kept in stock, which was to a British Standard, and which met the hardness requirement (see further below).

5.89 Cellular's internal development processes require that it manufacture samples of material and submit them to the customer for approval prior to production. Its Initial Sample Inspection Report (ISIR) was duly submitted to Avimo on, or about, 19 May 2000. The ISIR specifically gave the hardness requirement of the material as 60 but made no reference to the carbon content of the material. It did, however, state on its face *"NEORPRENE TO DRAWING SPECIFICATION"*. Avimo approved the sample by signing and returning the ISR to Cellular, following which Cellular duly fulfilled Avimo's order.

5.90 Between 2002 and 2007, Cellular received further similar orders from Thales for more rubber Avimo seals of varying sizes. These orders were also fulfilled by Cellular. The material used remained the same as that approved under the ISIR in 2000. In respect of each new part number ordered by Thales between 2002 and 2007,[78] Cellular submitted a further ISIR, in materially identical terms to those I set out above. All orders were

[75] Known at the time as the Thomson Group of companies (later the Thomson-CSF Group before becoming the Thales Group).

[76] It should also be noted that, pursuant to the Business Sale Agreement (BSA) between Thales and Taunton, only continuing supply contracts were transferred and it would appear, both from the list of customer contracts at Schedule 1 to the BSA and the documents held by Thales and Taunton, that no supplies of the Avimo seal pursuant to the Avimo Drawings were being made to the MOD at the time of the BSA.

[77] The only documents located were a limited number of Purchase Orders from Thales to Dunlop dated between 12 December 1992 and 30 September 1999.

[78] The original Avimo Drawing specified 15 parts of different dimensions.

accompanied by a 'Certificate of Conformity' which comprised the following signed short statement at the end of the batch document: *"Certificate of Conformity: It is certified that the supplies detailed hereon have been manufactured, inspected and tested in accordance with the conditions and requirements of the purchase order and unless otherwise noted below, conform to the specification(s) relevant thereto..."*

Non-conforming – only 50% 'carbon black' content

5.91 In fact, Cellular manufactured the batches of seals supplied to Avimo/Thales from a material known as ZCOM 533 Polychloroprene. ZCOM 553 is a standard Neoprene conforming to BS 2752 and which does meet the hardness criteria prescribed in the Avimo Drawing.[79] Subsequent investigation has revealed, however, that ZCOM 553 contains 53.5 parts carbon black filler (more particularly 53.5 parts of N550 FEF (Fast Extension Furnace) carbon black) per 100 parts of polymer (being general purpose slow crystallising polychloroprene),[80] compared with the 100 parts specified on the Avimo Drawing. The seals manufactured by Cellular therefore had only about 50% of the carbon black content specified in the Avimo Drawing.

5.92 During the course of investigations by the Nimrod IPT in September/October 2008, Cellular explained that it would have been unable to meet the rubber hardness requirement called for by the Avimo Drawing using the prescribed proportions of carbon black. Investigation by QinetiQ subsequently revealed that Avon mixture *"No. 18 x 5"* referred to in the Avimo Drawing contained a carcinogen which the Avon Rubber Company had banned in 1964. A distinguished expert from the MOD Materials Integrity Group (MIG) further confirmed to the Review that the 'recipe' prescribed in the Avimo Drawing was very much a product of its time and that it would not be easy to replicate it today for two reasons: (1) some of the additive chemicals used in 1947 are no longer readily available; and (2) health and safety legislation has limited the use of some of the component materials (*e.g.* those in the Avon mixture) because of their carcinogenic effect. Indeed, the MIG expert was not sure that it would be possible today with modern ingredients to manufacture a workable chloroprene mixture containing 100 parts carbon. He informed the Review that Neoprene with 100 parts carbon black content is no longer manufactured and the maximum level found is about 60 parts carbon black.

5.93 It was the MIG expert's view, which I accept, that changing the carbon black content of the mixture from 100 parts carbon to 53.5 parts carbon led, in effect, to the creation of a different material. He explained that the 'filler' in an elastopolymer is fundamental to the way the compound performs. He said the 100 part carbon requirement in the Avimo Drawing imparts two properties: first, the polymer's hardness; and, second, its tensile strength. Altering the amount of filler to such a significant degree as 50% will have an impact on the amount that the material swells when exposed to various fluids and also an impact on its compression set and stress relaxation. He explained that the significantly lower carbon black content in the seals manufactured by Cellular would therefore have given those batches of seals markedly different fluid absorption, stress relaxation, and compression set characteristics, which would have made them more prone to swelling and splitting and to reduced fatigue life. It seems likely that a significant proportion of the splitting, pitting, and premature deterioration of the Avimo seals discovered by QinetiQ in late 2008 was a direct result of Cellular's use of this raw material.

5.94 The MIG expert's views accord with the results of tests carried out by QinetiQ in about September/October 2008 using Gas Chromatography–Mass Spectrometry on unused Avimo seals. These tests identified chemical differences between seals manufactured in 1982 and 2007. Fuel swell tests carried out on the seals further showed significant swelling of the seal material in F34 fuel of the order of 33% volume for 100 parts carbon black and 38% volume for ZCOM 553. QinetiQ concluded that swelling of the seals was a significant factor in the cause of the mechanical damage observed in Avimo seals removed from the Nimrod fleet. Following swelling of the seal, the clamshell portion of the Avimo coupling prevented the seal from expanding outward and forced the seal to extrude into the gap between the pipes, causing buckling and creasing of the seal. The seals would then be more prone to mechanical fatigue and pinching from relative movement of the pipes, leading to premature failure by bulging and splitting.

[79] See Cellular's Material Test Report, dated 27 July 2005, discussed further below.

[80] As per the certificate of Ferguson Polymer Limited, provided to the Review by Cellular.

The Procurement Process

5.95 In view of the non-compliance of the Avimo seals manufactured by Cellular with the Avimo Drawing, the MOD instigated an investigation into the procurement process for Avimo seals. The results of that investigation have revealed that it is far from being straightforward, or even seemingly logical, and raise a number of serious questions about the MOD's procurement processes in general. I turn to consider this below.

5.96 Prior to the formation of the Defence Logistics Organisation (DLO) in 2000, each Service largely procured its own spare parts. This was certainly the case for RAF aircraft spares. The DLO was intended to improve the efficiency of the support to the Armed Forces by adopting common procurement processes and by removing duplication/triplication of effort (see further **Chapter 12**). As part of this drive to uniformity and creating "purple"[81] organisations, the management of some aircraft spares which had previously been under the strict control of the RAF's own organisation was transferred to non-air systems organisations, the most notable being the 'Non-Project Procurement Organisation' (since disbanded), and in the main subsumed within the Medical and General Stores IPT (M&GS(IPT)).

Convoluted Procurement chain

5.97 Avimo seals are purchased on behalf of the MOD by the M&GS IPT[82]. Management[83] of the Avimo couplings and seals is undertaken by the Aircraft Commodities IPT.[84] The Review was informed that this arrangement is used because the M&GS IPT (unsurprisingly) does not have the relevant engineering/airworthiness expertise needed.

5.98 The current Project Engineer (PE)[85] responsibility for the Nimrod lies with the Nimrod IPT Safety Engineer. The Engineering Authority (EA)[86] responsibility for the Avimo couplings and seals prior to fitment, however, lies with the Aircraft Commodities IPT Leader. The flowchart below provides an overview of the engineering responsibilities for Avimo seals.

5.99 The Procurement chain for sourcing Avimo seals is convoluted.

[81] A 'Tri-Service' organisation.

[82] Formerly the Non Project Procurement Organisation (NPPO).

[83] Management in this context is defined as the provision of engineering, commercial, finances, quality assurance and administrative services for the support of the relevant equipment and consumables.

[84] Formerly known as the Aircraft Support IPT.

[85] JAP 100A (Issue 8, April 2008) defines the Project Engineer as *"the lead engineer within an IPT (may be the IPT Leader) who is a suitably qualified and experienced aircraft engineer specifically assessed by the Airworthiness Competency Set (ACS) and evaluated by the Aviation Flight Test Regulatory Authority (AFTRA) prior to being duly authorised by the IPTL by the issue of a Letter of Authority (LOA)"*. PEs advise their IPTL on the adequacy of the Generic Aircraft Release Process (GARP), Release to Service (RTS) or Military Aircraft Release (MA Release) as appropriate and assist their IPTL in ensuring compliance with airworthiness regulatory requirements. Specifically, PEs are authorised, as described in JSP 553, to issue RTS Recommendations (RTSR) to the RTS Authority (RTSA).

[86] JAP 100A-01 (Issue 8, April 2008) defines Engineering Authority as *"The engineering staff responsible, usually to the IPT Leader, for exercising engineering judgment in managing those support functions that have a bearing on the safety of a range of aircraft or other technical equipment."*

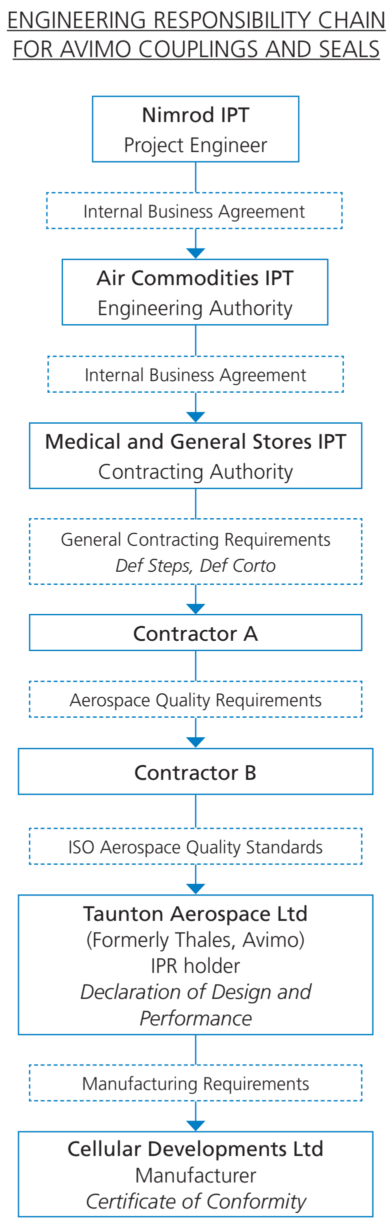


Figure 5.11: Current Engineering Responsibility Chain

5.100 Avimo seals are purchased by the M&GS IPT pursuant to a tri-service partnering arrangement for the supply of general engineering hardware concluded with a defence contractor (Contractor A) in 2002 (Contract NPPO/CB3/0002). Prior to the granting of this contract, a list of 'air use' items managed by the Aircraft Commodities IPT was notified to the M&GS IPT by the Aircraft Commodities IPT, and placed on an annex to the contract's 'Statement of Requirements'. The 'air use' attributes were required to be confirmed by 'Certificates of Conformity' accompanying the items from the 'True Manufacturer' to the supplier. This was attached to the invitation to tender for the contract, together with a list of 18 Aircraft General Spares (AGS) suppliers, known to the MOD. Pursuant to the contract as concluded, in order to preserve the airworthiness requirements of the air use items, M&GS IPT mandated Contractor A to use a specific company (Contractor B) for the supply of suitably certified aviation parts. Contractor B is a competent ISO 9001:2000 and CAA accredited company fully capable of supplying suitably certified components for fitment to MOD aircraft.

5.101 Contractor B in turn obtained the Avimo seals from Avimo/Thales (also a competent ISO 9001:2000 and CAA accredited company) who, as explained above, sub-contracted the manufacture of the seals to Cellular. The seals were ultimately supplied to the M&GS IPT (via Contractor B and Contractor A). The MG&S has an Internal Business Agreement (IBA) with the Aircraft Commodities IPT, which has an IBA with the Nimrod IPT. The Nimrod IPT then has a contract with BAE Systems, which has contracted with FRA to fit the seals on the Nimrod. The situation is perhaps best illustrated by the following flow chart:

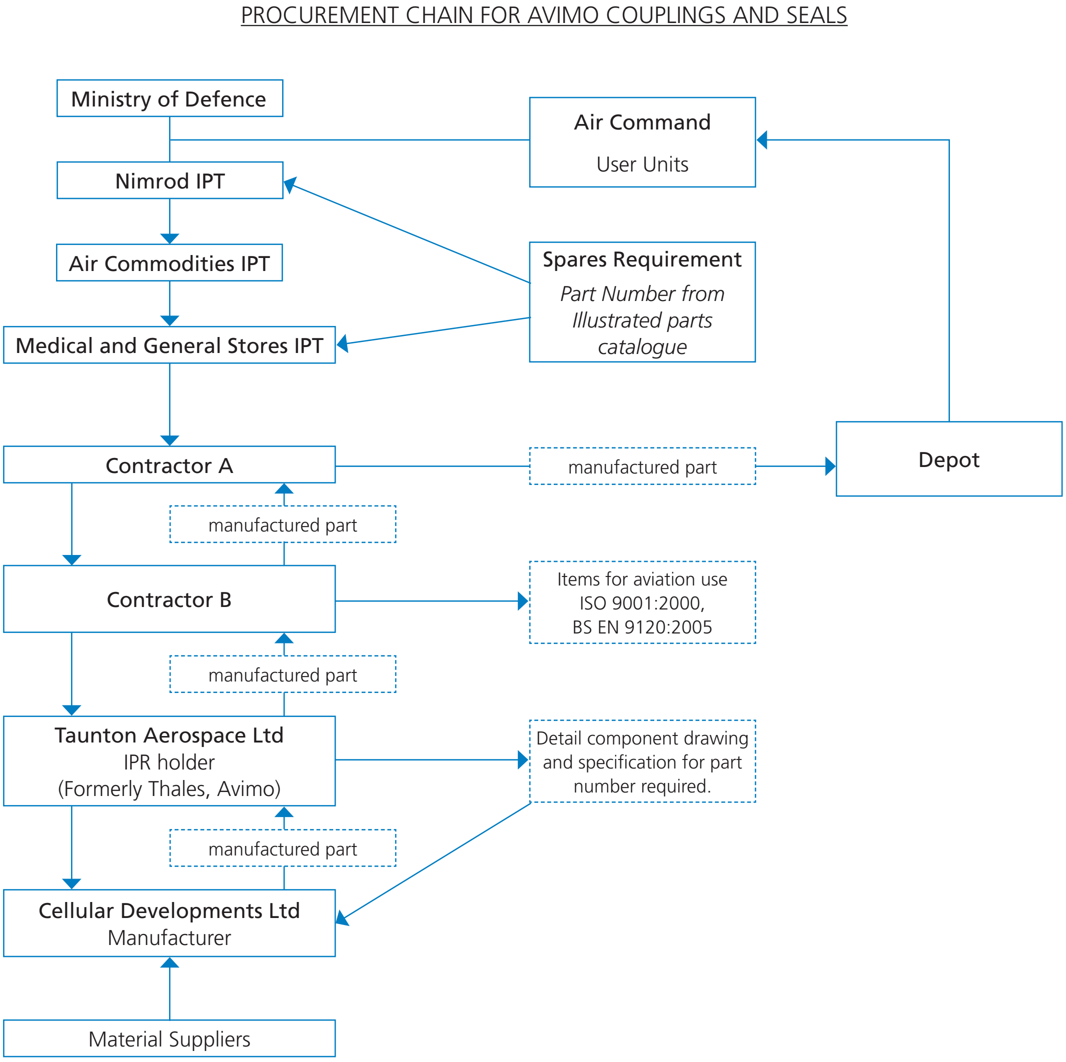


Figure 5.12: Current Procurement Chain

Contractual chain

5.102 The contract between the M&GS IPT and Contractor A[87] (the NPPO Contract) contained comprehensive instructions and detailed information on the quality standards required and the procedures for the supply and alternatives, by concessions authorised by the MOD, both in its text, and in the standards and terms and conditions invoked by it.[88] It also clearly provided for the totality of the requirements to be passed down to any sub-contractor utilised by Contractor A (section 7.4.3).

5.103 Whilst a copy of the relevant contract was not seen by the Review, the Review was advised that Contractor A did seek to pass down the Quality Assurance (QA) contract conditions contained in Contract NPPO/CB3/0002 to its sub-contractor, Contractor B, by way of a contract entitled "Multipart Defence Supplies Agreement", which included the relevant QA terms and conditions. Contractor B in turn created a Purchase Order which detailed a limited number of QA requirements, e.g. ISO9000 and shelf-life. The Review was also told that Contractor B maintained a supplier selection process which involved issuing questionnaires regarding company certifications and capabilities.

[87] NPPO/CB3/0002.

[88] See, *e.g.*, section 1.4 on Specifications ("*1.4.2. All Articles and Services to be supplied shall conform in all respects with the Specification*"), section 3.1 on Quality Standards ("*3.1.1. The Contractor shall operate a quality management system in accordance with the requirements of Def Stan 05-92 Issue 2 and it shall be implemented in accordance with the guidelines stated in Def Stan 05-94 Issue 3 …*").

5.104 As explained above, Contractor B contracted with Thales, who in turn sub-contracted the production of the Avimo seals to Cellular. Thales' Purchase Orders to Cellular stated as follows: *"THIS PURCHASE ORDER HAS BEEN RAISED TO COVER THE COST OF SUPPLYING THE FOLLOWING ITEM/S STRICTLY IN ACCORDANCE WTH CURRENT DRAWING AND/OR SPECIFICATIONS REQUIREMENTS UNLESS OTHERWISE SPECIFIED HEREIN."*

5.105 Each delivery of seals to Avimo/Thales by Cellular was accompanied by a Certificate of Conformity in the terms set out above. Each subsequent delivery of seals by Avimo/Thales to Contractor B was accompanied by a Delivery Note, which provided as follows: *"Certified that the whole of the supplies detailed hereon have been inspected, tested and, unless otherwise stated, conform in all respects with the requirements of the contract of order. The quality assurance and control arrangements adopted in respect of these supplies have accorded with the conditions of our ISO9001 approval and MOD registration."*

5.106 Each Delivery Note appears to have been stamped *"Q.A. PASSED"*. It is not entirely clear whether this stamp was made by Avimo/Thales or Contractor B upon receipt of the seals.

5.107 Notwithstanding the statements contained in the various Purchase Orders, Delivery Notes and Certificates of Conformity, the fact of the matter is that the Avimo seals supplied by Cellular did not conform to the material specification in the Avimo Drawing. It would appear both that Cellular did not appreciate the significance of this and that neither Thales, Contractor B, Contractor A or the M&GS IPT were ever made aware, or became aware, of the changed composition of the rubber compound used in the Avimo Seals. I set out below my analysis as to where responsibility lies for this failing.

Warning sign in 2005 missed

5.108 Some three years prior to the discovery of the problem in 2008, there was an occurrence in 2005 which is likely to be related to the non-conforming Avimo seals. On 7 July 2005, a Form 760 (Narrative Fault Report) was raised after an Avimo seal (Part No. 52/29B) was seen to swell excessively when immersed in fuel. As a result of this discovery, maintenance personnel at RAF Kinloss conducted informal tests by leaving a selection of seals in a bucket of fuel for a few days. They reported that: *"...the results don't look good. All of the seals have shown signs of swelling! Some have split and blistered"*.[89]

5.109 At about the same time (*i.e.* end of July 2005), the Nimrod IPT, on behalf of the Air Commodities IPT, tasked BAE Systems to investigate the issue, by way of the testing of four seals in order to ascertain if they had been manufactured in accordance with the Avimo Drawing and the Material Specification for ZCOM 533 Polychloroprene (Material Specification) supplied by Cellular,[90] copies of which were sent to BAE Systems. In its written submission to the Review, BAE Systems stated that, following the initial request for assistance from the Nimrod IPT, it informed the IPT that it was unable to execute a comprehensive test programme due to various limitations. Whilst no record of the limitations exists, BAE Systems stated that the limitations were believed to include the short timescale within which a response was required and a lack of capability within BAE Systems to determine all aspects of the specification (such as ozone resistance).

5.110 Amongst other things, the Material Specification provided to BAE Systems identified the hardness of the material as 60+/-5.[91] It contained no reference, however, to the number of carbon parts (used as filler) per 100 Neoprene parts (although this was specified on the Avimo drawing also sent to BAE Systems). The tests conducted by BAE Systems were carried out using aviation fuel AVTUR F34 and involved placing samples of the seals for periods of 74 hours in air at room temperature, in air at 100°C, in fuel at room temperature and in fuel at 100°C. The parameters monitored were hardness, weight and a single dimension (the width). BAE Systems confirmed in its evidence to the Review that the testing did not consider, *inter alia*, the chemical composition of the rubber. Nonetheless, chemical analysis in isolation would not be able to determine the amount of carbon used as filler (it could only determine the total amount of carbon in the compound, some of which would be part of the compound's molecular chain). This could only be determined by discussing the manufacturing process with the manufacturer.

[89] Unreferenced e-mail, dated 25 July 2005, from Nimrod Major Servicing Unit (now Nimrod Servicing Group) to Nimrod IPT.

[90] Dated 27 July 2005 (by hand).

[91] The distinguished expert from MOD Materials Integrity Group confirmed that this does for all practical purposes accord with the 65% hardness requirement laid down in the Avimo Drawing.

5.111 On the basis of the limited testing carried out,[92] in its report dated 16 September 2005, BAE Systems concluded that the results of the tests were *"typical for neoprene under these conditions and give no indications of non-conformance to the supplied specification"*. There was no discussion of, or even reference to, the carbon content of the material. The Air Commodities IPT, for its part, accepted BAE Systems' advice and actioned the MOD Form 761 accordingly; however, it did note that the "*Nimrod EA/DA may wish to consider more fuel resistant material in future*".

Comment

5.112 In my view, these events in 2005 are redolent of the detection of the same inadequacies of the material being used since 2000 to manufacture the Avimo seals as were subsequently discovered by QinetiQ in 2008. Unacceptable swelling and deformity was observed by maintenance personnel at RAF Kinloss in 2005 which led them to refer the seals to BAE Systems for conformity checking. It is likely that this was the same type of swelling and deformity which has recently been observed and traced to non-conforming material. It is regrettable that a more thorough examination of the reasons for the undoubted deterioration of the Avimo seals was not carried out in 2005. BAE Systems was tasked to 'test' the seals to see if they had been manufactured in accordance with the Avimo Drawing and the Material Specification. BAE Systems informed the Nimrod and Air Commodities IPTs that it had been unable to conduct a comprehensive test programme due to various limitations but the results of its limited tests suggested *"typical for neoprene"* (see above). Unfortunately, the matter was allowed to rest there, despite the initial observation of a batch of seals which showed *"swelling"* and were *"split and blistered"*. It is a matter of concern that none of those within the Nimrod and Air Commodities IPTs deemed it necessary to question further. This does not suggest a rigorous attitude.

Current Position

5.113 As a result of the discovery of the non-compliant formula being used for the Avimo seals, the MOD decided to seek a replacement for the Neoprene material and this replacement is now used for all Nimrod Avimo seals. The Nimrod IPT has advised the Review that the material is similar to that used in the FRS seals. An Interim DDP[93] has been issued which sets strict criteria on seal life.

Relevance as potential cause of loss of XV230

5.114 The fact that there may have been Avimo seals fitted in the Nimrod fleet post-2000 manufactured from non-conforming material which had a tendency to degrade and split is obviously significant as a potential cause of the loss of XV230. As mentioned above, the starboard No. 7 Tank Dry Bay has one Avimo seal in the No. 7 tank defuel line located immediately above the SCP elbow. This is one of the pipes that would have been in use and under pressure during AAR.

5.115 It should be noted, however, that none of the seals identified by QinetiQ as having suffered mechanical damage in September/October 2008 were showing any signs of actually leaking at the time of their removal from the aircraft. QinetiQ explained, however, that the reason why these couplings had not failed was because the seals initially tended to split underneath the clamshells and the examples seen had all maintained a seal between the rubber and the clamshell. Depending upon where the failure initiation was, and the speed of propagation, the failure progression could eventually reach the exposed seal between the two clamshell portions, whereupon the seal would no longer be safe and it was simply a matter of time before it failed. None of the seals examined to date had reached this point.

5.116 Since the loss of XV230, there has been more than one incident or Serious Fault Signal which could now, with the benefit of hindsight, be assessed as most likely having been caused by the mechanical failure of an Avimo seal due to the material used in its composition. By way of example, on 25 April 2007, an Annex A to Leaflet 070 was raised regarding an incident on XV236 on 18 April 2007, when an FRS coupling at the No. 7 tank

[92] In their response to the IPT (CHD-TFN-M-ISA-QM-1423, dated 16 September 2005) BAE Systems clearly identified that they were *"unable to execute a comprehensive test programme"*.

[93] Taunton Aerospace DDP4126 Issue2-Interim, dated 3 June 2009.

starboard defuel valve was found to be leaking (categorised as a 'Seep'). On investigation, the seal of a nearby Avimo coupling, (possibly dismantled to allow the FRS coupling to be changed) although not leaking, *"was found to be badly deformed and distorted, suggesting that the seal has been fitted for some considerable time …"*. In my view, an equally likely explanation is that this was, in fact, one of the seals manufactured by Cellular after 2000 from the new, non-conforming material.

Who is responsible for the fact that non-conforming Avimo seals were fitted to the Nimrod?

5.117 A number of questions arise in view of the matters set out above as to the roles and responsibilities of: (a) those manufacturing and/or selling Avimo seals at the time; and (b) those organisations within the MOD responsible for their procurement.

5.118 DE&S Safety & Engineering carried out an audit of the supply chain for the NPPO Contract[94] following the discovery of the non-conforming Avimo seals. The conclusion it reached was that adequate supplier certification and contractual conditions existed for the delivery of the Avimo seals, but only if the processes and controls within those certifications and specific conditions were implemented. The audit concluded that there were four root causes of the provision, delivery and acceptance of the non-confirming seals:

5.117.1 The Design Authority/Rights Holder (*i.e.* Avimo/Thales) did not carry out a review of a very old drawing with a view to its validity and potential obsolescence issues, but continued to place Purchase Orders.

5.117.2 The manufacturer of the items (*i.e.* Cellular) did not declare its inability to produce the items to the contractual drawing in line with the contractual QA requirements placed upon it.

5.117.3 There was a lack of effective, if any, QA review of Cellular.

5.117.4 Contractor A and Contractor B operated at the 'Part Number' level and essentially relied on third party certification and Certificates of Conformity in satisfying themselves that a product met customer requirements. Typically, no product related enquiries were made, e.g. as to obsolescence.

5.119 The audit went on to recommend that the structure of contracts which involve spares of any, but in particular old, designs should have obsolescence management considerations defined.

5.120 I discuss below the extent to which I agree with these conclusions, and where I consider the ultimate responsibility for the provision of the non-conforming seals lies.

Cellular

5.121 I consider first of all the position of Cellular, in respect of whom it seems to me three questions arise.

5.122 First, should Cellular have appreciated that the original order (and subsequent orders) from Avimo/Thales were for aviation use? In my view, no. Cellular was a general rubber manufacturing company and not a specialist aviation supplier. There was nothing in the Avimo Drawing to suggest that the order was for fuel couplings, let alone aviation fuel couplings, or even for aviation use. There was, in fact, very little to indicate what the pipe couplings to which the order related would be used for. There was a reference to *"water, oil & glycol resistant rubber"* in relation to the first category of part number. There was a reference to *"Rolls Royce"* in relation to the third category of part number. But there was nothing in the component drawing to indicate precisely what sort of pipe couplings the second category of part number was for. In these circumstances, in my view, it was reasonable for a general rubber manufacturing company to assume that the order was for a general purpose part, *i.e.* not a 'controlled' part or aviation part. I accept the evidence of Cellular's Managing Director who told the Review that his company had had no idea that the order had been used in aviation until contacted by the Nimrod IPT in late 2008.

[94] DE&S SE DQA FF Audit Report No: 2008-1784-2, dated 28 January 2009.

5.123 Second, can Cellular be criticised for complying with the 'hardness' criteria in the component drawing but not the '100 part neoprene/100 part carbon black' criteria? It appears that Cellular focused on the 'hardness' criteria in the component drawing and paid less heed to the carbon content criteria. In my view, this focus was understandable in the circumstances. 'Hardness' is the key property which defines the tensile properties of the polymer; it is therefore the key attribute which the manufacturer of a polymer, especially a general purpose one, will focus on producing. Once the hardness criterion is achieved, I share the opinion of the MOD's MIG expert that a reasonably prudent manufacturer in Cellular's position would probably consider that they had met the (limited) requirements specified in the Avimo Drawing. That conclusion is reinforced by two factors: first, the fact that this is also what BAE Systems (which does have specialist aviation knowledge) focused on when testing the material in 2005; and, second, the MIG expert's evidence that Neoprene with 100 parts carbon black content is no longer manufactured and the maximum level found is about 60 parts carbon black. In these circumstances, given a reasonable belief that the seals were for general purpose, in my view, a reasonably prudent manufacturer in the position of Cellular could not properly be criticised for thinking that it had reasonably satisfied the specification.

5.124 Thirdly, can Cellular be criticised for not raising a query about the '100 part neoprene/100 part carbon black' criteria with Avimo/Thales at any stage? In my view, whilst Cellular might have raised an issue, a criticism on this basis would be unfair. Cellular was a small, non-aviation specialist rubber manufacturing company unaware that the seals were for aviation use. It was also only charging a very modest sum per seal (varying between £3.35 and £15.00 for the various types of seal manufactured between 2000 and 2007, see further below).

5.125 In summary, therefore, I do not consider that Cellular is properly open to any criticism, and have instead concluded that responsibility lies elsewhere for the fact that the composition of the Avimo seals (as fitted to the Nimrod post 2000) did not accord with the Avimo Drawing.

Avimo/Thales

5.126 The position of Avimo/Thales is potentially more complicated given that, unlike Cellular, Avimo/Thales was aware that the seals were being supplied to the MOD (and hence that they were being used for military equipment). However, like Cellular, Thales was able to point to the fact that the Avimo Drawing contained no mention at all of the seals being an aviation or a 'controlled' part, or indeed any reference to fuel. Thales' Aerospace Division does in fact have its own *"Guide for the Grading and Traceability of Parts and Joints"* procedure, which is mandatory for all Thales' airborne products and which seeks to ensure that specific procedures are followed, so as to ensure compliance with the requirements of Def-Stan 00-970 and Def-Stan 05-123, in respect of *"Identifiable Parts"*[95] and *"Grade A"* and *"Grade B"*[96] parts, respectively. An equivalent company procedure existed at the date of Thales' acquisition of Avimo Ltd.[97] There was, however, nothing in the Avimo Drawing to indicate that the seals should be treated as a controlled part for aviation use and/or that any particular procedures therefore needed to be followed as regards their manufacture.

Inadequacy of the Avimo Drawing as a specification

5.127 In my view, the real root of the problem lies in the fact that the original Avimo Drawing was not in reality a material specification at all, but merely a component drawing. Indeed, as an aircraft specification, it was described to the Review by an expert as *"atrocious"*. It is important for aviation parts that specifications are crystal clear and that the key requirements are spelled out clearly. There should have been a full material specification of the Avon company rubber mixture and the actual polymer. When drawing up a particular specification of this nature, it is necessary to look at the specific requirements of the application which might not be covered in any generic specification. In the present case, the generic specification did not cover details of physical properties required, such as swell limits *etc*. If you purchase an off-the-shelf polymer, this might meet a generic specification but the generic specification might not be sufficient for the specific application. Either the procurer needs to ensure that its requirements are fully articulated in the procurement contract, or it needs to work to some defence standard above the generic one. It should be noted that there is no Defence Standard for polychloroprene.

95 Def-Stan 05-123, Part 2, requires that a list of Identifiable Parts is generated for inclusion with equipment design records. Identifiable Parts are defined as those parts deemed most likely, in the case of a fault, to affect equipment airworthiness or operational effectiveness.

96 Def-Stan 00-970 requires all metallic joints, with the exception of standard or component joints, to be graded A or B. The consequence of grading a part, or joint, 'A' is to invoke airworthiness traceability of the part material and manufacturing process.

97 Company Procedure "Control of Hull Integrity/Quality Assured Items, Identifiable Parts and Grade A Aircraft Parts", dated June 1996.

5.128 In my view, a proper material specification for the Avimo seals ought to have expressly specified: (a) that the part was for use in an aviation fuel system; (b) the key physical properties required; (c) the chemical composition required and actual polymer; and (d) the minimum life required. The original Avimo Drawing was not a proper aerospace specification.

Obsolescence and failure to reassess the Avimo Drawing

5.129 The problem with the Avimo Drawing was compounded by the fact that the inadequate material specification was never clarified at any stage; neither after the original Avon mixture referred to in the Avimo Drawing was banned in 1964, nor after Dunlop stopped manufacturing the replacement material in 2000 and a new manufacturer had to be found. As the audit carried out by DE&S identified, it is a matter of concern that, in the 60 years since the Avimo Drawing was produced, nobody within the MOD, Avimo/Thales, or indeed any of the other parties in the sub-contractor chain (see above), appears to have ever reconsidered whether it was necessary to replace, or at least update, such an old component drawing. More care needs to be taken in relation to old component drawings for 'legacy' aircraft.

Lack of any effective quality control

5.130 The second feature of particular concern regarding the non-conforming Avimo seals is the apparent total lack of any real and effective quality control in the Procurement chain, comprising the M&GS IPT, Contractor A, Contractor B and Avimo/Thales, notwithstanding the various Certificates of Conformity, *etc.,* discussed above. It is not clear, however, precisely who was responsible for what. The Aircraft Commodities IPT had apparently believed that the M&GS IPT had aerospace engineers in their chain and that the M&GS IPT was the QA authority for the Avimo seals procurement contract and were, therefore, managing all aspects of QA.[98] The M&GS IPT, on the other hand, apparently took the view that it only procured for the Aircraft Commodities IPT, and that the Aircraft Commodities IPT were responsible for the QA and Engineering Authority (EA) and Safety Assurance (SA) aspects of the items that they managed. Regardless of who in fact held the QA responsibility, the Aircraft Commodities IPT acknowledged that it was "*extremely unlikely*" that a QA assessment of Cellular had been carried out by either the M&GS IPT or the Aircraft Commodities IPT.

5.131 This would appear to be correct. The evidence provided to the Review suggests that Contractor A, Contractor B and Thales relied simply on sub-supplier controls, which established a capability to produce a type of product, and then relied on the Certificate of Conformity produced by the sub-supplier as evidence of the satisfactory completion of a purchase order. It would appear, however, that Contractor A and Contractor B had no real knowledge of any item they were ordering beyond its part number. In my view, it is plainly impossible for any effective quality control to be exercised without some involvement in, and understanding of, the technical content of an order and a process of checking and sampling where necessary.

5.132 In my view, however, the lack of effective quality control exercised by the companies involved is primarily a consequence of an overly convoluted and inappropriate procurement chain in which the MOD contracting party (M&GS IPT) had no specialist aviation knowledge and the ultimate manufacturer (Cellular) was not even informed as to the intended use of the product.

Price mark-up – 300% to 823%

5.133 As indicated above, the price that Cellular charged Avimo/Thales for the seals varied between £3.35 and £15.00 in respect of different part numbers between 2000 and 2007. The price that Thales charged Contractor B in the equivalent period varied between £8.06 and £100.00. The price ultimately paid by the M&GS IPT was between £15.29 and £123.50.

[98] DE&S(Air)(Wyt)508324/120/1.

5.134 The average total mark-up appears to be in the region of 300% for most parts. However, in the case of one part (MR 7000 52/26), the mark-up was 823%. in July 2004, Thales paid £15.00 per part to Cellular; Thales in turn sold the same part to Contractor B at a price of £100.00 per part in August 2004; and the M&GS IPT ultimately paid £123.50 per part in November 2004. It is very difficult to see what, if any, added value was obtained by the M&GS IPT in paying such a mark-up. Presumably, the comfort that the M&GS IPT thought it was getting was that it was purchasing the seals from an accredited aviation supplier. The reality, however, appears to be that the sub-contractors lower down the chain were, in fact, exercising no effective quality control at all.

Avimo Seals – Conclusions

5.135 It is a matter of very considerable concern that potentially critical non-conforming parts could have found their way into an RAF aircraft.

5.136 This case highlights three serious questions about the procurement process:

5.135.1 First, the dangers of aviation and other specialist parts being sourced along with general spares. This is simply not satisfactory. The sourcing of aviation and other safety critical parts should be in the hands of appropriate specialists. It should not be in the hands of the M&GS IPT;

5.135.2 Second, the importance of ensuring that those contracted to supply aviation parts to the military prepare proper specifications for their sub-suppliers which spell out: (a) the key criteria; and (b) the fact that these are 'controlled' parts for aviation use; and

5.135.3 Third, the importance of ensuring that those contracted to supply the military with spares and parts maintain and implement proper and effective quality control systems in relation to their sub-suppliers.

Causation

5.137 I turn to consider the likelihood of the failure of a fuel seal failure having caused the fire on board XV230 and, if so, whether it is more likely to have been an FRS or Avimo seal.

5.138 In my view, the failure of a fuel coupling is a compelling candidate for the cause of the escape of fuel which led to the fire in the starboard No. 7 Tank Dry Bay. There are eight FRS seals and one Avimo seal located in the starboard No. 7 Tank Dry Bay within inches of the Cross-Feed/SCP duct.

5.139 As a result of AAR, the elements of the refuel system within both the No. 7 Tank Dry Bays would have been pressurised and full of fuel shortly before the fire was detected by XV230's crew. Analysis by QinetiQ for the BOI showed that a leak of such fuel, ignited by the SCP duct, could initiate the fire within the known timescale. It will never be possible to determine exactly which of XV230's couplings it was that leaked. However, the BOI, supported by the long term-Air Accident Investigation Branch and the US Air Force Safety Centre crash investigators (see **Chapter 3**), believe that, if a leaking coupling was the source of fuel, it would probably have been in close proximity to the point of ignition, *i.e.* it would have been one of the fuel couplings in the starboard No. 7 Tank Dry Bay. I agree. This accords with probability and common sense.

5.140 I have spent some time examining Nimrod aircraft in various stages of maintenance at RAF Kinloss and Boscombe Down. Whilst the failure of other fuel couplings located outside the starboard No. 7 Tank Dry Bay remains a possibility, it is quite apparent to the naked eye that the internal leak paths which fuel from such remote failed couplings would have to follow to the ignition point in the starboard No. 7 Tank Dry Bay are, for the most part, tortuous: negotiating numerous structural members and avoiding drain holes. Such obstacle courses make these alternative sources of fuel appear most unlikely. I consider alternative causation theories below.

FRS or Avimo?

5.141 Is an FRS or an Avimo coupling more likely to have been the cause of the fuel leak on XV230? In my view, the probabilities favour an FRS seal rather than the Avimo seal having failed in the starboard No. 7 Tank Dry Bay of XV230 leading to the fatal fire. It is, however, a finely balanced matter. I have come to this view principally for three reasons:

5.140.1 First, there has been recent powerful empirical evidence that FRS couplings can and do suddenly spring major leaks and maintain a flow rate which would provide more than sufficient fuel for the fire observed on XV230. Two instances were recorded on video. In February 2007, the BOI was given a video of a fuel leak on XV250 which was in theatre at the time. In December 2008, a further video was taken of two fuel leaks on XV229. A still from the video of XV250 is set out below.

Figure 5.13: Leaking fuel coupling

5.140.2 Second, whilst it is true that we now know Avimo seals fitted post-2000 are made with non-conforming material which makes them prone to deterioration and splitting, so far, no Avimo seal has actually been found leaking. This may be due to the fortunate construction of the encircling metal flange.

5.140.3 Third, numerically, the probabilities favour an FRS coupling being the culprit on this occasion because there were eight FRS couplings in the starboard No. 7 Tank Dry Bay and only one Avimo seal.

5.142 As I have said, however, this is a finely balanced matter and there is a significant possibility that it could have been the Avimo seal which failed on this occasion, particularly given its prime location immediately above the SCP elbow.

5.143 I deal elsewhere with the question of whether a fuel coupling leak or AAR was the more likely source of the fuel which led to the loss of XV230.

Responsibility

5.144 The MOD must bear a share of responsibility for the probability that the failure of an FRS or Avimo fuel seal contributed to the loss of XV230 principally for three reasons. First, the failure of the MOD to do enough to monitor fuel leak rates over the years. Second, the failure of the MOD to give better guidance for the fitting of couplings and elimination of fuel pipe leaks. Third, the failure of the MOD to give consideration at any stage to a pro-active approach to fuel couplings, *e.g.* a seal inspection and replacement programme, notwithstanding: (a) the five-year inspection regime stipulated in the original DDP for FRS couplings[99] (which was the predicate for stipulating 'indefinite life'); and (b) the substantial increases in the Out-of-Service date of the MR2 fleet as a result of delays in the MRA4 programme.

[99] BOI Report, Exhibit 75.

5.145 The MOD's approach has been characterised by two main features. First, a reluctance to replace a belief that leaks were an inevitable fact of life and that, apart from specific cases,[100] attempts to reduce them, by *e.g.* seal replacements, might even exacerbate the problem (see above). Second, a belief that aircraft were 'leak tolerant', *i.e.* ignition sources had been eliminated, or at least reduced to an acceptable level.[101] This proved to be a tragically unsafe assumption because of the Cross-Feed/SCP duct lurking in the starboard No. 7 Tank Dry Bay which did not meet relevant design standards.

5.146 At the practical level, RAF personnel expended considerable efforts over the years in curing individual leaks, but it appears that at the level of the IPT no-one was consolidating the history of leaks, nor making sufficient efforts to analyse the underlying causes and provide guidance that might have reduced the leak rate.

Leaks can be reduced by pro-active approach

5.147 As to the first belief, the work prompted by the BOI following the loss of XV230 has shown that, with careful application and real focus, there are steps that can be taken significantly to reduce the risk of seal failure, *e.g.* by addressing misaligned couplings which can cause leaks many years after a coupling has been fitted. Further, carrying out detailed investigation has also revealed manufacturing problems, *viz.* the Avimo couplings delivered since 2000 have been manufactured to an incorrect formula. Regrettably, an opportunity to correct this in 2005 was missed, probably because of the lack of focus on the consequences of seal failure. The same lack of focus allowed the earlier 2001 Maintenance Policy Review to be completed without investigating fuel leak rates as a specific issue. The very documents that ground crew were supposed to use to enable the correct fitting of couplings were not only inadequate but also recommended a means of pipe assembly that could impose stress on the fuel system. Curing these faults and weaknesses is possible if a pro-active approach is taken. Moreover, these are simple actions which can be taken at zero, or minimal, cost.

Real ALARP

5.148 In my view, when dealing with a hazard as potentially catastrophic as an airborne fire in an aircraft with no means of ejection or escape, there must be a holistic approach to ALARP, *i.e.* approaching those sides of the fire equation which can be addressed with equal vigour, *i.e.* reducing the chances of ignition sources and fuel leaks.[102]

Postscript

5.149 I understand the pressures and workload that have been engendered post-XV230 on the Nimrod community, and in particular that which has fallen on the Nimrod IPT. It is, however, disappointing to note that even now it can take the Nimrod IPT several months to process reports that have a bearing on flight safety. I refer to the report on the leaks on XV229 the author of which, I understand, worked through the Christmas period so that his report would be available as soon as possible. It is regrettable that, some six months after the issue of the report to the IPT, the IPT had still not commented upon it, nor passed it to the Review as a completed document.

[100] *e.g.* some under-wing leaks, XV249's rash of leaks discussed earlier *etc.*

[101] Three elements are necessary to enable combustion: oxygen, fuel and an ignition source. Remove just one of these and combustion will not occur.

[102] It being accepted that it is physically impossible to eliminate oxygen presence in the majority of circumstances. Removal of oxygen is, of course, the principle behind the final defence against fire: the fire extinguishing system.

Alternative Fuel Source theories

Mr Bell's Alternative Theory - Fuel Leak from No. 3 Engine

5.150 During the Inquest into the loss of XV230, Mr Michael Bell (brother of Flight Sergeant Gerard Bell, deceased) put forward a theory that the source of the fuel for the fire in the No. 7 Tank Dry Bay was from the No. 3 engine bay. Evidence was available that, after the start of the fire, when the aircraft was descending towards Kandahar, the No. 3 engine was operating at a slightly lower HPRPM than the others; the difference being of the order of 7%. This discrepancy was interpreted by Mr Bell as indicating a fuel leak within the No. 3 engine fuel system and, therefore, a possible source of fuel for the fire.

5.151 A number of witnesses were questioned in order to test the theory but the consensus from RAF Flight Engineers, BAE Systems, and Rolls Royce witnesses was that, whilst there could never be conclusive proof of the accident cause because of the lack of physical evidence, this theory represented a much less likely course of events than other scenarios.

5.152 The main weaknesses of the argument are as follows:

5.151.2 First, the path that fuel would have to take to reach the starboard No. 7 Tank Dry Bay from No. 3 engine is not readily obvious, as there is no direct access. Internally, the only realistic route would require the fuel to penetrate the inboard firewall titanium panels (for the most part sealed round their edges) and then, in a sufficient quantity, surmount the lateral members of the Rib 1 landing and the panel at the rear of the Rib 1, before accumulating in the No. 7 Tank Dry Bay. In this case it is also difficult to explain why the fuel would not ignite on the many hot elements in the engine bay, triggering an engine fire. Externally, the fuel from an engine bay leak is most likely to disperse rearwards in the substantial airflow, rather than traverse sideways along the rear spar area and re-enter the No. 7 Tank Dry Bay.

5.151.3 Second, original evidence of the lower HPRPM[103] on No. 3 engine came from the aircraft's accident data recorder, known as the DARU. The recording medium is a continuous loop of wire capturing around 25 hours of data, so information from the previous flight was also available. The reduced HPRPM was also apparent on the data from the previous flight and also in the same part of the flight profile, *i.e.* in the descent from high level with the throttles at idle. Taking this evidence into account, the BOI deduced that, if the reduction had been caused by a fuel leak, it would have been found during the servicing of the aircraft after the previous flight. I agree with that conclusion.

5.151.4 Third, during all other phases of flight, the No. 3 engine was performing normally. Indeed, only minutes before the fire broke out on XV230, the engines had been at quite high power settings during the AAR uplift and no abnormalities were evident to the crew (who commented frequently on the engine power settings). Rolls Royce gave evidence at the Inquest that it was theoretically possible for there to be a leak in the fuel system such that the engine would continue to perform normally. However, this has to be set against the previous occurrence noted above, which clearly did not cause a fire in the No. 3 engine bay; such a fire would be extremely likely if there had really been a large fuel leak.

5.153 In my opinion, Mr Bell's theory of a fuel leak from No. 3 engine represented an attempt by a very experienced aviator to explain what he saw as an anomaly. It is nonetheless my view that there are overwhelming reasons, including physical and expert witness evidence, to discount this theory as not realistic or credible.

The Coroner's Source of Fuel

5.154 The Oxfordshire Assistant Deputy Coroner, Mr Andrew Walker, found the most likely source for the fuel was a leak from the fuel feed system to engine Nos. 3 and 4. Such a leak, he said, would have provided *"a continuous source of fuel"* which would *"travel along the aircraft into dry bay 7"* to the seat of the fire. In my view, this is highly unlikely.

[103] High Pressure RPM.

5.155 The pipes for the fuel feed system to engines Nos. 3 and 4 are located at the leading edge of the starboard wing. For fuel to reach the No. 7 Tank Dry Bay from this point, it would have to have: (a) tracked back some 17 feet; (b) crossed at least 18 lateral members; (c) passed through an almost solid dividing wall; and (d) avoided air vent holes in Rib 1, which would also act as fluid drains, before reaching the point of ignition (see Figure 5.14). Furthermore, the fuel pipe at the wing leading edge has no couplings within the vicinity of the most likely route to the No. 7 tank dry bay; thus, any leak would have to originate from a leak within a pipe, which all the technical experts agree is a much less likely event. Whilst not impossible, this proposal was most improbable, as QinetiQ, the BOI and the AAIB found.

5.156 In my view, the Coroner's finding as to the most likely fuel source did not accord with the realistic probabilities and precluded the potential for AAR to be a factor in the fuel leak (see **Chapter 6**). There are far more probable scenarios, which take account of the fact that AAR was being undertaken at the time.

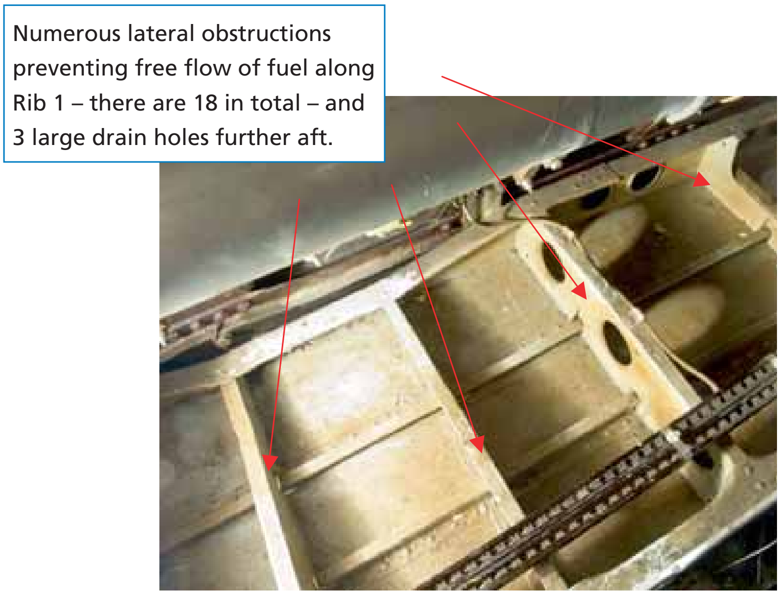


Figure 5.14: Obstructions on the Rib 1 Landing

CHAPTER 6 – OVERFLOW OR PRESSURE FROM AIR-TO-AIR REFUELLING

Contents

Chapter 6 addresses Air-to-Air Refuelling. It answers the following questions:

- What was the history of the Air-to-Air Refuelling modification to the Nimrod fleet?
- How and why did Air-to-Air Refuelling pose a risk to the Nimrod?
- Were the Air-to-Air Refuelling modifications in breach of design standards and regulations applicable at the time?
- Who was responsible for any breaches of design standards and regulations?
- Causation.

Summary

1. The Nimrod MR2 and R1 fleet was first fitted with an Air-to-Air Refuelling modification as an Urgent Operational Requirement for the Falklands conflict in 1982 (Mod 700). A permanent Air-to-Air Refuelling modification was fitted in 1989 (Mod 715). Both modifications were fitted by the Nimrod Design Authority, British Aerospace (now BAE Systems).

2. The fitting of Air-to-Air Refuelling gave rise to three risks which were insufficiently appreciated at the time: (a) the risks associated with fuel being ejected from the blow-off valves during flight and tracking back into the fuselage; (b) the risks associated with an overflow of fuel into the vent system and fuel leaking from the No. 1 tank vent system around the aircraft; and (c) the higher flow rates and the potential for pressure spikes associated with Air-to-Air Refuelling. The cumulative effect of subsequent changes to the Air-to-Air Refuelling sequence and the tanker to be used (Victor, VC10 and Tristar) may have exacerbated (a) and/or (b).

3. The risks posed by blow-off valves operating in flight during Air-to-Air Refuelling and fuel tracking back and entering the fuselage were raised during the Nimrod Mk3 Airborne Early Warning (AEW3) project in the mid-1980s. However, only the risk posed on the port side was addressed and not the equivalent risk on the starboard side. The AEW3 project was shelved and dye tests recommended by BAE Systems which may have revealed the problem were never carried out. The MOD and BAE Systems share responsibility for the failure to follow this up, or to read this knowledge across to the MR2 and R1 fleets.

Responsibility

4. The Air-to-Air Refuelling modification in 1989 (Mod 715) carried out by British Aerospace was in breach of applicable design regulations and standards at the time (Defence Standard (Def-Stan) 00-970) in two respects: (a) regarding blow-off valves being located where discharge of fuel could pose a fire hazard; and (b) regarding fuel pipes being located close to high pressure hot air ducts. In my view, it was British Aerospace's duty as the Design Authority for the type to ensure that Mod 715 complied with Def-Stan 00-970 and validate the refuel system for its new in-flight Air-to-Air Refuelling function. It failed to do so.

Causation generally

5. I am satisfied that the Board of Inquiry was right to find that overflow of fuel during Air-to-Air Refuelling (from No. 1 blow-off valve and/or the vent system) was one of the two most probable likely causes of the fuel which led to the fire on board XV230 (together with a Fuel Coupling Leak,

6. I have concluded that the balance of probabilities favours overflow during Air-to-Air Refuelling being the most likely source of the fuel which caused the loss of XV230 for four main reasons:

   (1) The recent evidence of the fault signal for XV235 which shows that fuel found in the Supplementary Conditioning Pack elbow muff probably originated from No. 1 Tank Cell 4 rear vent.

   (2) The recent careful examination of the No. 1 Tank Cell 4 rear vent confirms the Board of Inquiry's view that it is a poor design for fuel and could leak when under fuel pressure. On the majority of occasions, the vent system will simply carry air but during manoeuvres and Air-to-Air Refuelling, fuel may enter it.

   (3) The recent evidence of the dye experiments on MRA4 which show the likelihood of fuel tracking straight back along the fuselage and entering the SCP elbow and No. 7 Tank Dry Bay.

   (4) The fact that fuel could have emanated from the two sources (the blow-off valve and vent system) *simultaneously* during Air-to-Air Refuelling, with both sources ending up in the starboard No. 7 Tank Dry Bay.

7. It is important to note that much of this evidence is new and was not available to the BOI, the AAIB or the US Air Force Safety Center.

Deployed crew of XV230

8. The deployed air and ground crew of XV230 have nothing to reproach themselves for. The two previous incidents of blow-off on XV230 were sensibly dealt with by imposing a limitation of 15,000 pounds on the No. 1 Tank. The assumption that there was no threat to the aircraft as a result of blow-off operating was perfectly reasonable.

Post accident

9. Air-to-Air Refuelling of Nimrods was suspended following an Air-to-Air Refuelling incident on XV235 in November 2007, and has not been resumed.

Introduction

History of Air-to-Air Refuelling modifications to the Nimrod fleet

6.1 It is important to have a clear and detailed understanding of the history of the Air-to-Air Refuelling (AAR) modification to the Nimrod fleet.[1]

1982: Original AAR modification fitted for Falklands campaign (Mod 700)

6.2 The Nimrod MR2 was converted to enable AAR for Operation Corporate (the Falklands campaign) during 1982, as an Urgent Operational Requirement (UOR) under Modification (Mod) No. 700. The pressing operational requirement to fit AAR meant that there was insufficient time to ensure that the AAR system design met all the requirements of Aviation Publication (AvP) 970.[2] The modification was conceived, fashioned and installed in a record 18 days. However, the refuelling hose from the AAR probe to the fuel system passed through the aircraft cabin requiring the crew to step over it. The Nimrod fuel system was originally fitted with blow-off valves in all but two fuel tanks (the 4A tanks), to ensure that tanks could not be over-pressurised to the point of structural

[1] Annex L of the BOI Report contains a summary of the history of AAR which this Chapter expands upon.

[2] Subsequently Defence Standard (Def-Stan) 00-970.

failure. The blow-off valves operate when tank pressure exceeds 2.7 psi and relieve pressure by releasing fuel to the atmosphere.

6.3 During the original fitting of Mod 700 in 1982, the risk of fuel from No. 5 tank blow-off valve (located forward of the engines on the aircraft's port side) entering No. 2 engine intake was appreciated. This potential hazard was addressed by the fitting of a pressure switch in the vent line of No. 5 tank, to close the refuel valve should fuel enter the vent line. No similar switch, however, was fitted to the vent line of either of the remaining fuselage tanks. Although the Review has been unable to determine the rationale behind this decision, it was probably for similar reasons to those quoted in subsequent reports[3] regarding the formal incorporation of AAR in the Nimrod design, namely that the No. 5 tank blow-off outlet is in front of the engine air intakes, whereas the others are behind them. It should be noted that the refuelling procedure for the original AAR installation required the refuel valves of all the tanks needing fuel to be opened as refuelling commenced and closed individually as each tank filled. This had the effect of distributing the fuel to a number of tanks simultaneously, with a relatively low rate to each one.

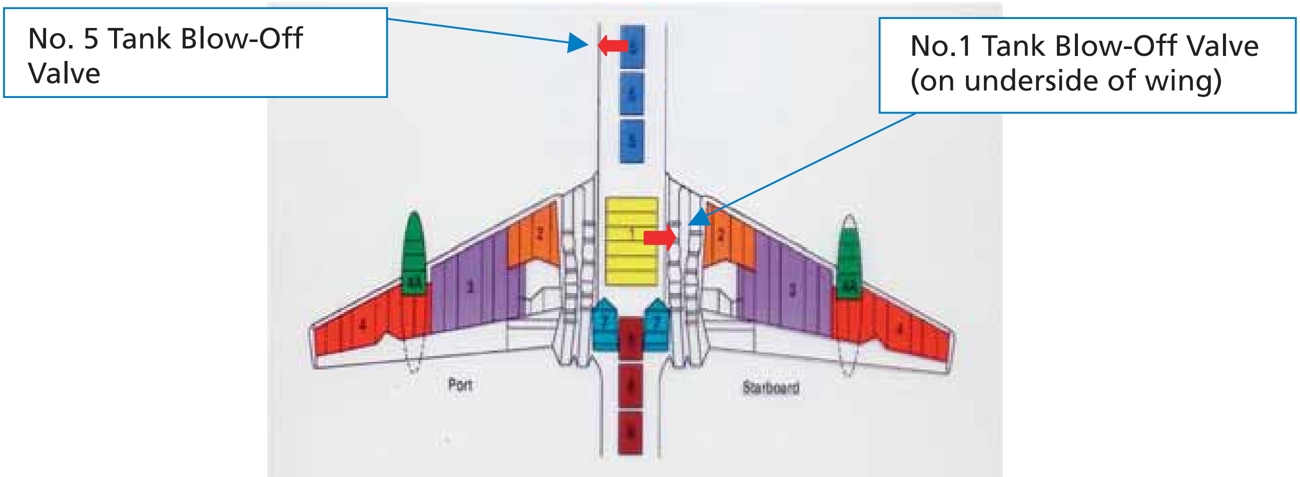


Figure 6.1: Location of Nimrod Fuel Tanks

1983-1985: AEW3 project included fitting of permanent AAR capability

6.4 The development of the Nimrod AEW3 in the mid-1980s allowed the MOD to seek a Nimrod AAR solution that would meet Defence Standard (Def-Stan) 00-970 requirements. Some of the work involved in this redesign can be traced through a series of documents detailing trials undertaken by the then British Aerospace PLC (now BAE Systems) in furtherance of MOD instructions.

6.5 In March 1985, BAE Systems issued a Report entitled *"ALL NIMROD AIRCRAFT REPORT ON INTEGRITY OF TANKS 1 AND 5 BLOW OFF VALVES DURING AIR TO AIR REFUELLING (P.D.S. TASK NO. 0351)"*[4]. Whilst the Report was produced pursuant to Post Design Service (PDS) Task No. 0351 as part of the AEW3 project, it was entitled *"ALL NIMROD AIRCRAFT REPORT…"* and clearly intended to be applicable to the whole Nimrod fleet. The report investigated the possibility of removing the blow-off valves within Nos. 1 and 5 fuel tanks, to prevent the chance of blown-off fuel being ignited by aircraft engines. The report recommended that the blow-off valve from No. 5 tank be removed and replaced with a flow restrictor, to prevent tank over-pressure. This modification was subsequently enacted. It was decided, however, that a similar arrangement within No. 1 tank would prolong AAR unreasonably and that the threat of fuel entering and/or igniting in the jet efflux (rather than entering the intake as with the No. 5 tank blow-off) was minimal. The report did, nevertheless, note that:

> *'… [T]here may be some cause for concern with regard to the wetted surfaces caused by a discharge of fuel and it is suggested that tests are made in flight using a coloured dye to study the behaviour of liquid in relation to the various ports and intakes, particularly the tail-pack pre-cooler in the bottom of the rear fairing. If the liquid is found to enter*

[3] See subsequent discussion.

[4] BAE-MPP-R-AEW-0063 (BOI Report, Exhibit 66).

this intake, it may be necessary either to switch off the tail pack before commencing an air-to-air refuel, or to carry out a modification on the blow-off valve outlets of Tanks 1 and 6 to prevent the fuel running down the skin.[5]' (emphasis added).

6.6 This report was distributed to 11 addressees (10 BAE Systems staff, and the MOD's representative on site – the Resident Technical Officer (RTO)). However, the report's distribution list does not indicate who, if anyone, was supposed to take forward the recommendations, and no evidence has been found that further work was undertaken on the threat presented by fuel entering ports and intakes after blow-off.

6.7 In May 1985 British Aerospace issued a Report entitled: *"NIMROD AEW3 MK 3 TESTING AND ASSESSMENT OF AIR TO AIR REFUELLING SYSTEM",*[6] which summarised a number of ground and air tests of the AEW3 AAR system. The Report also referred to the report discussed above, which it said stated:

> *"4.1 The report also concluded that there may be some hazard from residual fuel running down the fuselage following a blow-off from Tanks 1 or 7, which should be the subject of further investigation."*[7] (emphasis added)

6.8 In July 1985 British Aerospace issued a Report entitled: *"NIMROD AEW3 MK 3 OPERATING INSTRUCTIONS FOR AIR TO AIR REFUELLING".*[8] The report set out operating instructions for the AEW3 during AAR, but made a number of points relevant to AAR operations generally:

> *"3.7.3. During the refuel operation, it is recommended that a look-out is kept through the escape hatch windows for fuel venting, in which case the blow-off valves of Tanks 1 and 7 may have discharged fuel. If venting is seen, and Tanks 1 and 7 are full, refuelling should be discontinued. (see also paragraph 3.13)."*[9] (emphasis added)

> *"3.13. After landing. WARNING If fuel spillage has taken place in flight due to venting or to a probe mishap, do not run the APU until the APU has been inspected and declared clear of fuel."* This highlights continuing concern about fuel entering 'ports and intakes' and reinforces that fuel entering fuselage panels was a possibility, even though the APU external panel lies flush with the fuselage.

6.9 These reports show that blow-off during AAR was recognised as a potential hazard. Although the potential hazard of No. 5 tank blow-off on the port side was dealt with, the hazard from the blow-off from No. 1 tank on the starboard side (and Nos. 6 and 7 tanks) was not. The threat of fuel entering the fuselage compartments was raised, but there is no evidence that it was ever investigated further. It is surprising that there is no record of any decision process which may have curtailed further work on these reports, particularly in view of the clear implications for flight safety.

1987: Changes to Refuelling Sequence

6.10 In a letter dated 15 January 1987,[10] BAE Systems advised the RAF that the extant sequence of refuelling could potentially cause structural problems because of wing bending relief. Following trials, the sequence was changed, such that rather than filling all tanks simultaneously, the wing tanks were refuelled first, followed by the fuselage tanks, once the wing tanks were full.

6.11 It is important to note that this had the incidental effect of increasing the instantaneous flow rate at which individual tanks were refuelled; the significance of this is explained later when the operation of the blow-off valve is discussed.

[5] Ibid, page 6.
[6] HAS MPP F AEW 0065 (BOI Report, Exhibit 6).
[7] The reference to No. 7 tank may been error as the earlier report talked of Nos. 1 and 6 tanks.
[8] HAS MPP F AEW 0068 (BOI Report, Exhibit 58).
[9] This may be a perpetuation of the previous report's error in substituting No. 7 tank for No. 6 tank.
[10] JNG/CSN, dated 15 January 1987.

1989: Mod 715 Installation Changes

6.12 In 1989 Mod 715 was introduced and the features developed as part of the AEW3 program were incorporated on the MR2. In particular, the restricted No. 5 tank refuel valve was introduced. This complicated the refuelling sequence as devised in 1987. To prevent longitudinal balance limits being breached, as No. 6 tank now filled faster than No. 5 tank, the air engineer had to switch the former's refuel valve on and off. No. 7 tanks would reach full before the No. 1 tank and, therefore, on most occasions, the only refuel valves open near the end of an AAR serial would be the two on the No. 1 tank and that on the restricted No. 5 tank.

6.13 The net effect of this was to increase substantially the instantaneous flow rate of fuel into the No. 1 tank during AAR.

6.14 Formal trials[11] were conducted to ascertain the functionality of the Mod 715 changes. However, the bowser used to provide fuel for the practical test of the AAR system was unable to deliver fuel at more than 30psi. The trials team extrapolated figures to calculate fuel flows at 50psi. A direct result of this was that the opportunity possibly to observe No. 1 tank blow-off was lost. In their response to this suggestion, BAE Systems said that the above report[12] showed the bowser pressure at 50psi for the last two minutes of the 25 minute trial and therefore that the opportunity to observe No. 1 tank blow-off was not lost. However, blow-off would be dependant on the higher rate of refuel at 50psi being present for the majority of the refuel to induce asymmetric filling of individual cells, which it was not in this case.

1989: Introduction of the Tristar Tanker

6.15 Until 1989, the Nimrod had refuelled primarily from the Victor and VC10, each with a single Hose Drum Unit (HDU) capable of delivering up to 1,800kg per minute. In 1990, the Tristar was converted to be a tanker aircraft and was cleared to refuel a variety of receivers, including the MR2. The Tristar's twin HDUs each delivered fuel at a greater rate (2,100kg per minute) than its predecessors because of the addition of two hydraulically driven Carter pumps. Trials for the Nimrod to receive fuel from the Tristar were completed in 1989. A fuel flow rate of 2,100kg per minute was achieved for the Nimrod.

6.16 The additional delivery capacity of the Tristar Carter pumps represented another potential increase in the individual tank refuel rates and increased further the potential for asymmetric filling of No. 1 tank.

Cumulative effect of changes ignored

6.17 The combined effect of these changes was to increase the flow rates at certain stages of AAR, and particularly during Tristar AAR. As the BOI found, at no stage were the cumulative effects of successive changes to the Nimrod AAR capability understood and analysed. As the RAF Kinloss Station Commander put it, at no point was *"a holistic view"* taken of the incremental effect of the changes.

2008: Prohibition of AAR on Nimrods

6.18 A year after the loss of XV230, on 5 November 2007, Nimrod XV235 diverted into Kandahar airfield following a leak in the bomb bay which occurred during AAR. The leak had been observed by the crew through the periscope that is fitted to allow aircrew to survey the bomb bay area in flight. The leak could not be replicated on the ground, despite many attempts. As it was no longer possible to state that leaks which might occur during AAR would be detected on the ground, AAR on Nimrods was prohibited by AOC 2 Gp and this has now been incorporated formally within the Nimrod's Release to Service documentation.

[11] British Aerospace Report HAS-MPP-T-801-0273 "Ground Test of the Air to Air Refuelling System", dated May 1988.

[12] Ibid, Figure 1 (footnote 7).

Analysis

6.19 The modification of Nimrods to take AAR gave rise to three particular risks associated with:

(1) The operation of tank blow-off valves in flight;

(2) Overflow of fuel from the No 1 tank vent system; and

(3) Higher flow rates and the potential for pressure spikes.

(1) The operation of tank blow-off valves in flight

6.20 The potential for blow-off to be the source of fuel for XV230's fire was first prompted by witnesses to the BOI, who stated that, on one occasion before its loss, the aircraft had returned from a sortie with evidence of a crescent shaped stain on the fuselage, which indicated that fuel had been ejected from the aircraft's No. 1 tank blow-off valve at some stage in flight. Fuel was also detected in the bomb bay. Following discussions with the air engineer on that sortie, it was deduced that the blow-off valve must have operated during AAR. The Air Engineer from the previous sorties had noted that the No. 1 tank appeared to stop filling at 15,000lbs, and subsequently used that figure as a self-imposed limit.[13] For these reasons, the BOI quite rightly considered blow-off as a possible source of fuel for XV230's fire and that it should be investigated.

6.21 When analysing the risks associated with the operation of blow-off valves in flight, it is important to ask the following four questions:

(1) Is blow-off likely to occur during AAR?

(2) If blow-off occurs during AAR will fuel track along the fuselage or be blown clear of the airframe?

(3) Could blown-off fuel enter fuselage panels, ports and intakes?

(4) Could blown-off fuel enter the SCP fairing and the No. 7 Tank Dry Bay?

6.22 I consider these questions in detail below:

(a) Is blow-off likely to occur during AAR?

6.23 The blow-off valves were designed to cope with a tank overpressure during ground refuelling, when any fuel blown-off would simply fall onto the tarmac. However, refuelling in the air was a different matter. During AAR, blow-off valves posed a potentially significant hazard because of their location on the sides of the fuselage of the aircraft by reason of the fact that excess fuel blown out could track back and enter intakes, vents, and other apertures in the fuselage further aft.

6.24 The BOI concentrated its efforts on the potential for blow-off from No. 1 tank, as it considered this one of the two most likely sources of fuel for the fire that led to XV230's loss. A brief summary of the BOI's explanation for No. 1 tank blow-off follows, but a more complete explanation can be found within the BOI Report at Annex N.

No 1 tank blow-off mechanism

6.25 The No. 1 tank is the main fuel tank within the fuselage and holds 16,000lbs of fuel. The fuel is held in four inter-linked rubber bags, each contained within a metal cell; the four cells are numbered one to four from front to rear. Fuel enters No. 1 tank through two refuel valves in Cell 3, and when it reaches the level of valves connecting it to Cells 2 and 4, flows into those cells. Fuel from Cell 2 flows into Cell 1 through two much smaller holes and consequently the four cells fill at different rates as shown in the diagram below, with Cell 1 lagging well behind the other three Cells. Float switches to automatically stop refuelling are placed in Cells 1 and 4 and operate automatically when the fuel in these cells reaches their level; both float switches have to operate to close the refuel valves and automatically stop fuel flow. The blow-off valve for No. 1 tank is in Cell 3.

[13] BOI Witness 22.

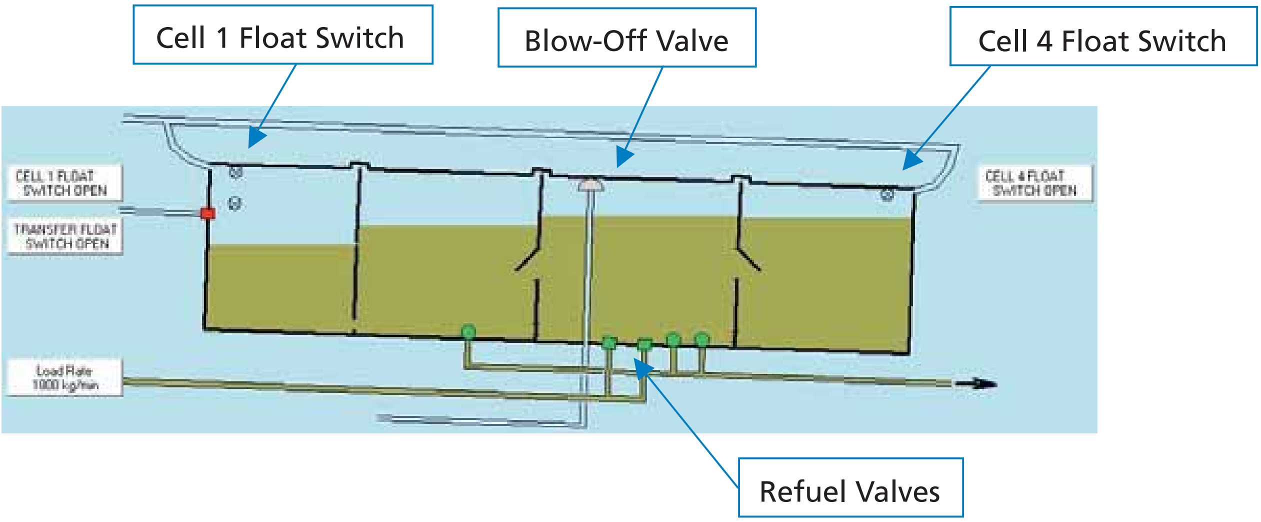


Figure 6.2: Screen Shot of HAL Model

6.26 The BOI commissioned Hydraulic Analysis Limited (HAL), a firm experienced in analysis of pipeline system pressures for the oil industry, to construct a computer model of the No. 1 tank.[14] This showed that because of the way in which the individual cells of the tank filled and the relatively high fuel flow rates during AAR,[15] it was likely that, as its contents reached approximately 15,000lbs, the three rear cells would be full, but not the forward Cell 1. Most importantly, the float switch in Cell 1 would not have closed and so fuel would still enter Cell 3. This, in turn, would cause the pressure in Cell 3 to rise and activate the blow-off valve. At this point, fuel would also have entered the vent pipe. It should be noted that the connection to the vent pipe from Cell 4 to the main aircraft vent system is located above and close to the No. 7 Tank Dry Bay; the significance of this is discussed later.

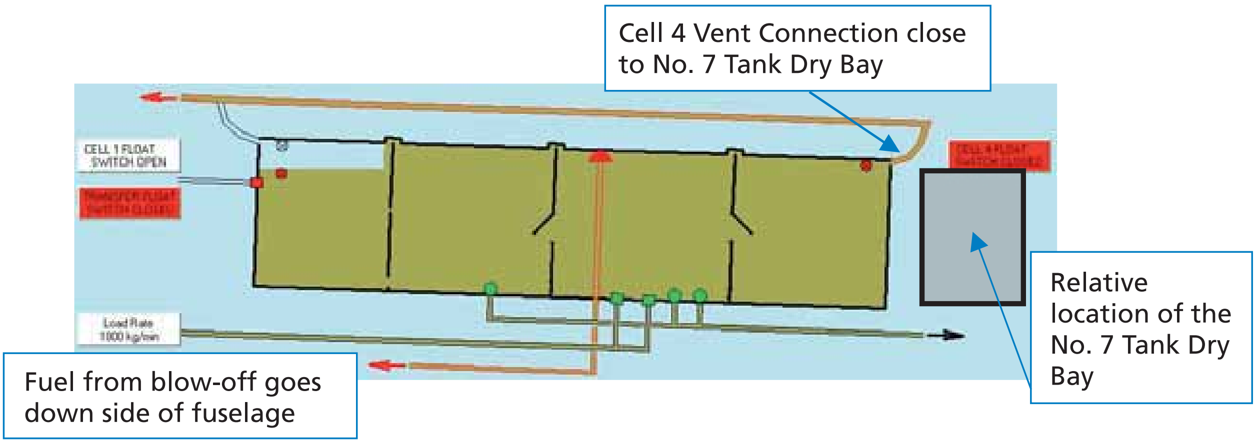


Figure 6.3: Screen Shot of HAL Model

6.27 During ground refuelling maintenance personnel take specific action to prevent blow-off occurring by reducing fuel delivery pressure as the fuel load approaches full.[16] Nonetheless, despite these precautions, blow-off has been seen to occur on the ground. No. 1 tank blow-off will occur in the air during AAR if the same conditions of overpressure are reached; indeed the BOI, in conjunction with HAL, showed that the higher delivery flow rates during AAR, combined with the design of the No. 1 fuel tank, meant that blow-off from the No. 1 tank was *likely* during AAR, should the No. 1 tank be filled or almost filled. Further, I should point out that the model proves that blow-off could occur at the 15,000lbs target the Air Engineer was aiming for, i.e. even if the

[14] BOI Report, Annex N. The BOI point out that until recent Gulf operations the Nimrod rarely filled to full during AAR.

[15] As previously discussed the change to the AAR uplift sequence in 1987 had increased fuel flow rates to individual tanks, and in particular the No. 1 tank.

[16] In the case of the aircraft's main fuselage fuel tank (No. 1) the engineers use a fuel leveling device to further reduce the possibility of blow-off.

limitation was adhered to precisely.[17] This fact was confirmed for the BOI independently by BAE Systems in a written submission.

6.28 There is no specific indicator to the crew inside the Nimrod that blow-off is occurring. The original design concept was of course that it would only occur on the ground, where its occurrence would be plainly evident and not a problem. Nonetheless, the Nimrod Air Engineer may become aware of blow-off by an unexpected reduction in AAR flow rates.

2006: Nimrod + VC10 tanker blow-off

6.29 There is one relatively recent example in which blow-off during AAR probably occurred. In late 2006, a Nimrod refuelling from a VC 10 tanker noted that, as the No. 1 tank reached 12,000lbs, venting occurred and the fuel flow rate diminished;[18] additionally the tanker calculated that it had passed significantly more fuel to the Nimrod than the Nimrod calculated it had received. On landing, the Nimrod's fuselage, from the rear of the bomb bay to the tip of its tail, was found to be covered in fuel and fuel was found 'pooled' in the rear element of the bomb bay structure, the 'rear hinged fairing'. Although at the time no convincing explanation for the fuel leak could be determined, it was subsequently discovered that the 'clack' valve between two of the No. 1 tank cells had been incorrectly fitted and operated in the reverse sense; this made it impossible, in flight, for fuel to enter the No. 1 tank Cell 4. Thus, the effective capacity of the tank was reduced to 12,000lbs. This was the point at which venting had been observed and No. 1 tank blow-off probably occurred. This sortie was the first occasion that this aircraft had undertaken AAR following a Major maintenance. Subsequently a 10,000lbs limit was placed on all Nimrod No. 1 tanks during AAR. As a result of this, the fault with the No. 1 tank valve was not finally revealed until the aircraft returned to the UK for maintenance.

6.30 I am satisfied, in the light of the work of the BOI and HAL, that blow-off will occur both on the ground and in the air should the right conditions occur. The fuel modelling undertaken by the BOI used data from the accident data recorder to demonstrate that No. 1 tank blow-off was possible under the flight conditions and fuel configuration of XV230. In particular, the attitude data was used as an input parameter to the HAL fuel model to explore the effect that varying degrees of pitch (nose up or down) would have on the moment when blow-off would occur. Evidence from the Tristar crew was used to establish the rate of refuel of XV230.[19] The results were tabulated in the BOI[20] and support the theory that blow-off was possible on XV230 within the time scale extracted from the mission tape.

(b) If blow-off occurs during AAR will fuel track along the fuselage or be blown clear?

6.31 The 2006 Nimrod with VC10 tanker blow-off incident referred to in the preceding section demonstrates one recorded occasion on which fuel blown off during AAR tracked back along the fuselage.

1985: AEW3 dye tests recommended

6.32 It is important to note that the risks posed by blow-off valves operating in flight during AAR, causing fuel to track back and enter apertures in the fuselage, were appreciated by British Aerospace (now BAE Systems) back in the 1980s when the original and subsequent permanent AAR modifications were being planned. As explained above, however, only the risk posed on the port side by the blow-off from No. 5 tank was addressed by modification.

6.33 Recommendations were made to investigate the potential hazard from fuel being blown-off from Nos. 1 and 6 tanks, including recommendations for possible AAR procedural changes (such as switching off the SCP for AAR) and a possible modification to the blow-off valve outlets. In particular, in 1985, BAE Systems recommended that

[17] BOI Report, Exhibit 71.
[18] Air Incident Report KIN 066/06.
[19] BOI Witness 31.
[20] BOI Report, Annex N.

investigations be carried out by way of in-flight dye tests. Unfortunately, it appears this was never followed up following the subsequent shelving of the Nimrod AEW3.

6.34 This was regrettable. Such dye tests would very probably have led to a realisation of the risks posed by the starboard blow-off valve. In this regard, I agree with the comment on the BOI by the Air Member for Materiel: *"It is particularly disturbing that the undesirable overflow characteristic of the AAR system design appears to have been identified during development trials in the mid 1980s for the Nimrod Airborne Early Warning (AEW) aircraft, yet (although corrective action was taken for No 5 Tank) no corrective action was taken for the No 1 Tank despite recommendations that it be investigated further."*[21]

6.35 If the dye test had been carried out, it is likely that, not only would the risk of fuel possibly tracking back into No. 7 Tank Dry Bay have been identified and addressed, but it is also possible that the ignition risk posed by the SCP elbow would have been highlighted by the dye penetrating the 'muff' insulation and, thus, the danger posed by the bleed-air system exposed.

6.36 In my view, responsibility for failure to follow up the question of dye tests after 1985 or read across this issue to the MR2 and R1 fleets must be jointly shared by BAE Systems as the Design Authority (DA) and the MOD.

2006: Dye tests for MRA4

6.37 Dye tests were, however, carried out by BAE Systems in 2006 in relation to the MRA4 programme,[22] and these have provided clear visual evidence of the manner in which liquid expelled from an aircraft can cover a significant area.

6.38 Flight tests were conducted on the MRA4 prototype PA3 in June 2006 to check whether water discharged from the forward and aft waste water drain masts would track back and impact on the wings and fuselage causing an ice problem. The test was carried out by pouring 0.5 gallons of coloured fluid into both the toilet and galley waste water systems during flight and evacuating it. The colour of the fluid, 'Desert Sand',[23] provided a strong contrast with the standard Nimrod grey external paint scheme. The test on the forward mast was carried out just prior to landing at a speed of 192 knots for the forward mast and 170 knots for the rear mast. This speed range was calculated as most likely to allow fluid to impact the aircraft fuselage. The aircraft avoided cloud and rain following the trial to prevent the dyed fluid being washed off.

6.39 After landing, a photographic record was made of all the areas where the impingement of fluid on the wings and fuselage had occurred. The results are instructive. They show the fluid fanning out and tracking back over and under the wing and entering parts of the fuselage. The toilet mast protrudes several inches from the aircraft. A boundary layer of air exists close to the aircraft structure. The air immediately proximate to the aircraft structure will travel at an extremely slow speed because of surface friction, relative to the aircraft, but this speed will increase as the distance from the aircraft structure increases, until the air is travelling at the same speed relative to the aircraft as the surrounding free-flow air. The thickness of this boundary layer varies, but is of minimal width. The significance of this is that the mast from the forward toilet protrudes directly into this free-flow air. Despite this, the fluid had clearly impacted the aircraft fuselage, as can be seen from the photograph below. The blow-off outlet of No. 1 tank is flush with the aircraft fuselage. Fuel exiting the blow-off will have to negotiate the boundary layer before it reaches the free-flow air. Thus, it would appear even more likely to track along the fuselage. It should be noted that there would be significantly more fuel involved in blow-off than liquid in this experiment. Furthermore, the higher speeds which the aircraft would be flying during AAR would make it more, not less, difficult for the fuel to reach the free-flow air. As BAE Systems' witnesses have made clear, the diagrams supplied to the BOI[24] reflect the flow of air around a particular section of the fuselage, rather than any likely fluid flow. That the fluid flow is likely to be more complex is suggested by the wide dispersal of the dyed fluid in the photographs below.

[21] Comment on the BOI by the Air Member for Materiel, Air Marshal Sir Barry Thornton dated 8 October 2007.

[22] BAE/D/NIM/RP/173496 and BAE/P/NIM/RP/162811.

[23] The fluid used was temporary camouflage coating (1314GB0361E) diluted with water.

[24] BOI Report, Exhibit 60.

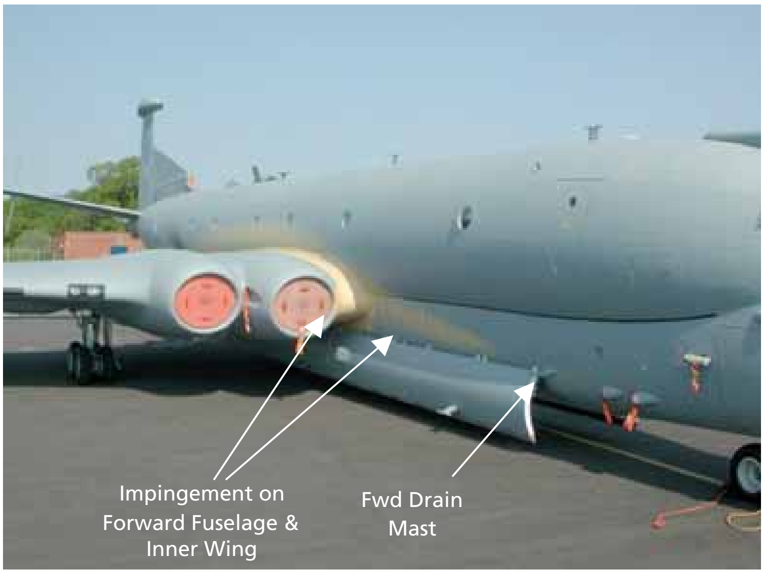


Figure 6.4: MRA4 Showing Dispersal of Dyed Fluid

Figure 6.5: MRA4 Showing Dispersal of Dyed Fluid (close-up of wing root)

6.40 If one extrapolates the results of this trial to the No. 1 blow-off valve operating, it is very easy to envisage fuel tracking back only 2.1 metres into the fairing of the SCP elbow and potentially the No. 7 Tank Dry Bay. The prospect becomes even more likely given the fact that if the blow-off valve activated during AAR, the quantities of fuel expelled would be very considerable.

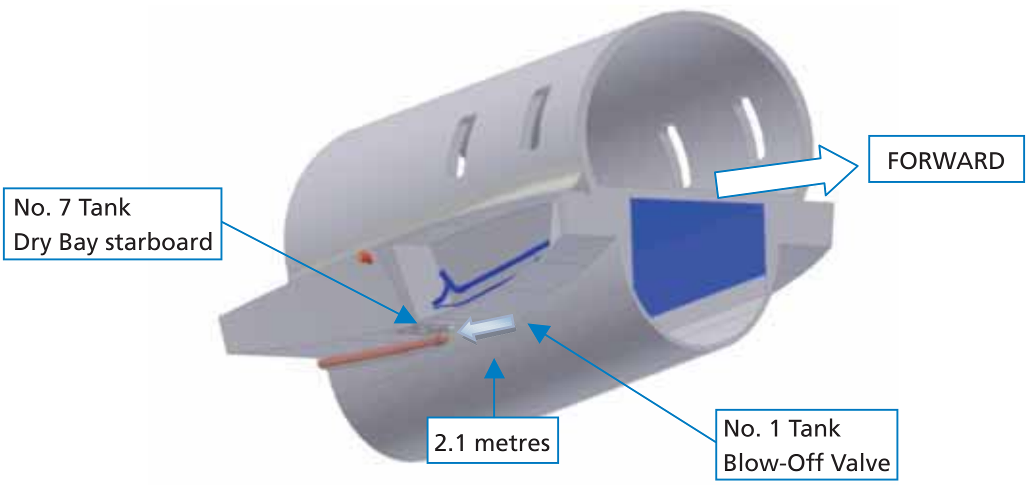


Figure 6.6: Relative Location of SCP External Duct and No. 1 Tank Blow-Off Valve

6.41 I am satisfied, in light of the above that, in the event of blow-off from No. 1 Tank, significant quantities of fuel will track down the skin of the aircraft fuselage aft.

(c) Can blown-off fuel enter the fuselage?

6.42 Blown-off fuel only represents a risk to the aircraft if it can enter the fuselage. BAE Systems most certainly believed in 1985 that there was the potential for blown-off fuel to enter 'ports and intakes' on the Nimrod and pose a threat to the aircraft. In the reports discussed above, BAE Systems advised that, if fuel was observed to vent during AAR, the APU bay should be checked before subsequent APU operation. BAE Systems also recommended modifying the blow-off valve outlets from Nos. 1 and 6 tanks to take blown-off fuel clear of the fuselage to prevent fuel running down the aircraft skin.

Incidents since 1985

6.43 There have been a number of incidents since 1985 which demonstrate how prescient were the concerns that BAE Systems had previously expressed. Unfortunately, none of these incidents was followed up:

6.43.1 An incident occurred during 1986, in which a faulty tanker-drogue allowed a significant amount of fuel to escape from the tanker's hose as the Nimrod made contact. The subsequent dispersal of the fuel illustrated the complex nature of airflow around the aircraft. Although the fuel was introduced into the airflow around the Nimrod probe it was subsequently found to have entered a number of fuselage compartments in the airframe – the life raft release handle compartment, the rear hinged pannier doors, the APU bay, the port wing root, the tail pack and water extractor.

6.43.2 In 1999, Nimrod R1 XV249 experienced a series of fuel leaks from an area at the rear of the port Rib 1 (an area in the wing root, just forward of the No. 7 Tank Dry Bay). Following subsequent sorties, fuel was found in the pannier bay (equivalent to the bomb bay in a MR2), in an area under the dinghy bay stowage in the wing, and in the tail cone. The fuel had probably exited the aircraft from drain holes at the rear of Rib 1 and then travelled along the fuselage, entering the tail cone compartment.

6.43.3 The incident in December 2006 referred to above (when an incorrectly constructed No. 1 fuel tank probably provoked blow-off during AAR[25]) also showed that blown-off fuel can enter fuselage compartments. After landing fuel was found in the rear hinged fairing, with residue along the underside of the tail up to (and inside) the self-defensive flare container in the tail of the aircraft. Unfortunately, there is no record of whether or not the No. 7 Tank Dry Bay was checked for fuel.

[25] Air Incident Report KIN 66/06.

6.44 The dyed water trials from the APU bay and the forward drain of an MRA4 (discussed above) show the manner in which fuel tracking down the aircraft fuselage will enter compartments, despite the fact that the panels are flush with the aircraft fuselage and that, in the case of these trials, the aircraft is recently manufactured and built to modern tolerances. Even 30 minutes after landing, dyed fluid was found *"dripping from the tail-cone bay door"; and when the door was opened it was noted that the fluid had "coated an area in the bay within approximately one foot all around the door"* (see the pink dye in the photographs below).

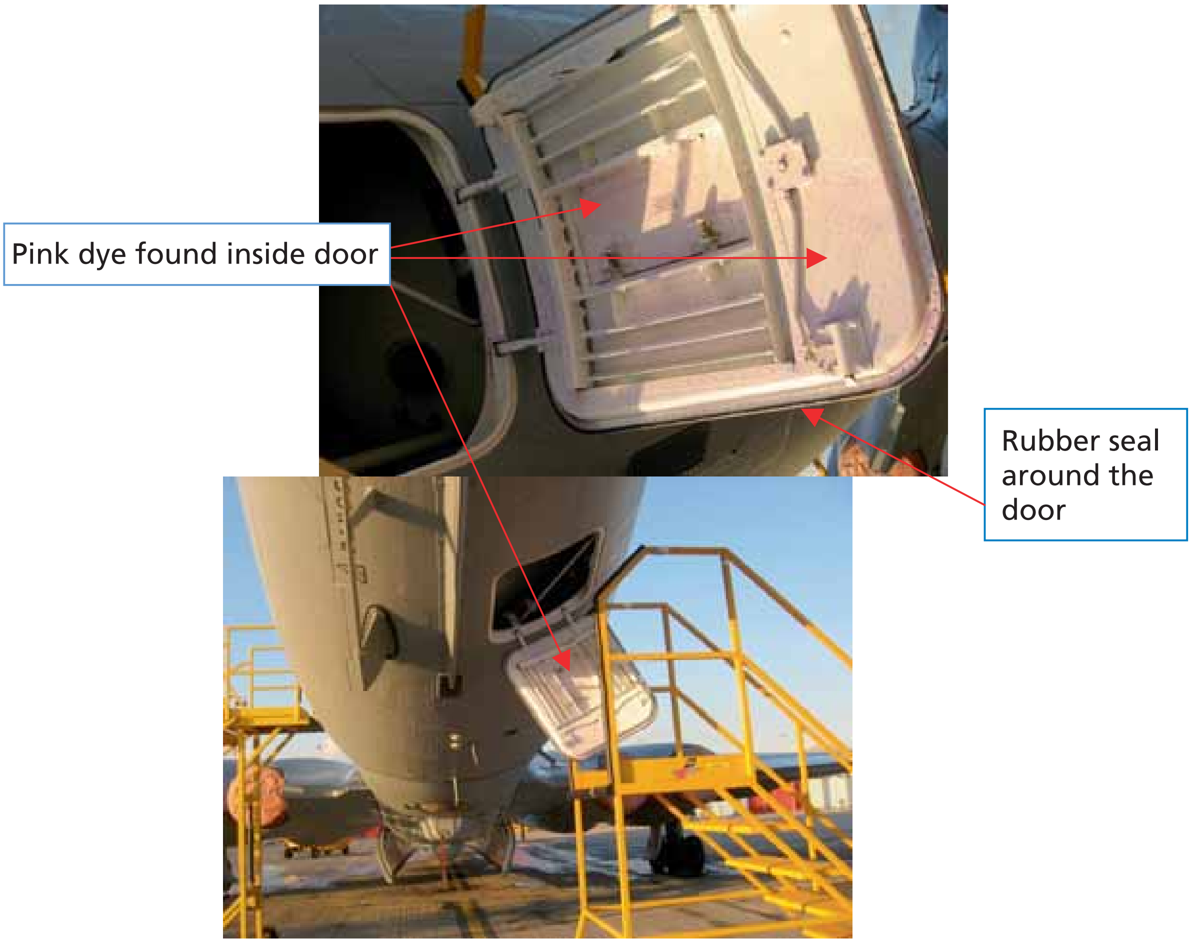


Figure 6.7: MRA4 Dyed Fluid Inside Tail Cone Bay Door

6.45 The report notes that there was no evidence of fluid pooling in the bay. The amount of fluid released into the airflow, however, was very small, only 0.4 litres in total, and the distance it had to travel large, namely several metres from the MRA4 APU bay (in the rear of the wing) to the tail cone bay. By way of contrast, when blow-off occurs during AAR, the flow rate is very large. It has been calculated to be approximately 120 litres every 10 seconds.[26] Further, as illustrated above, blown-off fuel would only have to track 2.1 metres along the fuselage skin to reach the SCP fairing. It should be noted that, although the MRA4 is indeed a different aircraft to the MR2, its fuselage is the original MR2 shape.

Further considerations

6.46 There is clear evidence from the incident in 2006 involving a Nimrod being refulled by an VC10 of fuel flowing down the outside of the airframe and entering several chambers on the MR2 external to the pressure hull: the bomb bay, the rear hinged fairing, the dinghy bay, aerial mounts, the self defensive flares chamber and the tail cone, to name only some.[27] Although the starboard No. 7 Tank Dry Bay was never identified as containing fuel following this incident, or other similar event, this may well be because this bay is not an area that was examined regularly prior to the loss of XV230 and, in any event, if fuel had entered the starboard No. 7 Tank Dry Bay lower

[26] Approximately 12 household buckets every 10 seconds.

[27] Air Incident Report KIN 066/06.

panel during AAR, much of it would have already drained via the drain holes. Although the BOI noted that approximately 300ml of fuel could remain on the panel below the level of the drain holes, if left there for any amount of time, it would tend to slowly drain as aircraft manoeuvres brought it to the level of the drains; and once on the ground any residual fuel would remain on the panel until it evaporated.

6.47 I am satisfied, in the light of the above, that it is clear that blown-off fuel can enter chambers within the aircraft fuselage.

(d) Could blown-off fuel enter the SCP fairing and the No. 7 Tank Dry Bay?

6.48 It is evident from the foregoing that: No. 1 tank blow-off can occur; that blown-off fuel will run down the surface skin of the aircraft fuselage; and that fuel can enter fuselage openings and bays. The remaining issue is, however, whether fuel could enter the SCP fairing and the starboard No. 7 Tank Dry Bay, in particular. The issue turns on the dynamic behaviour of the fuel once it leaves the blow-off outlet on the aircraft's starboard side. No experiments have been undertaken to replicate the fuel's behaviour and, now that Nimrod AAR has been halted, the results of any experiments would be purely of academic interest. I nonetheless turn next to analyse the evidence that is available.

XV230 witness trail

6.49 At the Inquest much was made of the fact that the 'fuel witness trail' (described by Witnesses 22 and 28 to the BOI) observed following a sortie around 9/10 August 2006 was a 'crescent' shape, descending from the No. 1 tank blow-off valve exit and crossing the bomb door hinges. It was suggested that, if this marked the flow of fuel, then logically it could not reach the No. 7 Tank Dry Bay. However, the MRA4 liquid release trial is instructive on two counts in explaining this. First, after the liquid had been released from the MRA4, the aircraft was landed as soon as possible. The simple fact is that traces of liquid flow (water or fuel) on the fuselage exterior will be erased after a period of time and BAE Systems needed an accurate record of the liquid's flow. After tanking, XV230 may well have spent a further eight hours in the air in August 2006. Second, the liquid trail in the MRA4 trial proves how the liquid goes directly backwards and spreads out, even when an aircraft is flying at a slower speed than XV230 would have been. In my view, the witness trail observed on XV230 on this occasion in question was probably residual fuel draining from the blow-off system as the aircraft made its approach to land.

Boundary layer of air

6.50 It is clear that ejected fuel can take a wide range of paths along the fuselage, as my discussion above of the observed fuel flows following a probable blow-off event show. Fuel escaping from the No. 1 tank blow-off will be ejected at pressures in the region of 2.7psi. On the ground, this may well allow the ejected fuel to appear to spurt out with some force. However, in the air, any blown-off fuel will need to breach the boundary layer of air on the fuselage before reaching the free-flow air. During AAR, the free flow air will have a velocity in the order of 400 knots at right angles to the much lower velocity of the expelled fuel. This matches the simple airflow diagrams provided by BAE Systems to the BOI.[28] However, the expelled fuel (of which there would be several hundred litres) is unlikely to execute a neat right angled turn, parallel to the fuselage, in an orderly stream and depart safely behind the aircraft. Common sense would suggest that, as the fuel stream hits the air flowing past the aircraft, random interaction between air and fuel will cause a more random dispersal of the fuel, such that it spreads out as it travels to the rear of the aircraft. The evidence from previous incidents supports this and also suggests that significant amounts of ejected and dispersed fuel will flow along the fuselage.

[28] BOI Report, Exhibit 60

Gap between fairing and fuselage

6.51 Is there a credible risk of such expelled fuel penetrating the SCP fairing and the starboard No. 7 Tank Dry Bay? The fairing that covers the SCP pipe attached to the Nimrod's starboard fuselage is 2.1 metres directly aft of the No. 1 tank blow-off valve. It is not sealed to the main fuselage in such a manner that liquid cannot penetrate it (see further below). From my inspection of various Nimrods, and as the BOI noted, there were clear gaps between the fuselage and fairing. It would require very little upwards migration of blown-off fuel for it to impact upon the SCP fairing. In my view, there is no reason to suppose that ejected fuel would not enter this fairing in the same manner that it has been observed to penetrate many other areas of the Nimrod's fuselage in previous incidents and the MRA4 experiments. Once inside the SCP fairing the fuel would have just centimetres to travel before reaching the SCP duct identified as the likely point of ignition.

6.52 The No. 7 Tank Dry Bay lower panel is at right angles to the obvious direction of the blown-off fuel flow. The entry path for blown-off fuel entering the No. 7 Tank Dry Bay would be through the gaps at the edges of the panel. The viability of blown-off fuel entering small gaps has been amply demonstrated by the dye experiments for the MRA4 referred to above. The gaps are close to the wing/fuselage interface where significant amounts of ejected fuel might find their way. Moreover, there is a favourable pressure gradient upwards through the No. 7 Tank Dry Bay which could induce fuel to enter, as noted by QinetiQ in the BOI combustion study.[29] Given the wealth of evidence demonstrating the number of other panels and intakes which fuel can and has entered in flight (see above), it is difficult to find a convincing argument that it would not enter the starboard No. 7 Tank Dry Bay.

6.53 I am satisfied, in the light of the above, that fuel blown off from No. 1 tank during AAR could enter the starboard No. 7 Tank Dry Bay.

BAE Systems' arguments

6.54 In its evidence to the Review, BAE Systems denied that fuel ejected from No. 1 blow-off valve during AAR could, or would, penetrate the lower panel of starboard No. 7 Tank Dry Bay. In their evidence to the Review, BAE Systems' Military Air Systems Chief Engineer for the Nimrod, Martin Breakell, and Head of Airworthyness, Tom McMichael put 'blow-off' as the least likely of the three potential sources of fuel identified by the BOI as possible causes of XV230's fire. They did not, however, suggest any other possible sources of fuel.

6.55 At the BOI's request, BAE Systems carried out an analysis of the potential for blow-off to occur during AAR. BAE Systems' analysts, using two independent techniques, confirmed that blow-off would indeed occur at the fuel flow rates experienced during AAR.[30] BAE Systems' subsequent evidence to the Review, however, appears to have been at variance with its own technicians' analysis. Martin Breakell appeared to suggest at the Inquest that fuel would enter the vent system and relieve any pressure build up without activating blow-off. This is incorrect; and contradicts BAE Systems' own technicians (as well as HAL) who had factored the presence of the vent system into their calculations. In his evidence to the Review, Martin Breakell said that to have a blow-off :*"You would have to overfill the tank. The flow rates would have to be greater than what is required. The pressure in the tank would be greater than what the design was, so you'd have to do something incorrect but it's there to do a fail-safe system if it was over-pressurised."* This also is incorrect; and again contradicts the view of BAE Systems' own technicians (and HAL) that blow-off required no incorrect actions by any individual. The operation of the blow-off valve is an inevitable function of the construction of No. 1 tank, coupled with the fuel flow rates experienced during AAR.

6.56 BAE Systems put forward a number of further, specific arguments as to why blow-off was unlikely to have been the source of the fuel for XV230's fire:

6.56.1 First, BAE Systems argued that the airflow would take any blown-off fuel away from the side of the fuselage and/or around the No. 7 Tank Dry Bay area. However, BAE Systems produced an airflow diagram which, in my view, can only be interpreted as showing that air flowing rearwards from the location of the No. 1 tank blow-off valve will pass over the SCP fairing.

[29] BOI Report, Exhibit 30.

[30] BOI Report, Exhibit 71.

6.56.2 Second, BAE Systems argued that blown-off fuel would not be able to gain entry to the No. 7 Tank Dry Bay because the lower panel is sealed with a bead of PRC mastic (a flexible sealant akin to bathroom silicone filler) and this would have affected a liquid proof seal. However, on such a panel on the underside of the wing, the most likely purpose of the mastic is to prevent fretting between the aircraft structure and the lower panel, not to prevent fluid ingress.[31] Nonetheless, the Review obtained the engineering drawings of the lower panel and these clearly show that the 'bead' is only required on the forward, rear and outboard edges of the panel, not the inner which is the most likely edge for any blown-off fuel to enter. When the blow-off valve operates, however, any blown-off fuel will be trapped close to the fuselage by the airflow and reach the inner edge most easily. I therefore reject BAE Systems' argument that fuel could not enter the No. 7 Tank Dry Bay because of the PRC mastic.

6.56.3 Third, BAE Systems argued that blown-off fuel would not be able to gain entry to the No. 7 Tank Dry Bay because drainage holes in the panel allowed liquid egress, but not liquid ingress, from outside. The ingress path postulated, however, is through the panel's inner edge, not the drain holes. BAE Systems' argument thus somewhat misses the point.

6.56.4 Fourth, BAE Systems argued that the No. 7 Tank Dry Bay has a positive pressure when measured against the pressure under the wing. Martin Breakell said in evidence to the Review: *"...[D]ry bay 7 is one of the main vent bays from the bomb bay to get air coming from the bomb bay, it's vented out through dry bay 7, you have always got a positive pressure differential, so it's going to want to blow out, rather than allow fuel to come in"*

6.57 This latter argument appears to rely on the fact that the pressurised cabin discharges air into the rear of the bomb bay and that the No. 7 Tank Dry Bay is the area from which this positive pressure is discharged; thus, the bomb bay and the connected No. 7 Tank Dry Bays would have a higher pressure than the pressure under the aircraft wing. BAE Systems suggested that this positive pressure differential would prevent the ingress of liquid. However, evidence from the QinetiQ combustion study suggests that the pressure gradient may not be as simple as propounded by BAE Systems. In simple aerodynamic terms, of course, the air pressure above the wing surface is lower than that below it (otherwise the aircraft would not fly). The QinetiQ team noted that there were significant gaps between the wing panels on the aircraft in the vicinity of the No. 7 Tank Dry Bay and that, considering the overarching pressure differential just described, this would initiate a sympathetic movement of air within the wing (*i.e.* from lower wing surface to upper wing surface). Any air exhausting from the bomb bay would join this upward movement of air and escape through the gaps in the upper wing surface panels. Therefore, it follows that the No. 7 Tank Dry Bays will not be pressurised.

Lack of recorded instances of blow-off in previous 25 years

6.58 A question which must be addressed is: Why had this phenomenon of blow-off during AAR not occurred before? The Nimrod had been conducting AAR for 25 years prior to the accident, yet it appears to have been an unknown phenomenon until the two occasions when it occurred in theatre prior to XV230's loss (see above). In my view, the explanation for this resides in the fact that, as shown by the BOI fuel model, a number of conditions need to coincide to provoke blow-off: small variations in the rate of refuel; the amount of fuel taken into the No. 1 Tank; and the attitude of the aircraft.

6.59 Further, for the first six years that AAR was conducted, the old uplift sequence (see above) would have prevented blow-off. It should also be noted that many sorties were conducted with Victor or VC10 tankers, which had a lower refuel rate than a Tristar. By contrast, AAR with a Tristar was comparatively rare with an average of nine Tristar sorties per year. Further, for most of the 1990s, the Nimrod Zero Fuel Weight (weight without fuel) was higher than it was in 2006, meaning that uplifting to full fuel capacity was not possible, as this would have exceeded the maximum allowable total weight. There were also restrictions on the amount of fuel which could be taken in relation to the Centre of Gravity position such that, once again, uplift to a full load was prohibited. There were also many occasions when tankers were unable to dispense all the fuel the Nimrod could take.[32]

[31] Further, if the PRC mastic is used as a weather-proof seal, it will be used on the top surfaces of the panels only, in order to prevent rainwater ingress.

[32] BOI Report, Part 2, paragraph 40(d).

6.60 Whether or not blow-off occurs is dependent upon a number of factors, as HAL's computer model shows. These factors are principally: (a) whether No. 1 tank is approaching full; (b) whether fuel flow rates into the tank are high enough; and (c) whether the aircraft attitude is suitable (this is influenced by aircraft speed, which, in turn, is a function of aircraft weight and the type of tanker). During AAR training it is unusual for a receiver to take significant amounts of fuel and therefore blow-off is not possible.

6.61 It is quite possible that blow-off had in fact happened on earlier occasions, but no evidence of it was visible post-flight. Any fuel which had gathered in the bomb bay or other panels could easily have drained away and, even if found, would have resulted in standard leak checks which would have revealed no faults. An area like the starboard No. 7 Tank Dry Bay could have had fuel in it but, unless it was seen to be dripping externally, would not have been checked as it is not routinely disturbed on normal servicing. Over the remainder of a flight normal manoeuvres would allow most of that fuel to drain away. It should also be remembered that the two prior occurrences of blow-off in 2006 gave rise to a stain on the fuselage which led back to the No. 1 tank blow-off valve. Without the build up of dust in theatre, however, there may have been no catalyst to draw attention to the blow-off valve. It is worth noting, in this respect, that Nimrods operating from RAF Kinloss are regularly taxied, post flight, through an automatic washing facility, which may further have disguised any external evidence.

6.62 The further question arises: If blow-off did occur previously why was there no fire until that on board XV230? The answer to this is likely to be the simple one that the SCP may not have been in use at the time that blow-off occurred, as it was often not required for cooling in the Northern latitudes.

6.63 There are, therefore, many reasons why blow-off may not have occurred and, if it had, why it was not noticed or did not result in a fire. I am satisfied that the absence of previously recorded incidents of blow-off occurring can be explained.

Causation

6.64 I am satisfied, for the above reasons, that fuel ejected from No. 1 blow-off valve during AAR could well have tracked back along the fuselage and entered the SCP elbow and the starboard No. 7 Tank Dry Bay, leading to the initiation of the fire on XV230.

6.65 An issue nonetheless arises as to whether there would have been a sufficient flow of fuel entering starboard No. 7 Tank Dry Bay to have caused pooling, and to allow the initial fire to take hold and become established and self-sustaining. The fire mechanism advanced by the BOI depends upon the existence of a pool of fuel on the horizontal lower panel of the No. 7 Tank Dry Bay, just forward of the point of ignition. Pooling could also theoretically have taken place in the bottom of the curved fairing around the elbow against the 'lip' leading to the bomb bay. The answer to this issue depends on when, during the sequence of AAR, any such blow-off first started occurring. Extensive modelling and reconstruction of the fuel configuration and known events was undertaken by the BOI. This showed that over a range of likely parameters the time for blow-off was around about five minutes 40 seconds after the start of AAR. This coincided with the transcript evidence of the length of time the AAR serial had lasted i.e. from 11:03:53 until 11:09:50 when the Air Engineer states *"we're full"*. Prior to this the SCP tripped off at 11:09:23, which may also have been an event related to blow-off.

6.66 The AAR of XV230 on 2 September 2006 took approximately six minutes, *i.e.* from 11:03:53 to 11:09:50. The fire warning went off at 11:11:33. Blow-off is likely to have occurred towards the end of the AAR uplift. If it occurred right at the very end of AAR, this would have left about one minute 30 seconds for the following sequence of events to have taken place:

- fuel tracking back along the fuselage;
- fuel then entering starboard No. 7 Tank Dry Bay;
- fuel then coming into contact with the Cross-Feed/SCP duct;
- auto-ignition delay of around 50 seconds;

- the commencement of a pool fire in the panel or the curved fairing; and
- the generation of the development of sufficient hot gases to set off the bomb bay fire warning.

6.67 The QinetiQ combustion study calculated this as a realistic timeline for events. I accept its assessment.

6.68 Further, as the BOI pointed out, should blow-off occur, it is likely that fuel would also enter the vent pipe system and leak from a fuel vent pipe from the No. 1 tank. I turn to analyse this issue and its significance below.

(2) Overflow from the No. 1 tank vent system and leakage from the aircraft vent system

6.69 The Nimrod fuel system had a 'vent' system designed to avoid over-pressurisation of tanks during filling by allowing air to vent to the outside. The adjoining cells within No. 1 tank have vent connections between them. No. 1 tank is connected to the main aircraft vent system through vent pipes exiting Nos. 1 and 4 cells. The outlet pipe for the rear cell (Cell 4) is located above, and just forward of the rear spar, which itself is located in the No. 7 Tank Dry Bays.

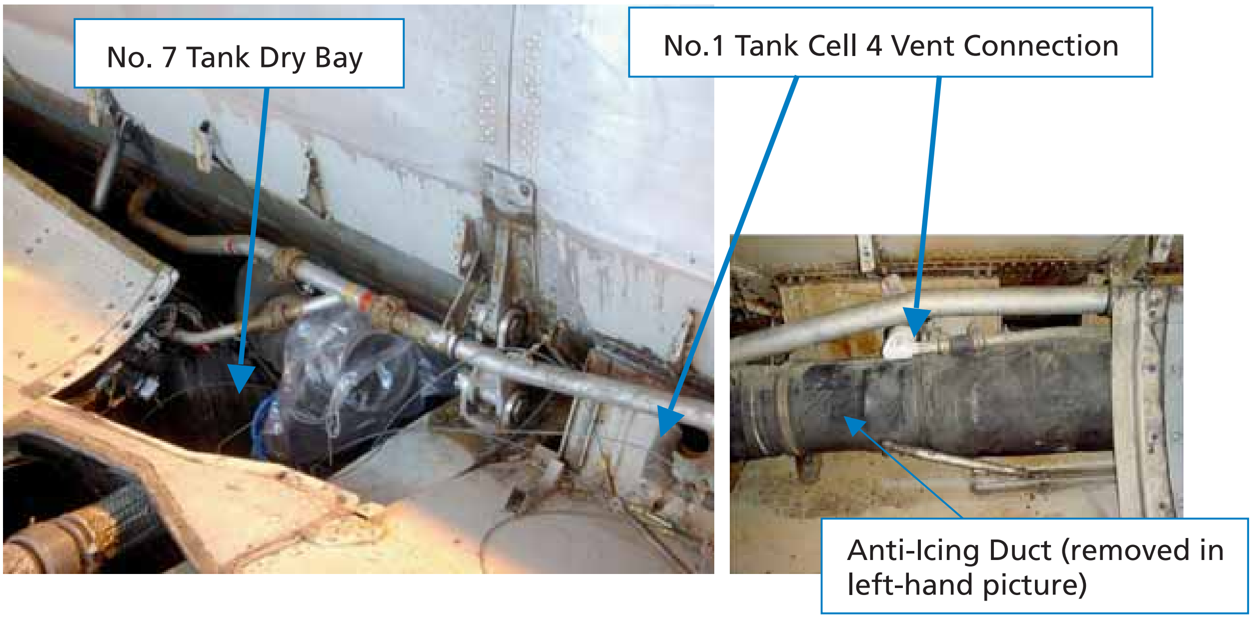


Figure 6.8: No. 1 Tank Cell 4 Vent Connection

6.70 The HAL fuel model shows that fuel will enter the vent system before the end of a refuel of No. 1 Tank. There are also clear examples of the vulnerability of the vent system in the event of overfilling of No. 1 tank cells.

2006 incident

6.71 On 31 October 2006, at RAF Kinloss, an aircraft about to enter Depth maintenance suffered a fuel leak during preparation for entering the hangar. An Incident Report was raised[33] and the technical investigation showed that fuel had leaked from the fuel vent system, including the No. 1 tank vent connections, and was spread liberally around the Rib 1 area on the starboard side, having escaped from the fuel vent pipe connections in that area. It should be noted that such vent pipe connections are not designed for fuel, but only for air. The reason for the presence of fuel in the vent pipe connections was identified as the aircraft having being slightly nose down on the dispersal during a refuel, resulting in the forward high level float switch in Cell 1 operating when it was full, but fuel continuing to enter all cells in the tank because the rear float switch in Cell 4 had not operated to close the refuel valves. The resultant overfill of Cell 1 found its way into the aircraft vent system and leaked out of the couplings in those pipes.

[33] Air Incident Report KIN/59/06 (BOI Report, Exhibit 57).

6.72 Cognisant of the above Incident Report, the BOI noted that the *"vent lines from No 1 tank are of light construction and secured by jubilee clips, which if overtightened can leak"*,[34] and recommended that they be modified to reduce the risk of fuel leakage.

2009: XV235 incident

6.73 A very recent incident involving XV235 has brought to light important evidence.

6.74 On 20 April 2009, during maintenance of XV235 at RAF Kinloss, a Serious Fault Signal[35] was raised for a fuel leak from a No. 1 Tank Cell 4 rear vent connection. The signal goes on to describe what was found as follows: *"Further investigation carried out suspect that* <u>*fuel soaked pre-cooler muff*</u> *Part No BA205123 located at the forward face of 7 tank dry bay may have been result of above leak"* (emphasis added).

6.75 Part No. BA205123 is the flexible muff located immediately aft of the SCP elbow. The incident on XV235 therefore provides powerful evidence in support of the BOI's conclusion that, if fuel had leaked from the vent connection during AAR on XV230, that fuel would have found its way to the No. 7 Tank Dry Bay and could have gathered at the flexible muff to provide the fuel source for the fire. Furthermore, such fuel would have the potential to pool on the lower panel.

2008: QinetiQ report on XV236

6.76 Subsequently, during the teardown conducted by QinetiQ on Nimrod XV236, a fault report was raised concerning the No. 1 Tank Vent Connections (see further **Chapter 15**).[36] In order to investigate the matter further, the connection was pressurised and leaked at 0.5psi gauge pressure; well below the blow-off valve setting of 2.7psi. The design features of the connection were described as follows: *"The metal vent pipe was fabricated from two diameters of tube: a 1.25" diameter tube, which had both a raised bead to form a seal with a 'push fit' rubber pipe and a bonding tag attachment; and a second approximately 1.5" diameter tube. The rubber hose was found to interface with the larger metal pipe section of approximately 1.5" diameter, which had no sealing bead present. Thus the joint was reliant on a single Jubilee clip to both seal and clamp. .... Due to the lack of a witness mark on this larger pipe, there is a lack of control of the position of the hose clip, which could lead to the hose being clamped only over the welded portion of the pipe assembly or only over part of the surface, which could lead to complete detachment."*

6.77 QinetiQ, therefore, raised similar concerns to the BOI in relation to the design of the vent pipe design and go further by positively suggesting that the jubilee clip could slip under pressure, allowing the rubber extension to reposition itself over the narrower section of the metal pipe, resulting in a significant leak of fuel. Also, the QinetiQ Report explained that the rubber extension had been positioned on top of a clear plastic tape which labelled the pipe as a fuel vent pipe; the tape further reduces the effectiveness of a seal between rubber and metal. It should be noted that other aircraft were subsequently checked at RAF Kinloss and found with the same condition, *i.e.* with the rubber extension positioned on top of the clear plastic tape.

[34] BOI Report, paragraph 40(d)1.

[35] Serious Fault Signal 181300, dated May 2009.

[36] QINETIQ/MS/SES/TR0902158/1, dated 02 July 2009.

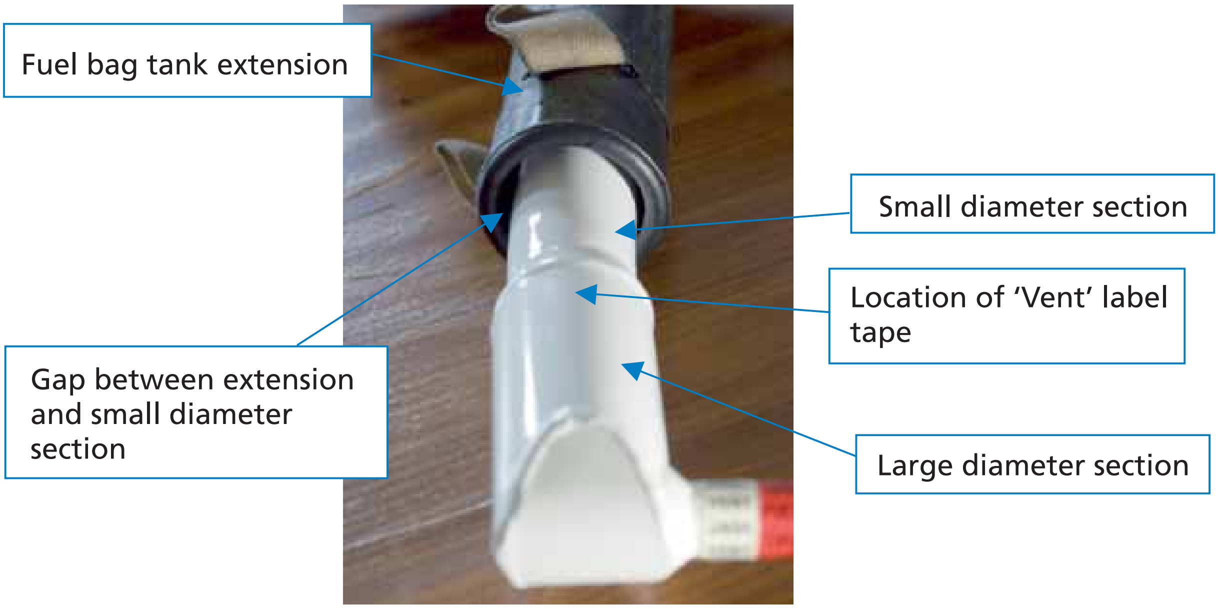


Figure 6.9: No. 1 Tank Cell 4 Vent Connection

6.78 In order to assist the Review, a trial[37] was carried out at RAF Kinloss to investigate where fluid would track if released in the area of the No. 1 Tank rear vent connection (see Figure 6.8 and 6.9). Although unable to replicate the exact pitch attitude of XV230, the results showed that fluid would track back into the No. 7 Tank Dry Bay and some would pool on the lower panel. Larger quantities of fuel (several litres) were required in order to cause the fuel to disperse widely over the panel. In addition to the 'on aircraft' trial tracking the movement of the fluid, the connection was also subjected to a bench test under pressure. Leaks were not apparent up to 5psi on the test specimen with the jubilee clip on the wider part of the vent pipe. However, as noted above by QinetiQ, the jubilee clip had potential to slip rearwards over the narrower section if located over the weld. Given the difference in the two diameters this would result in a large leak, as can be seen from the photograph above.

Vent pipe couplings

6.79 There is also evidence that, in addition to the possibility of a leak from the direct vent connections to Cells 1 and 4 of No. 1 Tank, fuel may also leak from the FRS couplings in the main vent system. In 1998 a technical improvement[38] was suggested to the IPTs predecessor, the Support Management Group. In proposing a Modification to the high-level float switches of No. 1 tank an engineer at RAF Kinloss was trying to deal with a recurring problem of minor fuel spills from the No. 1 Tank. In his explanation of the problem, he wrote: *"Of course fuel doesn't always flow freely through the vent lines, often it finds a way to leak through these lines at various connections and soaks either Rib 1 port or starboard. This alone causes a large quantity of fuel to soak all the equipment there"* (emphasis added).

6.80 Several of the FRS connections in the fuel vent pipes are directly above the No. 7 Tank Dry Bay and fuel dripping from them would drop onto the lower panel and pool.

6.81 I am satisfied, in the light of the above, that there are several ways in which fuel can migrate into the No. 7 Tank Dry Bay from the aircraft vent system and pool on the lower panel.

Venting could occur without blow-off

6.82 The incident on XV235 shows the potential for fuel to enter the vent system in the event of the No. 1 tank Cell 4 overfilling, allowing fuel to leak into the area of the No. 7 Tank Dry Bay. This could happen without reaching an internal tank pressure sufficient to cause blow-off. It is therefore possible that a leak from the vent system,

[37] NAEDIT/1505/09/14/Task 01, dated September 2009.
[38] SMG/512712/16/SM60a1, dated 18 November 1998.

on its own, could have provided the fuel for the fire on XV230. However, when blow-off occurs, an internal tank pressure of 2.7-2.9psi occurs and this pressure will also be felt in the vent pipes and at the vent connection under discussion. This could increase the tendency of the vent connection to leak or even to become detached. Thus, it is possible that fuel could both be blown-off and leak from the vent line connections.

6.83 In June 2009, STI/Nimrod/944 was issued by the Nimrod Integrated Project Team (IPT) to improve the integrity of the connection between the No. 1 tank fuel vent stub pipe and the aircraft fuel vent system. This entailed manufacturing a raised bead on the wider part of the vent stub pipe and introducing a mark to ensure that the bag extension overlapped the bead by a set amount.

Fuel venting through air vent system was known problem

6.84 It is clear the phenomenon of fuel venting through the air vent system was a well-known and long-standing problem. Minutes dated 18 February 2003 referring to BAe's Proposals for the Nimrod Life Extension Programme state: *" … [A]t BAe's presentation in Dec 92 on their latest proposals for a Nimrod Life extension to meet AR(A) 420, it became apparent that BAe were not fully aware of all our problems, or of the work being carried out in 3 specific areas: the fuel system, engine intakes and the wing/fuselage attachments. We have therefore produced the briefing notes at Annex A ….".*[39]

6.85 The briefing notes refer to two problems which needed to be addressed as part of the Nimrod Life Extension Programme: the first was leaking of bag tanks; the second related to fuel venting. The briefing notes stated: *"Fuel venting has been a long standing problem. There are 2 causes: the failure of the high level float switches to cut off the fuel when the tanks are full, and thermal expansion. The latter is a common occurrence when operating in hot climates. Both problems result from inadequate system design and are controlled in service by limiting the fill level of the tanks. Thus the BAe life extension proposal should address these built-in design faults.".*

6.86 Thus it is clear that there was a known problem with the float switches which allowed fuel to enter the vent system from which it might leak. It is not clear what steps were subsequently taken, if any, to address the problem.

Causation

Causation of vent pipe

6.87 I am satisfied that the vulnerability of No. 1 tank to asymmetric filling and fuel entering the vent system, and the inadequate design of the vent pipe connection for the No. 1 tank to cope with fuel, could have led to a leak during a blow-off occasioned by AAR. I am also satisfied that, because of the position of the vent connection above the rear spar, it was also possible that leaking fuel could have migrated to the lower panel of the No. 7 Tank Dry Bay and into the SCP elbow muff.

6.88 In the event of fuel being pressed up in No. 1 tank into the vent pipe system, the vent pipe connection could have experienced up to six times the pressure at which QinetiQ found it leaked. I am satisfied that it was quite possible that the connection would have failed, allowing a significant quantity of fuel to escape. It was also possible that the vent connection was weakened by the previous blow-off events.

Overflow: joint effect of blow-off and vent pipe

6.89 There could, therefore, have been *two* sources of fuel reaching the No. 7 Tank Dry Bay during blow-off, namely: (1) fuel blown-off tracking along the fuselage; and (2) fuel leaking from a vent pipe connection. Both of these could have ended up in No. 7 Tank Dry Bay simultaneously and these two sources might jointly have been sufficient both to cause initiation of a fire as well as the sustaining of a fire. This is the joint phenomenon which the BOI termed 'overflow'.

[39] Loose Minute dated 18 February 2003 referring to BAe's Proposals for Nimrod Life Extension to Meet SR(A) 420.

(3) Increased pressure in the fuel system due to surges

6.90 The rate at which a Nimrod is refuelled using AAR is far greater than when using a bowser on the ground. In broad terms, ground refuelling engenders pressures in the region of 50psi at a rate of up to 1,460kg per minute, whereas normal AAR pressure is in the region of 30-40psi when refuelling at a rate of up to 2,100kg per minute[40]. A detailed description of the refuel system is in the BOI Report at Annex M. Tests at the time of Mod 715 by the MOD Aeroplane and Armament Experimental Establishment (A&AEE)[41] established that pressure surges during AAR might create pressure 'spikes' of up to 90psi on the ground and 84psi in flight, but these would be below the proof pressure of the system of 112.5psi. These tests entailed closing off a number of tanks together under full flow conditions and measuring the pressure surge obtained; this is a much more severe test than would be encountered in an operational environment as the Air Engineers are trained not to allow such a condition. In any event, a pressure surge would be very short-lived and would not have enough energy to cause any damage to the system.

6.91 In relation to XV230, there is clear evidence from the Tristar Air Engineer,[42] who controlled the AAR at the time, that no pressure surges were observed during XV230's refuel.

6.92 The potential for pressure surges to have a cumulative effect has to be balanced against the long service history of the Nimrod and the absence of any pattern of refuel system leaks after AAR. It appears that correctly assembled couplings are capable of withstanding both normal and surge pressures as noted in the trials at A&AEE. As explained in **Chapter 5**, a more likely cause of sudden fuel leaks is the propensity of an incorrectly assembled coupling suddenly to move at some point in its life and give rise to a large leak. This is as likely to happen during a ground refuel as it is in the air, though it remains a possibility that an extra surge during AAR may be the final trigger causing such movement.

Causation of 'surge' pressure

6.93 During normal flight, the refuel system would not be under pressure. Once AAR commences, however, the system would be subject to normal refuel pressures. If a coupling in the refuel system was going to leak, it is therefore more likely to happen during AAR as the refuel system is now under pressure. In terms of causation of the accident, the question is: did an additional surge of pressure during AAR contribute to a coupling leak on the day? I agree with the BOI that there is no evidence pointing towards a pressure surge on the day being the trigger for a leak. If it was a fuel coupling which began to leak it would have been because the coupling had a pre-existing fault; it could just as easily have leaked on the previous ground refuel.

6.94 I am satisfied, therefore, that the additional flow rate of AAR is very unlikely to have been causal to the accident.

Breach of design standards

AvP 970 and Defence Standards

6.95 I set out in **Chapter 4** the original design regulations and standards applicable to the Nimrod type, namely AvP 970,[43] and explain how derogation from AvP 970 was not allowed unless *"… the requirements are obviously inapplicable or are over-ridden by the requirement of the Aeroplane specification"*.[44] I further explain how Mod 715, *i.e.* the formal incorporation of AAR within the aircraft design, was required to conform with Def-Stan 00-970, issued 12 December 1983, which superseded AvP 970.

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[40] BOI Report, Annexes L and M.

[41] Now part of QinetiQ.

[42] BOI Witness No. 31.

[43] The military equivalent to British Civil Airworthiness Requirements (BCARs).

[44] AvP 970, 1965 Edition, Volume 1, paragraph 1.2.

6.96 I have concluded that Mod 715 was in breach of Def-Stan 970 in two major respects:

(1) Breach of Def-Stan 00-970 requirements regarding blow-off valves

6.96.1 First, the Nimrod Mod 715 design failed to meet the safety standards regarding the design and location of fuel blow-off valves. Def-Stan 00-970 required that *"no vent or discharge provision shall end at any point where the discharge of fuel from the vent outlet in flight or on the ground would constitute a fire hazard."*.[45] The location of the No. 1 Tank blow-off valve, some half-way down and flush with the aircraft fuselage, and directly forward of the starboard No. 7 Tank Dry Bay, fails to meet these requirements. Should blow-off operate during AAR, fuel can be discharged into the 400 knots airflow at a rate of some 120 litres in ten seconds. (This rate would be sufficient to fill an average domestic car fuel tank in under three and a half seconds). As explained above, fuel discharged in this way could track back and flow between panels and into voids within the aircraft, including the starboard No. 7 Tank Dry Bay and possibly the SCP pre-cooler inlet.[46]

(2) Breach of Def-Stan 00-970 requirements regarding location of fuel pipes

6.96.2 Second, the Nimrod Mod 715 design failed to meet the safety standards regarding fuel pipes in the AAR system. Def-Stan 00-970[47] required that: *"Fuel pipes should not run through crew/passenger compartments nor close to high pressure hot air ducts and electrically operated equipment in bays. Where it is not possible to comply with this, the pipes shall be without couplings, and preferably of steel. The pipe run through such zones shall be completely jacketed, and overboard drains shall be provided."* Within the starboard No. 7 Tank Dry Bay, AAR refuel pipes run in close proximity to the Cross-Feed and SCP pipe work, which contain hot, high pressure air. The fuel pipe-work includes numerous couplings, is not made of steel, and is not jacketed.

Breach by BAE Systems of Def-Stan 00-970

6.97 In my view, when BAE Systems carried out Mod 715 in 1989 to convert the temporary AAR modification (Mod 700) into a permanent modification, it failed to ensure that the whole AAR capability was compliant with Def-Stan 00-970, in particular, as stated above, it did not ensure that No. 1 tank blow off valve was compliant with Def-Stan 00-970 or validate the Nimrod refuel system for its new role as part of the AAR capability for compliance with Def-Stan 00-970.

6.98 BAE Systems submitted to the Review that, when introducing Mod 715, it was only required to ensure that *"the AAR refuelling probe and hose down to (but not including) the pre-existing fuel gallery"* was compliant with Def-Stan 00-970.[48] In my view, this is not correct. The requirements of Mod 715 were quite clear, namely, Part A: *"To make provision for and introduce Air to Air Refuelling (AAR) capabilities"*; and Part B: *"To remove the SOO (AAR) capability introduced by Mod 700..."*. Mod 715 went on to state expressly: *"This modification will re engineer the AAR installation to meet Def-Stan 00-970 CA release requirements" and "Part A of the modification introduces an AAR capability that meets all the criteria for a full CA Release".*

6.99 BAE Systems' Chief Engineer, Martin Breakell, sought to argue in his evidence to the Review that BAE Systems' requirement was nonetheless limited by the terms of its Feasibility Study in relation to Mod 715[49] which, he suggested, made it clear that BAE Systems was merely responsible for ensuring that the AAR refuelling probe and hose added by Mod 700 was compliant with Def-Stan 00-970. In my view, however, there is nothing in the Feasibility Study to justify this conclusion. Indeed, quite the opposite: the Feasibility Study makes it clear that BAE Systems was to consider the effect of the AAR capability on the aircraft as a whole and to ensure that it would meet the requirements of relevant regulations:

[45] Volume 1, Chapter 713, paragraph. 4.4.

[46] As identified by BAES during the AEW trials (Ref: BAe-MPP-R-AEW-0063).

[47] Volume 1, Chapter 704, paragraph 3.4.4.

[48] BAE Systems' Written Submissions dated 9 April 2009, paragraph 280.

[49] Report No. 801/MAN/DES/266, dated 15 March 1983.

6.99.1 The conclusion of the Feasibility Study clearly states: *"This report describes the incorporation into a Nimrod MR Mk 2 of an AAR capability which will meet the requirements of a full CA Release."* (emphasis added)

6.99.2 Section 5 of the Feasibility Study expressly considers whether the aircraft's existing fuel venting system required any modification and concludes, in this respect, that as regards tank No. 5, *"During AAR a fuel discharge from this valve may cause difficulties due to possible fuel ingress into the port engines. To alleviate this possibility a differential pressure switch, identical to the Mod 700 installation, will be fitted"*. There would have been no need for BAE Systems to have considered such issues if its responsibilities in relation to Mod 715 were as limited as it now sought to suggest.

6.99.3 The attachments to the Feasibility Study included schematic drawings of the refuel system as a whole.

6.100 In my view, therefore, reading Mod 715 and the Feasibility documents together, it is crystal clear that it was intended that BAE Systems was responsible for ensuring the entire AAR capability, including the internal fuel system, was Def-Stan 00-970 compliant.

XV230's experience

6.101 On return from a sortie in August 2006, the Nimrod detachment personnel found a small amount of fuel in XV230's bomb bay, and traces of fuel having been discharged from the No. 1 tank blow-off valve during sorties prior to the aircraft's loss. The Nimrod detachment air and ground crew examined the symptoms and made a logical deduction that the No. 1 tank blow-off had operated and that fuel from the blow-off had penetrated the bomb bay along the hinge line. A *de facto* limit of 15,000lbs was subsequently operated by crews when filling No. 1 tank during AAR and the symptoms disappeared. This limitation was not formally recorded in the aircraft documentation but I have no doubt that it was put into operation by crews, and it was relayed to FS Davies when he was briefed prior to his first AAR sortie in theatre and carried out by him.[50] Crew 3 was a highly experienced, close-knit and capable crew.

6.102 In any event, there was no evidence available to the personnel at the time that blow-off might give rise to any hazard. The No. 1 tank blow-off, unlike the No. 5 tank blow-off, had been left functional after the Nimrod was made AAR capable. The blow-off was clearly capable of functioning, and indeed was meant to function, either on the ground or in the air, to prevent over-pressurisation of the tank by fuel. It was, therefore, in my view a reasonable assumption on the part of all concerned that there was no particular hazard in it functioning in either environment.

6.103 The Air Member for Materiel, Air Marshal Sir Barry Thornton, notes, in his comments on the BOI, *"it is unfortunate that no aircraft incident reports were raised as a result of these events"*,[51] while discussing the detachment's reaction to the occurrence of blow-off. In my view, however, in the circumstances pertaining at the time in theatre, it is quite understandable that no incident report was raised. If blow-off had occurred on the ground during refuel, no similar action would have been taken. The aircraft had been refuelled on the ground without incident. The symptoms had also disappeared following the application of the 15,000lbs limitation. Thus, there was no reason for anyone to think that were any significant underlying problems with the No. 1 tank's refuel system.

6.104 In my view, the air and ground crew have absolutely nothing to reproach themselves for. The blow-off valve was working normally as it was intended to operate. An incident report or call back to RAF Kinloss for instructions would have been unlikely to have elicited any different solution to the problem. The BOI acknowledged that, even after the accident, it took several months of painstaking investigation to uncover the cause and possible effects of a blow-off. No one in theatre had any reason to suppose that it was anything other than the correct operation of the aircraft systems. No one in theatre had any reason to suppose it might be a safety matter. No one in theatre was, or could reasonably have been, aware of the serious ignition danger lurking in No. 7 Tank Dry Bay.

[50] BOI Report, page 2-34, and Witness Statement 22.

[51] BOI Report, Comments of Air Member for Materiel, paragraph 14.

Causation generally

6.105 I am satisfied, for the reasons set out above, that AAR could have been the cause of the fuel in the starboard No. 7 Tank Dry Bay, either because of fuel ejected from No. 1 blow-off valve and/or fuel entering and leaking from the vent system during the AAR operation. In my view, the BOI was right to rank this as one of the two most likely causes, alongside a fuel coupling failure. The possibility of a blow-off having occurred on this occasion is heightened by the fact that the phenomenon had manifested itself on previous XV230 sorties. Even though the crew were operating a 15,000lbs limitation on fuel in No. 1 tank during AAR, the HAL modelling shows that blow-off can still occur with less than 15,000lbs.

6.106 For the reasons given in **Chapters 5** and **6** above, I am satisfied that the BOI were right to conclude that the two most likely sources of the fuel leading the fire on board XV230 were: (a) a leak from a fuel coupling in starboard No. 7 Tank Dry Bay; or (b) overflow of fuel during AAR.

6.107 I set out below, in summary, my analysis of the reasons for and against each of these two causal mechanisms.

(a) Leak from Fuel Coupling in the starboard No. 7 Tank Dry Bay

6.108 The following reasons favour a leak from a fuel coupling in the starboard No. 7 Tank Dry Bay being the source of fuel:

(1) The close proximity of eight FRS couplings and one Avimo coupling to the Cross-Feed/SCP duct.

(2) A leak from these couplings would drop fuel directly onto the lower panel, allowing it to pool.

(3) There have been recent instances of FRS couplings suddenly springing large leaks.

(4) There is a known mechanism for couplings suddenly springing large leaks, namely mis-assembly.

(5) The refuel gallery was pressurised during AAR, and therefore the fuel coupling mechanism is not inconsistent with AAR taking place.

(6) There has been an increasing trend of coupling leaks.

6.109 The following reasons militate again a leak from a fuel coupling in the starboard No. 7 Tank Dry Bay being the source of fuel:

(1) The timing of the AAR sequence and the fire would suggest that there had to have been either a small leak commencing early on during AAR or a large leak near the end of the AAR sequence. However:

(2) If AAR had triggered a large leak from a dormant mis-assembled coupling, why did the fire not start earlier in the sequence when fuel first entered the refuel system?

(3) Large leaks of the type recently experienced are a comparatively rare event.

(4) There is no evidence of coupling leaks on previous sorties or ground refuelling.

(b) Overflow during AAR

6.110 The following reasons favour overflow during AAR being the source of fuel:

(1) XV230 had experienced blow-off during AAR on previous sorties.

(2) The HAL model demonstrates that blow off could occur at 15,000lbs.

(3) The Mission tape shows that AAR finished at the right time, i.e. at a time consistent with overflow being the cause.

(4) Blow-off occurs in huge quantities at a high rate: 120 litres of fuel every 10 seconds.

(5) The blow-off valve is only 2.1 metres directly forward of the fairing in way of starboard No. 7 Tank Dry Bay.

(6) There is ample empirical evidence of the likelihood of blow-off fuel migrating back along the fuselage and entering panels.[52]

(7) Gaps in the fairing could allow fuel to ingress the starboard No. 7 Tank Dry Bay, come into contact with the SCP elbow, and pool.

(8) One is certain to get fuel in the vent lines before blow-off occurs.

(9) There is a recorded incident of fuel leaking from the No. 1 tank vent connections in 2006.[53]

(10) The recent XV235 fault signal shows that No. 1 Tank Cell 4 rear vent connection was the probable cause of fuel wetting the SCP elbow muff below.[54]

(11) Recent experiments have confirmed that fuel from No. 1 Tank Cell 4 rear vent drops onto and pools on the panel at the bottom of the starboard No. 7 Tank Dry Bay.

(12) The No. 1 Tank Cell 4 rear vent pipe connection was designed for air not fuel, is a poor design, and could have leaked under even low fuel pressure.[55]

(13) No. 1 Tank Cell 4 rear vent could have been weakened by blow-offs on previous XV230 sorties.

(14) Fuel could also have leaked from the couplings in the vent pipe connections.

6.111 The following reasons militate against overflow during AAR being the source of fuel:

(1) There have been only three known incidents of blow-off on Nimrods in 25 years.

(2) It is not straightforward for blown-off fuel to pool on the lower panel in the starboard No. 7 Tank Dry Bay.

(3) The crew were operating a 15,000lbs limitation in relation to Tank No. 1.

(4) No venting from XV230 was observed at the time by the Tristar tanker.

Balance of probabilities of overflow during AAR being the source of fuel

6.112 I have carefully weighed up all these factors, and all the evidence I have heard and read, and have concluded that the balance of probabilities favour overflow during AAR being the source of the fuel which led to the fire in the starboard No. 7 Tank Dry Bay which caused the loss of XV230 (*i.e.* (b) above). In my view, four factors tip the balance in favour of overflow during AAR being the cause:

6.122.1 First, the recent evidence of the fault signal for XV235 which shows that fuel found in the SCP elbow muff probably originated from No. 1 Tank Cell 4 rear vent.

6.122.2 Second, the recent careful examination of the No. 1 Tank Cell 4 rear vent shows it is a poor design for fuel and could leak when under fuel pressure.

6.122.3 Third, the recent evidence of the dye experiments on MRA4 which show the likelihood of fuel tracking straight back along the fuselage and entering the SCP elbow of the MR2.

6.122.4 Fourth, the fact that fuel could have emanated from the two sources *simultaneously* during AAR and both ended up in the starboard No. 7 Tank Dry Bay, *i.e.* both: (i) fuel blown off from No. 1 blow-off valve and tracking two metres down the starboard fuselage into the fairing over the SCP elbow; and (ii) fuel simultaneously entering the vent system and leaking out of No. 1 Tank Cell 4 rear vent and pouring down onto the SCP elbow muff and panel at the bottom of No. 7 Tank Dry Bay below. An initial splash

[52] AEW3, MRA4 experiments, XV249, XV232 *etc.*

[53] Air Incident Report KIN/59/06 (BOI Report, Exhibit 57).

[54] Serious Fault Signal 181300 May 09, raised on 20 April 2009, during maintenance of XV235 at RAF Kinloss.

[55] See QinetiQ's Fault Report: QINETIQ/MS/SES/TR0902158/1, dated 2 July 2009, during the Ageing Aircraft Audit conducted on Nimrod XV236.

of fuel on the SCP elbow from (i) could have initiated a fire which could then have been fuelled by fuel dropping down and pooling as a result of (ii) (or vice-versa).

6.113 It it important to note that much of this crucial evidence has been very recent and has not been available to others who have previously considered the question of causation, in particular the BOI, the AAIB and the United States Air Force Safety Center (AFSC).

CHAPTER 7 – DAMAGE FROM CROSS-FEED/SCP DUCT FAILURE

Contents

Chapter 7 covers the possibility of a Cross-Feed/Supplementary Conditioning Pack duct failure and answers the following questions:

- How and why did a Cross-Feed/Supplementary Conditioning Pack duct failure pose a risk to the Nimrod?
- Did this represent a breach of applicable design standards?
- Was the maintenance policy for hot air ducts satisfactory?
- Were there warnings of risks from hot air duct failures?
- Did a hot air duct failure cause the loss of XV230?

Summary

1. A rupture of the Cross-Feed/Supplementary Conditioning Pack duct represented a potentially serious hazard to the Nimrod because of the risk of hot air (400°C+) damaging the numerous adjacent fuel seals in the starboard No. 7 Tank Dry Bay, leading to the escape of fuel and an in-flight fire.
2. This scenario represented a *"single point failure"* and a breach of general *"fire zone"* safety standards applicable to the original Nimrod MR1 and MR2 designs in 1969 and 1979, in particular Aviation Publication (AvP) 970 Chapter 715 (see **Chapter 4**).
3. British Aerospace's[1] advice in 1983 to the MOD on predicted duct life had proved pessimistic when compared with the actual life of ducts in service; a policy of pressure testing was adopted which worked successfully for the next 21 years.
4. In November 2004 corrosion caused the fracture of a duct within the Supplementary Conditioning Pack system of Nimrod MR2 XV227, resulting in considerable damage and the near loss of the aircraft.
5. The XV227 incident amply illustrates the catastrophic risk the Cross-Feed/ Supplementary Conditioning Pack duct posed to the aircraft.
6. A second duct failure (albeit a different duct in the engine bay) occurred on XV229 on 8 August 2005 and was caused by fatigue, possibly provoked by physical damage. The incident was not adequately analysed by the Integrated Project Team in considering the possibly increased threat to the aircraft from such failures.
7. The damage occasioned to XV227's airframe and systems by the hot air leak should have been a 'wake up call' to everyone. With the benefit of hindsight, the potential for interaction between the fuel and hot air systems existing in close proximity within the No. 7 Tank Dry Bay represented a significant risk to the aircraft and its crews. Simply looking at the list of damaged components should at the very least have provoked a careful re-examination of the conclusions of the Nimrod Safety Case.
8. The Nimrod Integrated Project Team's decision to switch the Supplementary Conditioning Pack back on in April 2005 was based on an imperfect understanding of the completeness of the hot air leak detection system. The analysis carried out by the Integrated Project Team in support of this decision was far from satisfactory.

[1] BAE Systems.

Causation

9. The Board of Inquiry was right to conclude that, whilst a Cross-Feed/Supplementary Conditioning Pack duct failure could not be ruled out as a causal mechanism for the fuel source, it was much less likely than the other two potential causes (fuel coupling leak or escape of fuel during Air-to-Air Refuelling). In my view, a sudden major rupture of the bleed-air system would not have gone unnoticed, let alone unremarked upon, by the crew of XV230. Moreover, such a failure would have made it impossible for the Air Engineer to report the Supplementary Conditioning Pack overheat, which he did at the start of XV230's emergency. Further, a small hot air leak is much less likely to have caused sufficient degradation unless coincidentally placed close to a coupling in the fuel system; it would also require a significant amount of time to do so.

Introduction

7.1 In this Chapter, I first analyse early problems with the bleed-air ducting experienced in the 1980s and 1990s and a later incident on XV227, before explaining my conclusion in relation to whether or not, a bleed-air duct failure is in fact a likely cause of the fire on board XV230.

The Nimrod Bleed-Air System

7.2 The Nimrod bleed-air system and its function are described in detail in **Chapter 4**.

Risks of fire from failure of Cross-Feed/Supplementary Conditioning Pack duct

7.3 In my view, there was a clear risk of a catastrophic in-flight fire resulting from a failure or rupture of the Cross-Feed/Supplementary Conditioning Pack (SCP) duct. This arose because of the high temperature (400°C+) and pressure of the air contained therein and the juxtaposition of the duct to numerous fuel couplings in the starboard No. 7 Tank Dry Bay. A failure of the duct would have allowed the escape of hot bleed-air which might damage the rubber seals leading to leakage of fuel onto very hot duct surfaces, either through pre-existing gaps in the insulation or through new gaps caused by damage occurring during the original failure. The risks were amply illustrated by the XV227 incident referred to below, when a duct within the SCP system fractured, allowing hot air to escape and cause considerable damage to the aircraft.

Breach of applicable design standards

7.4 In my view, this scenario represented a *"single point failure"* and a breach of general *"fire zone"* safety standards applicable to the original Nimrod MR1 and MR2 designs in 1969 and 1979, in particular AvP 970 Chapter 715.[2] As explained in **Chapter 4**, I do not accept the (frankly far-fetched) argument put forward on behalf of BAE Systems that a failure of the Cross-Feed/SCP duct would somehow 'blow all the fuel away' and that an ignition scenario was not credible. (For duct design issues, see **Chapter 4** generally).

Maintenance policy

7.5 Prior to the loss of XV230, the Nimrod bleed-air system was maintained under a policy of 'Corrective Maintenance'. The hot air ducts between the engines (including the Cross-Feed ducts) were subject to a leak test under pressure at Minor, Minor Star and Major maintenance.[3] Insulation muffs were removed during this process to facilitate inspection. The Maintenance Policies (MP) for the inspection note that: *"Examination is to be both audible and visual, checking for leaks and cracks. Particular attention is to be paid to the ducting bellows*

[2] AvP 970, Volume 1, re-issue, 1 June 1960.

[3] Using Maintenance Procedures (MP) 48-00 and 23-11/6.

and leak detection fluid is to be used if small leaks or cracks are suspected".[4] In addition, those ducts within the engine bays were visually inspected at Primary maintenance.[5] It should be noted that the SCP duct which failed on XV227 was not included in any of these pressure tests. It was pressure-tested after reassembly during scheduled maintenance, but the main aim of the associated maintenance procedure was to confirm the correct functioning of the SCP system, rather than to check for duct leaks.[6]

7.6 In a note to the Nimrod IPT dated 17 April 2008[7] discussing leakage from the hot air ducts, BAE Systems stated that *"all leaks detected over the past 20 years are localised to the bellows assembly"* and *"current Maintenance Procedures are successfully detecting defects"*. The note also stated that *"there have been no catastrophic failures of ducts on the aircraft that have been subject to these Maintenance Procedures"*. Nonetheless, by the time this note was written, a decision had been made to retain the testing procedures, but to replace the Nimrod's high pressure hot air ducts (the Cross-Feed duct and its connections to the engines). The SCP system has not been used since the loss of XV230. Two factors appear to have acted as the catalyst for this change. First, the findings of the XV230 BOI in relation, in particular, to the poor state of much of the Refrasil insulation around the ducting. Second, the implications of an earlier incident in 2004 involving XV227, which highlighted the risks of corrosion in the hot air ducts causing their failure.

7.7 The maintenance policy of the Nimrod bleed-air system is now effectively one of 'Preventative Maintenance', which has led to a large number of the bleed-air ducts being replaced.[8] Since 31 March 2009, only Nimrods in which the bleed-air ducting has been replaced have been permitted to fly.

History of Nimrod Hot Air Ducting and Corrosion

7.8 During conversion of the Nimrod MR1 to MR2,[9] the hot-air system's four-way duct in the bomb bay was changed to a five-way duct to allow connection of the SCP. The fact that the introduction of the SCP would lead to a change in Cross-Feed system usage and the discovery of *"considerable corrosion"*[10] in ducts removed from MR1 aircraft led to British Aerospace Plc (BAe) being contracted to produce a report detailing the predicted fatigue lives of the hot air system's ducts.[11] Depending on how the aircraft's system was utilised (*i.e.* whether the ducting was in continuous operation), the report concluded that certain ducts would not meet their required life.[12] BAe accordingly recommended that certain safeguards were put in place, such as a duct rectification or replacement programme, fitting a pressure-reducing valve on the Cross-Feed duct next to the engines, as well as carrying out regular inspections to minimise the risk of any premature failures. Six copies of the report were provided to the MOD's Resident Technical Officer (RTO) based at BAe for onward distribution within the MOD and the RAF.

7.9 It would appear from a HQ Strike Command document on *Hot Air Ducting – Corrosion/Fatigue* dated 25 November 1983 that the RAF took on board many of BAe's recommendations, deciding that the high pressure ducts, including the five-way duct, should be changed at the second major servicing after conversion and that a task should be placed on the Central Servicing Development Establishment (CSDE) to investigate and recommend a servicing policy/procedure for periodic inspection of the Nimrod MR2 high pressure air ducts.

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[4] MPs 48-00/3 and 23-11/6.

[5] Zones 410, 420, 430 and 440 in accordance with AP101B-0502/ 0503-5A1 sin 480006.

[6] Maintenance Procedure 23-12/1 Tail Pack – Functional Test.

[7] MB/0014-04-/dpw dated 17 April 2008.

[8] This is called the Nimrod Hot Air Duct Replacement Programme (HADRP).

[9] The RAF took delivery of 35 upgraded MR2s between 1978 and 1984. XV230 was one of those upgraded.

[10] "Nimrod MR Mk 2 Fatigue Lives of Hot Air Ducting for the Supplementary Cooling Pack System", BAe-MSO-R-801-0188, dated May 1982, paragraph 8,

[11] Ibid.

[12] Ibid.

7.10 Following BAe's May 1982 report, the RAF provided further information regarding the Nimrod's operational procedures to BAe in October 1982. In light of this further information, BAe re-calculated the fatigue lives for the Cross-Feed bleed-air ducting and set out its calculations in a further report dated January 1984[13]. As before, a copy of this report was provided to the MOD's RTO. The report highlighted the potential damage that could be caused by a fracture of an element of the hot air system, recognising that there *"could be potential damaging to structure (spar), aircraft control systems and bomb bay loads"*.[14] It concluded that, from theoretical calculations, the fatigue lives for the Cross-Feed ducting had either been exceeded (for the ducting mounted on the outboard side of rib 2) or were low (for the ducting between the two Cross-Feed air valves up to the five-way duct) compared to the required life of the aircraft. It was nonetheless acknowledged that a *"safe factor of 5"*[15] had been applied and that *"only one serious leak has occurred"*.[16]

7.11 In light of its findings in its January 1984 report, BAe recommended that *"a programme of inspection and replacement should be initiated immediately"*.[17] Subsequent documents (see below) make clear the fact that the policy of 'replacement' now simply referred to replacing ducts as they failed, not undertaking a structured replacement programme. It recommended that inspections for leaks should be carried out at the earliest opportunity and at every Minor maintenance thereafter, with defective ducting being replaced. The report also recommended that *"a programme is initiated to provision adequate spares to support the replacement of all the hot air ducts in runs 1 and 2b[18] at least once in the life of the aircraft"*.

7.12 On 12 January 1984, the Nimrod Structural Integrity Working Party (NSIWP) was informed that the January 1984 BAe report "*showed that many of the ducts on the aircraft had already survived for nearly twice the calculated (factor 5) life"*, thus the *"previous philosophy of changing at 2nd major was therefore no longer relevant."*[19] To make it perfectly clear *"BAe reiterated that pipes were no longer lifed but changed on condition."*[20] At a subsequent meeting of the NSIWP, the Headquarters Strike Command (HQ STC) representative stated that, while the short-term policy was to leak check, *"in the longer term the policy would be to change the complete system once in the aircraft lifetime"*.[21]

7.13 Following these reports and meetings, the MPs discussed above were introduced. These MPs appear to have been successful, in that there have been no catastrophic failures of ducts in the areas which they addressed; however, as was discovered after the XV227 incident, the only pressure test of the SCP system aft of the PRSOV was conducted after Major maintenance. It would further appear that, in accordance with the BAe recommendation on spares provision, in February 1984, HQ STC initiated urgent provisioning action for 20 aircraft sets of spare ducts.

7.14 The long-term aspiration to replace the ducts was still being advertised by HQ STC in October 1984: *"the EA's long term policy is to replace all the ducts concerned at least once during the remaining in-Service life of the Nimrod"*.[22] However, whilst the ensuing years saw continued discussion of a proposed replacement programme for the ducts,[23] it never in fact materialised. This may well have been at least in part due to the low number of leaks detected during testing. For example, a report of the Nimrod Aircraft Engineering Defect Investigation Team (NAEDIT) in 1989 noted that *"It appears that the resources expended on applying [the leak checks of the high pressure duct system] have yet to find faults consistent with the concern expressed by the DA* [BAE] *over the fatigue life of the ducting."*[24] Given that this report was produced almost seven years after the initial BAe report highlighting that many of the ducts had passed their fatigue lives, the MOD's questioning approach to the initial BAe recommendations is perhaps understandable, if not wholly justifiable. However, despite its apparent

[13] BAe report 801/MAN/DES/277, dated January 1984.

[14] Ibid, paragraph 3.2.

[15] Ibid, paragraph 4.2.

[16] Ibid, paragraph 4.3.

[17] Ibid, paragraph 5.1.

[18] The Cross-Feed system, from the engines to the 5-way duct.

[19] Minutes of the NSIWP held on 12 January 1984 (DD Nimrod 16/19, dated 18 Jan 1984).

[20] Ibid.

[21] Minutes of the NSIWP held on 30 October 1984 (DD Nimrod 16/19, date indecipherable).

[22] STC/13004/7/1/ Strike Eng 21a, dated 9 October 1984.

[23] For example, in April 1988, the MOD was still stating that "*a programme to replace [25 hot air ducts] will be implemented at Major servicing*": STC/13004/7/1/Srt Eng 21a, dated 7 April 1988.

[24] NAEDIT/1505/88/21/Task (Ao1124), dated 22 Mar 1989.

efficacy (see above), the testing procedure of pressurising the ducting, checking visually and by holding one's hands against the ducts was far from foolproof.[25] Further, this testing method plainly could not detect the spread of corrosion within ducts. This also illustrates the potential pitfalls of a Corrective Maintenance policy that is not supported by a programme of additional safeguards, such as component sampling.

7.15 It is also likely that, as time wore on, the Nimrod's anticipated Out-of-Service date was a factor in the decision not to replace the ducts. For example, an internal Minute dated 24 July 1990[26] refers to a *"review of requirements based on the now planned earlier retirement of the aircraft*". Whatever the precise reason, what is most concerning to my mind is that, following the BAe reports in the 1980s, the over-arching concerns that had been expressed in relation to the corrosion and fatigue lives of the hot air ducts appear to have faded into obscurity. Whilst the hot air ducting did come under the spotlight again in the early 1990s, this was due to a series of hot air leaks provoking a number of Rib 2 overheat warnings. More particularly, in the five years leading up to December 1994, a total of 57 hot air leaks within the Rib 2 area were reported. It was determined that the majority of the incidents (36) were caused by *"unserviceable Avica V-flange couplings".*[27] As part of the remedial actions, improvements were suggested to the leak detection procedure in order to increase the chances of detecting small leaks following maintenance.

7.16 During the course of the investigations into the hot air leaks in the Rib 2 area, both NAEDIT[28] and Aerospace Maintenance Development and Support (AMDS)[29] were tasked to investigate methods of hot air leak detection on the Nimrod. It would appear, however, that these investigations were not carried forward once the problem with the V-bland clamp issue (see above) was resolved.

7.17 In light of the above, by the time of the failure of the hot air duct on XV227 (see below), it is fair to say that there had been almost 25 years in which sporadic concerns had been expressed in relation to the hot air duct system on the Nimrod. It is also fair to say, however, that the fatigue lives provided by BAe in the 1980s did indeed prove to be hugely pessimistic. From the evidence provided to the Review, the great majority of reported duct leaks prior to XV227 originated from V-flange couplings, seals or misaligned pipes. These failures caused minimal, or no, damage. However, that a serious failure has not yet occurred does not mean that it will not do so, or that the minor precursor does not have more serious potential. Even if they were overly pessimistic, the BAe reports of the 1980s clearly demonstrate that the potential dangers of a hot air duct fracturing were known about from the very first considerations of the corrosion found in the ducts at that time. Inevitably, there is always an element of uncertainty in calculating the potential for any event to occur.

7.18 The documents provided to the Review indicate that the MOD believed that it would detect a leaking hot air duct before it became a risk to the aircraft. In the case of those areas subject to pressure testing, the evidence would suggest that the belief was correct (at least in terms of catastrophic failures). However, the SCP system, downstream of the five-way valve which had featured in BAe's initial reports on concern with corrosion in 1982, was not part of the pressure testing regime,[30] and the XV227 incident in late 2004 amply demonstrated the potential catastrophic damage that a ruptured hot air duct can inflict.

Nimrod MR2 XV227 incident (November 2004)

7.19 On 23 November 2004, Nimrod XV227 suffered a potentially catastrophic in-flight failure of the expansion bellows in the SCP duct system (flexible duct assembly 6M4V10673A). These expansion bellows are joined to the SCP 'elbow' and are located at the bottom of the starboard No. 7 Tank Dry Bay in the specially fashioned fairing external to the fuselage*, i.e.* the area identified by the BOI as the most probable source of ignition for XV230's fire.

[25] "Tornado Environmental Control System Hot Gas Leak Procedure", AMDS Report 2150/97, dated July 1997; SMG/512752/8/SM60a1, dated 14 September 1998; AMDS Report No. 2292/97, dated September 1997.

[26] D/MAP/205/2/3/2, dated 24 July 1990.

[27] "Aerospace Maintenance Development and Support (AMDS) Task 2525/94 – Nimrod Rib 2 Hot Gas Leak Detection", LC/165827/2525/94/AMDS/AE, dated 17 February 1997, page 1.

[28] NAEDIT Task 1/97, dated 31 January 1997.

[29] See AMDS Report No. 2292/97, dated September 1997: "Investigation to Improve Hot Air Leak Detection on Nimrod".

[30] Possibly because it operated at a lower pressure than those areas that were pressure tested.

7.20 When XV227 landed on the day of the incident, the aircrew had not noticed any abnormalities, but were advised by the ground crew that there was a hole in the fairing of the SCP duct. Examination by the ground crew indicated that the expansion bellows had fractured, allowing the hot air to escape, both to atmosphere and within the No. 7 Tank Dry Bay. Because of the potentially catastrophic nature of the event, a Unit Inquiry (UI) was convened. I discuss the findings of the UI further below.

Cessation of use of the SCP following the XV227 incident

7.21 On 26 November 2004, the Nimrod IPT issued an Urgent Technical Instruction (UTI)[31] that required, within seven days, a visual fleet inspection of the duct that had failed on XV227 (looking for evidence of hot air leakage) and of the adjacent structure (looking for any signs of scorching and discolouration). Given the proximity of the failed duct to the No. 7 fuel tank, UTI/NIM/026, issued on 10 December 2004, further required that the SCP should be electrically isolated for "*Nil use*" across the fleet pending further advice from the IPT.

Investigations following the XV227 incident

7.22 The IPT's initial report of the incident on XV227 (Annex A to BP 1301) recognised that it might have wider implications for airworthiness and referred to the need to investigate whether any similar ducts posed a risk to the airworthiness or the flight safety of the Nimrod fleet. BAE Systems was accordingly commissioned by the Nimrod IPT to carry out a formal fault investigation of the failed duct and to undertake a study to identify similar bleed-air ducts that might be vulnerable to a similar failure (PDS Task 16/3468).

7.23 BAE Systems provided its conclusions in relation to PDS Task 16/4368 to the Nimrod IPT on 7 January 2005,[32] identifying those sections of ducting which incorporated bellows which were subjected to high pressures and temperatures. BAE Systems noted that *"the duct failure presents a significant risk to the continued safe operation of the Nimrod aircraft"* and recommended that a feasibility study be conducted to develop a bleed air leak detection system. The IPT duly tasked BAE Systems to carry out such a study.

7.24 On 10 January 2005, following laboratory analysis, BAE Systems reported the results of its fault investigation of the failed duct.[33] BAE Systems concluded that the ducting contained a number of locations along its length where pitting corrosion had occurred, in particular at the enclosed ends adjacent to the welded joint securing the retaining ring to the ducting. The strength of the duct had also been weakened by cracking in the area of the corrosion. A few days later, on 14 January 2005, BAE Systems sent to the Nimrod IPT its Fault Investigation report (MOD Form 761) into the incident. That report contains a number of noteworthy comments, as follows:

7.24.1 The narrative report included that *"it was suspected that fuel contamination had occurred due to the proximity of fuel tank 7 to the hot air leak."* (The fuel contamination referred to was discoloration of the residual fuel in the No. 7 fuel tank.)

7.24.2 The section on fault trend analysis noted: *"For reference only: A bleed air duct failure of this nature, in this aircraft zone, is recognised in the Nimrod Baseline Safety Case hazard ref. NM/H73."* (It is regrettable that further analysis in relation to the hazards identified in the Nimrod Safety Case (NSC) was not undertaken; see further **Chapters 10** and **11**).

7.24.3 The fault investigation and conclusions noted that *"the failed Flexible Duct was manufactured in 1980 and it is believed that it was installed on to XV227 in 1986. This duct is not a lifed item although a report was published by BAE which recommended the lifing of this type of duct (1982) ... It is not apparent whether any of the information in this report was adopted into the Nimrod Servicing Schedule."*

7.24.4 It was noted in the recommendations that the Nimrod IPT had placed an order enabling a fleet-wide replacement of these ducts. Pending the introduction of the new items or any favourable outcome of the follow on work (*i.e.* the investigation into the bleed air detection system) BAE Systems recommended that the SCP remained isolated as directed under UTI/NIMROD/026.

[31] UTI/NIM/025, dated 26 November 2004.

[32] Reference: MBSY/WRB/06015, dated 7 January 2005.

[33] "Investigation into failure of Nimrod duct assembly (AFT/NIMROD/657)", Document No: CHD-TFM-R-ISA-MB1383, dated 10 January 2005.

7.25 In February 2005, BAE Systems published its Feasibility Study into the Introduction of a Bleed Air Leak Detection System.[34] The study recommended a system which could be used both to detect leaks and automatically shut down the cross-bleed air. The study also noted that the flow-limiting venturi, used to detect air leaks in the SCP duct downstream of the duct that failed on XV227, would only detect leaks above a certain threshold level *"thus a high magnitude of leaking airflow would exist undetected"*[35]. The ten page document was, however, a high-level feasibility study and noted that *"the current main concern...rests with the detailed design solution further required to achieve a fully workable system".* As discussed further below, the Nimrod IPT was in due course to decide against fitting such a system, on the grounds that to do so was *"not practical* [when] *factored against the MR Mk2 OSD"*.[36]

7.26 On 3 March 2005, pursuant to PDS Task 16-3491, BAE Systems sent to the Nimrod IPT its *"Provisions of Repair/Recovery Advice"* in relation to the failure of the SCP duct on XV227.[37] The work undertaken by BAE Systems in this respect included an investigation into the residual strength of the lower rear spar in the area adjacent to the failed duct which had been affected by heat. This was found to have been reduced by approximately 25%. (In the event, the damage to the aircraft was so severe that it was deemed to be incapable of repair and XV227 was cleared for one flight only, in benign weather conditions, to join the MRA4 conversion programme). BAE Systems' advice of 3 March 2005 also referred to the fact that seals removed from pipe couplings adjacent to the duct failure were found to have suffered significant deterioration, stating that it was *"strongly suspected that the deterioration of the polysulphide seal material has been caused by exposure to excessive temperatures".*

The decision to switch back on the SCP

7.27 In view of the corrosion detected on the duct that failed on XV227, the IPT decided that that particular duct should be replaced on all Nimrod MR2s. On 26 April 2005, the Nimrod IPT issued a Routine Technical Instruction (RTI) which permitted the SCP to be switched back on, and used in flight, once the relevant bellows section of SCP ducting had been replaced, which work had to be carried out at the first suitable maintenance opportunity after receipt of the replacement duct.[38] Pursuant to this Instruction, the replacement of the relevant section of ducting duly took place on the MR2 fleet between April 2005 and April 2006.[39]

Rationale of the Nimrod IPT's decision to switch back on the SCP

7.28 The IPT's decision to allow the use of the SCP following the XV227 incident was based on its belief that all hot air leaks (with the exception of any from the SCP bellows that had failed on XV227 and which were to be replaced) would be detected by the aircraft's overheat detection system or other warning system (see further below). As the SCP bellows had been replaced and, as the only example of that duct to fail (XV227's) was over 20 years old when it fractured, it was felt that there was a minimal risk of the same duct failing again. The logic of this line of argument meant that the IPT could consider resuming use of the SCP before receiving the results of BAE Systems' further work into corrosion in other elements of the hot air system: even if a duct failed it would be detected, enabling the crew to shut the system down before damage was caused to the aircraft. The IPT had sought clarification from BAE Systems as to the capability of the hot air leak detection systems, but were told *"we are unable to comment on the capability of the existing system to detect such leaks without further study and tasking."*[40] This would appear to demonstrate either: (a) a surprising lack of knowledge of the capabilities of 'as designed' systems by the aircraft designer itself; or (b) a marked reluctance to disclose important, safety related design information without being formally tasked and paid. In seeking clarification, the IPT was obviously considering the possibility of the existing hot air warning system not having comprehensive coverage. It seems it then decided to go ahead and undertake its own assessment of the position.

[34] Report No. MBU-DES-R-NIM-210758. dated February 2005.

[35] Ibid.

[36] Out-of-Service Date.

[37] RJO-NIM-05-003.

[38] RTI/NIM/119, dated 23 April 2005; Nim(ES)Av(A).

[39] The relevant section of ducting was replaced on XV230 on 4 July 2005.

[40] E-mail dated 19 January 2005, titled "RE:Task 16-3468", from BAE Systems and Nimrod IPT.

7.29 However, the IPT's assessment proved to be imperfect and was based on an overly optimistic understanding of the capabilities of the centre section overheat detection system. The Nimrod's overheat detection system has 28 detectors (temperature sensitive switches) that operate warning lights on the air engineer's panel if they detect a temperature rise above a pre-set level. The detectors are connected in five groups, operating at either 150°C or 230°C depending on their installed position. One group is positioned in each Rib 2 (between each pair of engines) and one group in each wing leading edge. The remaining group forms a *"centre section"* overheat detection system, as described in the Aircrew Manual Book 1 (Technical).[41] However, this description is, to some extent a misnomer: this element of the system in fact consists of ten sensors in two groups either side of the aircraft fuselage. The actual locations of the sensors are: one in the No. 7 Tank Dry Bay, one just in the bomb bay (adjacent to the No. 7 Tank Dry Bay) two in Rib 1 and one in Zone 2 of the inboard engine.

7.30 In view of the detection temperature of the centre section overheat sensors, it is unlikely that they would detect anything other than a leak in their close vicinity, meaning that a significant section of the Cross-Feed pipe as it traverses the bomb bay is effectively unmonitored. Further, in the case of XV227, the No. 7 Tank Dry Bay had been filled with enough hot air to cause significant and widespread damage. One of the centre section overheat system's detectors is in that bay and yet there is no record of it being activated. Unfortunately, there is no record of whether or not this sensor was subsequently tested for serviceability. It was worth remembering, however, that in the case of XV230, the BOI recorded that the centre section overheat warning was not reported as activated by what was, without doubt, a large fire within the aircraft's starboard No. 7 Tank Dry Bay, the heat from which reached into the bomb bay. The BOI did note that there could be two explanations for this: (1) the electrical power to the system could have been disrupted by the fire before it could register the rise in temperature; or (2) another possibility was that the centre section overheat was triggered at about the same time as the other alarms, but the air engineer chose not to mention it on intercom as it was, by then, superfluous.[42] There is nonetheless, in my view, sufficient evidence to conclude that the centre section overheat sensors would not necessarily detect a leak in the Cross-Feed pipe as it traverses the bomb bay.

7.31 This was, of course, a weakness that had existed in the aircraft since its inception, but a more detailed analysis should have picked it up. Indeed, the XV227 UI had noted this weakness: *"there is no hot air leak warning system for the ruptured duct <u>or the cross-bleed air duct</u> as it passes through the bomb bay"*. One of the UI's recommendations was that a leak-detection capability should be fitted for the *"ruptured duct <u>and cross-air bleed ducts"</u>* <u>(emphasis added)</u>, although this was subsequently rejected as it could not be fitted in the remaining life of the aircraft. The UI report was published in July 2005, some two to three months after the decision was taken to switch the SCP back on in April 2005. As noted above, the BAE Systems study into a leak detection system had also identified a weakness in the current warning system, *i.e.* that the venturi/under pressure warning system would only detect relatively large leaks. However, at no stage does anyone appear to have attempted to reconcile the conflicting views of the IPT, BAE Systems and the UI over the efficacy of the aircraft's hot air leak detection system.

7.32 It was suggested at the Inquest by Air Commodore George Baber that the decision to allow the SCP to be switched back on was not simply an engineering decision, but was further influenced by pressure from the aircrew community: *"And in conjunction with discussions with our operating crews, and it wasn't just a sole IPT decision, this was done in conjunction with the operating crews, the decision was made that this was a sensible thing to do"*.[43]

7.33 Whilst a number of Nimrod IPT witnesses confirmed to the Review that the operator community was keen to regain the use of the SCP (particularly as summer approached in the Gulf), there is no evidence to suggest that the decision to switch the SCP back on after the XV227 incident was improperly affected by operational pressures. On the contrary, the aircrew at RAF Kinloss relied on the engineering judgment of the IPT to provide them with an aircraft that was safe to operate.

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[41] AP101B-0503-15A, Part 2, Chapter 8.

[42] With a bomb bay fire alarm, an underfloor warning activated and reports of smoke coming from two underfloor bays, reporting the centre section overheat would have added nothing to the crew's understanding of the situation.

[43] Inquest transcript, 13 May 2008, page 227.

BAE Systems' June 2005 Report

7.34 Following the duct failure on XV227, the Nimrod IPT recognised that none of the bleed air ducts were lifed items and tasked BAE Systems with producing a lifing policy for each of the ducts identified as vulnerable to a similar failure as that which occurred on XV227 (PDS Task 06-3487). In the course of its work, BAE Systems reviewed its 1982 and 1984 reports on the fatigue lives of the ducting (see above). In its new report,[44] BAE Systems concluded that, due to the difficulty of inspecting the relevant ducts and the potential for collateral damage to the primary structure of the aircraft or its critical systems (such as hydraulic and fuel pipes and flying control cables), and adopting conservative calculations, the majority of the ducts identified in the report were *"life-expired"* and required replacement.

Unit Inquiry Report

7.35 In July 2005, the RAF UI issued its Report in relation to the duct failure on XV227.[45] The investigation's conclusions mirrored those of BAE Systems in January 2005, namely, that the cause of the duct failure was pitting and cracking corrosion in the section of duct which failed. The UI found that the lack of any maintenance policy for the section of the duct that failed was a contributory factor in its failure and recommended that a lifing policy should be introduced for the ruptured duct and all similar ducts. In paragraph 29, the UI report stated:

> *"It is important to note that there are other ducts of similar construction used within the engine bleed air systems. As the conditions that caused the extensive corrosion in the ruptured duct are present throughout the rest of the system, it must be considered that other ducts will be subject to the effects of corrosion. However, the possible implications of a failure in some other sections of the bleed air system are mitigated by the presence of hot air leak warning systems. There is no hot air leak warning system for the ruptured duct <u>or the cross-bleed air duct as it passes through the bomb bay</u>"* (emphasis added).

7.36 Thus, unlike the Nimrod IPT, the UI appears to have appreciated that the duct which failed on XV227 was not the only element of the Nimrod's hot air duct system which was unprotected by a leak detection system (see above). Accordingly, the UI's recommendations included not only that a lifing policy be introduced for the ruptured duct and all similar ducts, but also that a hot air leak warning system be introduced for the ruptured duct and cross-bleed air ducts.

Rejection of BAE Systems' lifing policy and proposed leak detection system

7.37 The recommendations made by BAE Systems in their June report for hot air duct life were accepted by neither the Nimrod IPT, nor personnel at RAF Kinloss. In his comment on the UI report, Officer Commanding Logistics Support Wing noted: *"Much work has already been started along the lines suggested. In particular, a SCP-duct sampling programme... will help inform the difficult decision facing the NIPT when considering changes to the current on-condition lifing policy when faced with a DA recommended 90 fgh[46] (approx P maintenance) inspection regime. This recommendation is deemed risk averse and almost certainly unaffordable and some informed compromise is needed."*

7.38 It is important to place the rejection of BAE Systems' lifing policy in context. The analysis and recommendations in its report of June 2005 represented the culmination of over 20 years of similar recommendations to life the Nimrod's hot air ducts. As noted above, the previous recommendations had, as a matter of fact, proved overly pessimistic. The BAE systems report, while recommending a safe life for some hot air ducts of 90 flights, noted that *"since conversion to MR Mk 2...a typical aircraft will have accumulated around 2400 flights"*. In other words, if BAE Systems' recommendation had been made and accepted at the start of the Nimrod's conversion to MR2, these ducts would have been replaced on each aircraft some 26 times in approximately 25 years. The

[44] "Fatigue Lives of Hot Air Ducting from Engines to Supplementary Cooling Pack System Precooler", Report No. MBU-DEB-R-NIM-FF0786, dated June 2005.

[45] Air Incident Report KIN/97/04.

[46] This would in fact appear to be a mistaken reference to the BAE systems' recommendation of a safe life for some ducts of 90 flights (approximately 450 – 500 flying hours), not 90 flying hours.

combination of consistently pessimistic Design Authority predicted lives for the hot air ducts and a minimal number of failures detected during inspection[47] seems to have engendered an atmosphere of *ennui* among those responsible for ensuring the integrity of the hot air system, such that no positive action had been taken to resolve and explain the discrepancy in views. However, while rejecting the duct lives determined by BAE Systems in June 2005, the Nimrod IPT was nonetheless convinced that the ducts should be lifed, but that more credible figures should be determined. As a result, BAE Systems was tasked with further work (see below).

7.39 As regards the UI's recommendation that a hot air leak warning system should be introduced for the duct which failed on XV227 and for the Cross-Feed bleed air-duct, even following the UI Report, the IPT continued to hold the view (relying on the presence of the centre section overheat detectors) that the only duct not covered by such a system was the one that had failed on XV227 and which was subsequently being replaced throughout the fleet.[48] In any event, the IPT ultimately decided not to proceed with the proposed warning system, on the basis that it was not practicable to do so given the length of time it would take to introduce such a modification into service compared against the MR2's OSD.[49] As mitigation in support of this decision, the IPT noted that the aircrew procedures in relation to SCP malfunctions had been amended so as to increase awareness of SCP duct failures.

Further investigations into the life of the ducts

7.40 The IPT did, however, adopt the other recommendations of the UI into XV227, including that the ducting which had been removed from XV227 should be the subject of a test programme in order better to inform decisions on a safe life for each duct. BAE Systems was tasked to carry out this exercise. From late December 2006 into 2007, BAE Systems issued a number of reports to the Nimrod IPT with the results of its pressure testing and examination of the ducts.[50] At a strategy meeting held at BAE Systems Chadderton on 20 February 2007, it was agreed that that BAE Systems would categorise the different sections of duct identified in its June 2005 report according to the likelihood of significant collateral damage to fuel pipes and tanks in the event of duct failure, and therefore the priority for their replacement. It was further agreed that BAE Systems would provide the IPT with a lifing policy for all of the relevant ducts.

7.41 BAE Systems reported back to the IPT in a letter dated 8 March 2007,[51] setting out its conclusions in relation to these two tasks. A replacement category of 1 (i.e. the most important) was attributed to the ducting which was close to the No. 7 fuel tank, and also to ducting which was close to fuel pipes in Rib 2. For the vast majority of the ducts, a safe life of 2,500 flying hours was given. For reasons which remain obscure, the Nimrod IPT did not receive a copy of BAE Systems' February or March 2007 reports until June 2007 (and hence these were not available to the BOI when preparing its report on XV230). Subsequently, in response to an IPT request for clarification dated 3 December 2007, BAE Systems confirmed that its lifing policy recommendation also covered non-critical, non-bellowed ducts and that its intent was that the life of all ducts in the system should be the same, i.e. lifed at 2,500 flying hours. This decision was agreed between the IPT and BAE Systems, based on a combination of BAE Systems' theoretical calculations and the results of tests on actual ducts. The life is significantly greater than the purely theoretical figures previously quoted, but also significantly less than the life displayed by the great majority of the aircraft's hot air ducts. The simple fact is that, having been replaced, the ducts will not need further replacement within the predicted life of the remaining Nimrods.

[47] This attitude does appear to be contradicted by an IPT generated document following the XV227 incident which states: *"many ducts have already been changed across the fleet due to leaks from the bellows or corrosion"*: ES(Air)(WYT)/512752/8, dated 6 October 2005.

[48] See the IPT's memo on the "Supplementary Cooling Pack Damage Sustained by Nimrod MR2 XV227 – Unit Inquiry Recommendations", ES (Air)/(WYT)512752/8, dated 6 October 2005.

[49] "XV227 Hot Air Duct Failure – Requirement for Leak Detection System", DLO (Strike) (Wyt)/512752/21/227, dated 5 July 2006; BOI Report, Exhibit 24. In fact, the Out-of-Service Date was at the time 2010, not 2012.

[50] e.g. Letter "Nimrod – Testing of Hot Air Ducts Removed from XV227" dated 8 December 2006 and BAE Systems' Document No. CHD-TFM-R-ISA-MB1486 "Pressure Testing and Examination of Nimrod Hot Air Ducts taken from Aircraft XV227 and XV228", dated 28 February 2007.

[51] BAE Systems' Reference: FAT/801R/07/009

Duct Failure on Nimrod XV229

7.42 While the investigations into the duct failure on XV227 were ongoing, on 8 August 2005, another Nimrod, XV229, suffered a failure of a Port Bomb Bay Air Supply Duct.[52] The failure was detected during an engine ground run and consisted of a crack, associated with the loss of a small amount of material. No detection systems were activated by the leak during the ground run, but the expelled air would have been below the 230°C activation temperature. This failure was within the engine bay of the aircraft and there was no secondary damage to the aircraft structure. A BAE Systems investigation determined that the cause of the failure was fatigue. It noted that "*the presence of mechanical damage local to the fracture may have been a contributory factor",* although adding *"as the service life of the duct was unknown, it is possible the initiation of the failure could have been due to cyclic loading".*[53] The IPT was subsequently advised by maintenance personnel that the close proximity of the engine intake to the duct had given problems during fitting in the past and might have been the cause of the observed damage.[54] Nonetheless, the final IPT conclusion was that the failure was caused by *"a fatigue failure with unknown initiation site, however, with mechanical damage...which may have been a contributing factor of the crack initiation".*[55]

7.43 Although the failures on XV227 and XV229 were not directly related, they had occurred within a relatively short period of time and their causes (corrosion and fatigue) could be seen as age-related. Thus, it would not be unreasonable to assume that these incidents could have represented the *naissance* of a series of such failures. I discuss in **Chapters 8**, **10** and **11** the manner in which the IPT took cognisance of this further failure, but failed to consider its wider ramifications.

The decision to switch off the SCP following the loss of XV230

7.44 Following the loss of XV230, on 3 September 2006, the IPT issued instructions to cease using those aircraft systems that might have provided the ignition point or fuel to the aircraft fire. Amongst these was the SCP (and the Cross-Feed duct). As the BOI developed its theory that the SCP was the most probable source of ignition, the instruction was left in force. The XV230 BOI recommended that: *"existing limitations, prohibiting the use of the SCP and of the cross-feed pipe in the air be continued, unless: the pipe insulation is modified in such a way that the pipe cannot act as an ignition source; the study into corrosion within cross-bleed pipes, undertaken following the hot air leak on XV227, is complete and its recommendations acted upon; a hot air leak detection system capable of detecting any leak within the cross-feed pipe and SCP (to the venturi) is fitted."*.[56]

7.45 As a result of the BOI's conclusions the decision was made to make permanent the cessation of the use of the SCP and of the Cross-Feed duct in the air.

Hot Air Duct Replacement Programme

7.46 Throughout 2008, the Nimrod IPT commissioned BAE Systems to carry out further testing (in particular, pressure testing) of hot air ducts removed from the Nimrod fleet.[57] Following completion of all of the pressure testing on the ducting, BAE Systems issued a final report on the structural integrity of the Nimrod's hot air ducts on 19 June 2008, summarising the results of the testing which had been conducted.[58] The report noted that, based on information provided by the IPT, more than 80% of the ducts replaced across the Nimrod fleet during the period 1982-2007 were from the Rib 2 area (i.e. between the environmental conditioning unit and the Cross-Feed air

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[52] Discussed further in **Chapter 8**.

[53] Investigation into the failure of Nimrod duct assembly (AFT/NIMROD/700) document number CHD-TFM-R-ISA-MB1434, Issue 1, dated 17 February 2006.

[54] Document OBA/NM/2089.

[55] Ibid.

[56] BOI Recommendation 65c.

[57] e.g. PDS Task 06/3778, dated 11 January 2008, to conduct laboratory proof pressure testing of 18 hot air ducts removed from Nimrod aircraft XV244 and retired nimrod aircraft XV246. See also BAE Systems' Report: CHD-TFM-R-ISA-ND1539, on proof pressure testing of hot air ducts (ECU to cross-feed cocks) taken from Nimrod aircraft XV244, dated 8 February 2008; and BAE Systems' Report: CHD-TFM-R-ISA-MB1540 Visual examination, x-ray and proof pressure testing of hot air ducts (ECU to cross-feed cocks) taken from Nimrod aircraft XV246, dated 20 February 2008.

[58] BAE Systems' reference: FAT/801R/08/016, Issue 3, "Nimrod – Structural Integrity of Hot Air Ducts – Final Report and Recommendations", dated 19 June 2008.

valves). Amongst other recommendations in the report, BAE Systems recommended that the ducting adjacent to Rib 2 should be replaced as soon as practicable, as these ducts were considered most likely to fail; the Cross-Feed duct should also be replaced as soon as practicable and the SCP should remain permanently mechanically isolated. The report concluded: *"The conclusion from this report confirms that defects continue to be found in ducts as previously reported, in particular from the ECU to Cross-Feed cocks.*[59] *The ducts are past their published safe lives and corrosion damage is prevalent. Consequently, it is recommended by the [Design Authority] that the above recommendations concerning duct replacement and provisioning, increased protection and increased inspections are adopted by the IPT at the earliest opportunity."*

7.47 As a result of this report, in June 2008 the Nimrod IPT issued a Special Technical Instruction (STI 926) regarding a fleet-wide duct replacement programme. This programme required the replacement of the high pressure hot air ducts between the ECU and the Cross-Feed valves, and also those that formed the Cross-Feed system. The Nimrod IPT determined that, for the risk to the aircraft to remain ALARP, the replacement programme should be completed by 31 March 2009 and that aircraft that had not had their hot air ducts replaced by this time would not be flown until the work had been completed. Although it had originally been planned that the programme would be completed by 31 March 2009, delays in the provision of replacement parts rendered this target unachievable; as a result a number of Nimrod aircraft were not flown after this date until the new ducts were fitted.

Causation

Relevance of XV227 and the Earlier Duct Corrosion Problems to the loss of XV230

7.48 The UI into XV227 concluded that the expansion bellows had failed due to corrosion and caused a leak of very hot bleed-air, for up to 40 minutes. Significant damage had been caused to the adjacent airframe structure and systems. In particular, the fuel seals in adjacent pipework were shrivelled almost to the point of destruction (see below). The fuel from the No. 7 tank had been used at an early stage in the flight and there was no evidence of any leakage of the small amount of residual fuel remaining in that tank. However, when fuel was subsequently transferred from the No. 7 tank, damaged seals in surrounding FRS couplings were observed to leak. One of the damaged seals is shown in Figure 7.1. Figure 7.2 shows an undamaged/unused seal. Furthermore, the minimum static reserve factor of the aircraft's rear spar had been reduced by approximately 25%, *i.e.* below the level which *"is normally accepted for safe unrestricted operation of the aircraft"*.[60] Indeed, as stated above, the damage to the aircraft was so serious that it was subsequently cleared for one flight only *"in clear and calm conditions"*,[61] with restrictions applied to its operating envelope, in order to re-locate to BAE Systems Woodford, to join the MRA4 programme.

Figure 7.1: Shriveled fuel seal from XV227 showing effects of severe heating

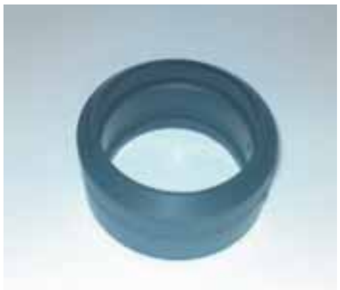

Figure 7.2: Normal Fuel Seal

[59] More properly referred to as 'air valves', not 'cocks'.

[60] Air Incident Report KIN/97/04, page 5.

[61] DLO(Strike)(WYT)/512725/17, dated 7 June 2005.

7.49 The XV227 incident amply demonstrates the risk of potentially catastrophic damage to the aircraft structure and adjacent fuel system seals from an engine bleed-air hot pipe fracture. If the incident had occurred earlier in the sortie, when fuel was present within the No. 7 tank and its adjoining pipes, there could have been a serious fire similar to that which befell XV230 and XV227 could have been lost. The XV227 incident accordingly caused the BOI to give careful consideration to the possibility that a similar hot air duct failure caused the loss of XV230, notwithstanding that it had not been provided with a copy of BAE Systems' February and March 2007 reports (see above).

Did a hot air leak cause the XV230 fire?

7.50 The incident on XV227 is indicative of a potential causal chain of the fire on XV230, *i.e.* a failure of the SCP duct leading to the escape of hot bleed-air causing damage to adjacent fuel seals leading to the escape of fuel and ignition. The BOI concluded, however, that, whilst the SCP was in use at the time and a Cross-Feed/SCP duct failure could not be ruled out, as a causal mechanism for the fuel source, it was much less likely than the other two potential causes (fuel seal failure or over-flow during AAR igniting on the SCP duct). I agree. Nonetheless, I turn below to consider the two ways in which the BOI suggested that a fractured bleed-air duct could have been causative of the XV230 fire, either: (a) a large hot air leak as a result of a major failure of the duct (as with XV227); or (b) a small hot air leak as a result of a smaller fracture.

(a) Large hot air leak

7.51 A major failure of a hot air duct within, or proximate to, the starboard No. 7 Tank Dry Bay could have led to a large hot air leak damaging adjacent fuel seals, resulting in fuel leaks which might have been ignited by hot and exposed elements of the broken duct. The principal reason given by the BOI for discounting such a leak was that it was unlikely *"to have gone unnoticed by the experienced Flight Sergeant Davies",* or the crew who *"would all have noticed the pressure change concomitant on the loss of conditioning air"*.[62] It is important to note that XV230 was operating with a pressurised cabin,[63] whereas XV227 was unpressurised; this would have masked the change in cabin pressure caused by the loss of XV227's SCP. Although the crew intercom recording shows that XV230's SCP tripped-off at 11:09:23 hours, Flight Sergeant Davies clearly did not think it significant and probably linked the event to AAR. Flight Sergeant Davies was one of the most experienced and able Nimrod Air Engineers in the RAF, with 7,817 flying hours on type;[64] an engineer of his experience would have had no difficulty in recognising the symptoms of a duct failure. Further possible explanations of the event are discussed below. Moreover, if this event had been the SCP duct failing, Flight Sergeant Davies could not have received the subsequent warning (reported concomitant with the bomb bay and elevator bay warnings) of an overheated SCP since an SCP failure would have removed most of the hot air from the SCP system.

7.52 There are two entries on the Mission Tape which indicate events associated with the SCP at the time:

7.56.1 The Mission tape at 11:09:23 records a remark from Flight Sergeant Davies (Air Engineer) as the SCP trips-off, causing a pressure change within the cabin: *": …we've just lost the tailpack sorry about your ears."*[65] This remark is made to inform the crew that he is aware of the event and is dealing with it, *i.e.* normal crew courtesy and co-operation on an MR2.

7.56.2 The Mission tape records at 11:12:01 Flight Sergeant Davies commenting, 28 seconds after the fire warning at 11:11:33 and reports of smoke coming from the rear bay: *"Yeah I have an under er an overheated SCP which could be the cause. Attempting to reset the warning"*.[66]

[62] BOI Report, paragraph 38 [2-27].

[63] When the Nimrod MR2 is operating at low level the crew will depressurise the cabin.

[64] BOI Report, Annex B, B-2.

[65] BOI Report, Exhibit 1.

[66] Ibid.

7.53 Dealing with the first entry, Flight Sergeant Davies' comment *"we've just lost the tailpack sorry about your ears"*[67] was made two minutes and 10 seconds before the fire warning. The BOI suggested three possible explanations for the SCP tripping off at this time: (a) the early stages of a fire melted the electrical insulation to the PRSOV (which runs close to the bomb bay firewire in this area), thereby causing a short and the loss of the SCP; or (b) fuel from the blow-off valve of the No. 1 tank could have disrupted the airflow through the SCP pre-cooler, instigating an overheat and shut down; or (c) the SCP has been known to overheat because of airflow disruption in the turbulence experienced behind a tanker, such that the loss of the SCP could be a simple coincidence.[68]

7.54 The second entry, Flight Sergeant Davies informing his captain *"Yeah I have an under er an overheated SCP which could be the cause. Attempting to reset the warning",*[69] was made 28 seconds after the fire warning. This could mean one of two things. It might be that the overheat light illuminated during the 11:09:23 failure and Flight Sergeant Davies was recalling this initial event as he attempted to rationalise the indications on his panel and the report of smoke from the aileron bay. The alternative explanation is that, once AAR was completed, but before the bomb bay fire warning, Flight Sergeant Davies had switched the SCP on again, and the second entry on the mission tape is a reference to a subsequent overheat, perhaps related to the fire.

7.55 In either case, a large hot air leak can be ruled out as a realistic possibility. If an overheat caused the first shut down then it cannot have been caused by a duct failure which would release from the system the hot air necessary to cause the overheat. If an overheat caused a second shut down (because the SCP had been reinstated) then the first event could not have been a duct failure as there would have been no air in the system to cause the second overheat.

(b) Small hot air leak

7.56 As an alternative causal theory, the BOI suggested the possibility of a smaller hot air leak from the Cross-Feed pipe going undetected and causing the necessary disruption to the couplings in adjacent refuel pipes in the No. 7 Tank Dry Bay. The BOI pointed out, however, that a smaller hot air leak *"would have needed a considerable time"* to cause the necessary disruption to adjacent alloy couplings. Hot air at 400°C would have taken some time to cause the necessary degradation. Moreover, it would have had to be coincidentally close to one of the aircraft's fuel couplings.

Conclusion

7.57 For these reasons, whilst the possibility of a small duct failure cannot be ruled out entirely as the cause of the fire on board XV230, in my view, it is a far less likely cause than either a fuel seal failure or AAR blow-off.

Would the Implementation of a Hot Air Leak Detection System have made any difference?

7.58 If the recommended hot air leak warning system proposed post XV227 had been fitted, would it have made any difference to the outcome of XV230's fire? The first point to emphasise is that XV230 could not simply have suffered a repeat of XV227's duct failure. The symptoms presented to the crew were not those that would have been presented if that had happened; the Air Engineer quite simply could not have reported an overheated SCP if the hot air required to supply it was leaking from a massive rupture. The second, and equally valid, point is that the lead times for development and implementation of aviation equipment mean that it is extremely unlikely that any leak detection system could have been fitted prior to the loss of XV230.[70] However, I consider below what possible assistance a leak detection system could have provided to the crew of XV230.

7.59 I am satisfied that, in the most likely scenarios for the loss of XV230,[71] the proposed hot air leak warning system would simply have provided another simultaneous indication that the aircraft had a fire in an area close to the bomb bay and aileron bay. It would not have aided the crew's diagnosis, or given them a greater chance of survival.

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[67] Ibid.

[68] BOI Report, paragraph 27 [2-15].

[69] BOI Report, Exhibit 1.

[70] The IPT estimated that it could not be fitted before the Nimrod retired from service.

[71] Fuel escaping from the fuel system (leaking coupling or No. 1 tank overflow during AAR) and being ignited on the SCP expansion bellows.

7.60 The BOI suggested, as the least likely scenario for the initiation of XV230's fire, the possibility that a hot air duct could have suffered a smaller failure than XV227's which might not have been detected by the aircraft's existing warning systems. Hot air from the leak might then have impacted on a fuel coupling causing it to fail. The leaking fuel would then have been ignited. Although possible, this proposition requires a hot air leak small enough not to be detected by a change in cabin pressure, but large enough to cause damage and coincidentally located next to a fuel coupling. The ignition sequence is also more difficult as a small leak would be unlikely to provide fragmented sections of hot air duct that might act as ignition points; the fuel would have to migrate to an exposed section of hot air duct.

7.61 If this, least likely of all scenarios, had come to pass, it is possible that the leak detection system recommended by XV227's UI could have identified the hot air leak and allowed the crew to shut down the system before a fire ignited. However, as I explain above, it is my view that, on the balance of probabilities, a leaking hot air duct was not the cause of XV230's fire and, accordingly, the decision not to implement this single recommendation of XV227's UI probably had no bearing on the tragic loss of XV230 and its crew.

Should the SCP have been switched back on after the XV227 incident?

7.62 There remains a further important question to be considered, however, namely whether the SCP ought to have been switched back on at all after the XV227 incident? As I explain above, in my view, neither the cause of the leak on XV227 nor the subsequent decision not to fit a hot air leak warning system were of direct causative relevance to the loss of XV230.

7.63 I set out above the rationale behind the IPT's decision to switch back on the SCP. Its reasoning was based on its belief that a leak from any bleed-air duct other than the section replaced following XV227 would be captured by the hot air leak detection system.

7.64 The IPT's decision to switch the SCP back on was an entirely logical one, based on its belief at the time that the existing hot air leak detection system gave complete coverage everywhere, save for the section of SCP duct which was about to be replaced. That belief was, unfortunately, based on an imperfect understanding of the extent of coverage of the hot air leak detection system gleaned from its own assessment. That assessment was made by a desk officer of junior rank within the IPT, based on the documents available. These would appear to have consisted of the Nimrod's technical manuals, detailing the air conditioning assemblies and associated warning systems, and flight reference cards, which detail *inter alia* the actions to be taken following the receipt of warning indications. Although the technical manuals indicate the location and activation temperature of the *"centre section"* overheat detectors, they do not provide any indication of the precise area for which they provide overheat warning, beyond the descriptions *"wing overheat detection system"*, and "*centre section bay port and starboard*". Nonetheless, the desk officer concluded that the sensors would detect any leak in what was described as the *"centre section"* and which he clearly understood to include the section of Cross-Feed duct traversing the bomb bay. The desk officer's superior added to the analysis a short covering note, agreeing that "*should a duct fail elsewhere* [i.e. not the duct that failed on XV227] *in the aircraft it would at least be detected*"[72]; the superior also added a short rider that "*this is of course providing the detection system is 'S'* [serviceable]. *An issue with 227....was the damage caused by the ....failure, so it might be prudent to consider peripheral damage, should a duct 'explode'*".

7.65 The Review has not been presented with any evidence to indicate that further thought was given to the concerns about the effects of peripheral damage before permission was granted to use the SCP once more. Although the initial report into detection system coverage was completed with the best information available to the IPT at the time, that information did not provide a clear indication of the precise area covered by the system and, it appears, the opportunity to consider the potential for the detection system to be disabled by escaping air was given only perfunctory consideration.

7.66 Four points are significant in my view. First, the IPT was obliged to look into what was essentially a design matter itself, because BAE Systems had declined either to volunteer the information, or examine the relevant plans without being tasked to do so (as it was entitled to). Second, the officers responsible for carrying out

[72] Covering note to unreferenced IPT document: "Analysis of BAES Task 16-3468".

the analysis were not aircraft designers. Third, the relevant group of detectors were described in the relevant documentation as the *"centre section"* overheat detection system and thus the reader might be forgiven for not appreciating that the sensors did not, in fact, cover the centre section of the centre section. Fourth, the hot air leak warning system and Cross-Feed ducting were part of the original MR1 design and were the same as had been installed when the aircraft initially entered service and, up to that point, nobody had queried its effectiveness or coverage (with the exception of the subsequent UI report). In these circumstances the errors in the initial analysis of the coverage of the aircraft's existing overheat detection systems were understandable. However, the level of analysis carried out at this stage was unsatisfactory and below what might be expected from an Engineering Authority. More careful analysis was called for, which might have revealed the 'gap' in the coverage of the system.

7.67 A further question arises as to whether the Nimrod IPT ought to have revisited that decision following publication of BAE Systems' June 2005 report into the life of the ducts and the publication of the UI report in July 2005. The BAE Systems paper investigating the bleed-air detection system noted that the flow-limiting venturi would not detect relatively substantial leaks from the SCP system. Furthermore, the UI flagged up the system's incomplete coverage and recommended a leak detection system for both the SCP and the Cross-Feed duct. There is no evidence that either of these documents gave rise to a re-consideration of the earlier decision to switch the SCP back on, or that wider implications were considered, notwithstanding that, even with the SCP turned off, the Cross-Feed duct would have been active during flight, presenting the risk of an undetected leak in any event. The IPT appears not to have considered the clear implications of the BAES and UI documents and to have remained fixated on their earlier, faulty analysis. If these later documents had been given the focus they deserved then a reassessment of the risks of duct failure would necessarily have followed. This might have led to a decision to restrict the use of the SCP and Cross-Feed system, or placed greater emphasis on the need to consider replacement of the Cross-Feed ducts. In many ways this seems another example of the IPT examining faults in isolation and failing to consider their wider implications or impact (see **Chapter 8**). It is also symptomatic of the general malaise of reports being received but not being reviewed with sufficient rigour.

Conclusion

7.68 The analysis carried out by the Nimrod IPT of the coverage of the overheat detection system was, in my view, far from satisfactory. It remains an unfortunate fact that the result of the decision to turn the SCP back on meant that, by a tragic coincidence, the ignition source which led to the loss of XV230 was available.

Section Three: Previous Incidents

CHAPTER 8 – PREVIOUS INCIDENTS AND MISSED OPPORTUNITIES

Contents

Chapter 8 answers the following questions:

- Were there any previous incidents which highlighted the fire risks of fuel coupling leaks and hot air ducts?
- What was the response to those previous incidents?
- Were opportunities missed?
- Were lessons learned?

Summary

1. There were a number of significant incidents in the years before the loss of XV230 which contained warning signs of some of the problems and issues which were potentially relevant to XV230:

   (1) The risk of an airborne fire from misaligned FRS couplings: Harrier XW921 (1988);

   (2) The potential for leaks from fuel couplings to migrate: Nimrod XV249 (1999);

   (3) The risks from split fuel seals: Nimrod XV245 (2000);

   (4) The fire risks from fuel coupling leaking onto a hot duct: Nimrod XV229 (2000);

   (5) The risks of a fuel coupling leak being ignited by a hot duct despite insulation: Tornado ZA599 (2002);

   (6) The risks of the rupture of bleed-air ducting destroying adjacent fuel seals: Nimrod XV227 (2004); and

   (7) The potential increase in risk following a second bleed-air duct failure: Nimrod XV229 (2005).

2. These incidents represented missed opportunities to spot risks, patterns and potential problems, and for these lessons to be read across to other aircraft.

3. Most tended to be treated in isolation as 'one-off' incidents with little further thought being given to potential systemic issues, risks or implications once the particular problem on that aircraft was dealt with. Rarely did anyone attempt to grasp the wider implications of a particular incident for the future, or spot trends or patterns or read across issues to other aircraft. There was a corresponding lack of corporate memory as to related incidents which had occurred in the past.

4. There is a danger in dealing with an incident as a 'one-off' without considering its potential wider ramifications.

5. No-one was taking a sufficient overall view. This re-enforces the need for a New Military Airworthiness Authority as recommended in **Chapter 21**.

Introduction

8.1 In **Chapter 2** I explain that, prior to the loss of XV230, in all the Nimrod's 35 years of service, there had been only four accidents resulting in the loss of an aircraft, namely, XV256 on 17 November 1980; XV257 on 3 June 1984; XW666 on 16 May 1995; and XV239 on 1 September 1995. Of these accidents, only one (XW666) could be attributed to a failure of the aircraft's systems and none of them are directly relevant to the loss of XV230, or illustrate any pattern of faults with the aircraft. I therefore do not discuss these incidents further in this Chapter.

8.2 There are, however, a number of incidents prior to XV230 which, whilst not resulting in the loss of an aircraft, may, on analysis, be said either to corroborate the findings of the BOI and this Report in relation to the most probable physical causes of the fire onboard XV230, or to have provided a warning or indication of the risks inherent in the Nimrod MR2 Cross-Feed/SCP system.

8.3 In the course of its investigations, the Review has examined numerous reports in relation to previous Nimrod and other aircraft incidents, including Boards of Inquiry, Unit Inquiries, Flight Safety Investigations, Air and Ground Incident Reports and Serious Fault Reports.

8.4 With the benefit of hindsight, it is of course possible to observe in many of these potential indicators of the hazard that resulted on XV230. The aim of this Chapter, however, is not to consider each and every one of these reports with the benefit of hindsight, but rather to identify those previous incidents which I consider could have been of particular significance as warning signs for the future, or which are, in my view, indicative of a more general failure to grasp implications or to learn lessons for the future.

8.5 Most tended to be treated in isolation as 'one-off' incidents with little further thought being given to potential systemic issues, risks or implications once the particular problem on that aircraft was dealt with. Rarely did anyone attempt to grasp the wider implications of a particular incident for the future, or spot trends or patterns or read across issues to other aircraft. There was a corresponding lack of corporate memory as to related incidents which had occurred in the past.

8.6 I turn to consider and analyse seven previous incidents which I consider relevant and significant.

(1) August 1988: Harrier GR3 XW921 Accident – Fuel leak leading to airborne fire.

8.7 An early indication of the potential problem of an FRS coupling failing and leading to a fire came in 1988, when a Harrier GR3 XW921 suffered an airborne fire as a result of a fuel leak. Although unable to be conclusive in their findings, the Board of Inquiry into the incident (Harrier BOI) determined that the fuel could have come from two possible sources, one of which was an FRS coupling failure.

8.8 In light of its findings, the Harrier BOI recommended that :

> *"The Harrier EA instigate an investigation into the integrity of this type of FRS coupling. The investigation should include consideration of introducing <u>geometric checks of the coupling on fitment</u>, and the introduction of a lifing policy for the coupling seal."* (emphasis added)

8.9 In a letter dated 31 May 1989 entitled "Harrier GR3/T4 – FRS Coupling Servicing – Schedule Amendment"[1], the Harrier Director of Aircraft Engineering 1 (Harrier EA) stated:

[1] D/DD Air Eng(RAF)56/2/10, dated 31 May 1989.

> *"Following a Harrier accident, the integrity of the FRS couplings was suspected. Some FRS couplings in the Harrier vent system are already changed at major servicing but the remainder are replaced on-condition. Although a fuel leak check is carried out after a servicing, there remains a risk of a major fuel leak from the FRS seals if they have either dried out or been subjected to any shear force. With a design life of some 20 years, age is not a significant factor. Nonetheless, for flight safety reasons we do not wish to leave Harrier FRS seals unchanged indefinitely. It is during a Major servicing that the FRS seals are most likely to dry out and this servicing is also the most desirable opportunity to change the seals. Consequently, we wish to introduce replacement of all Harrier GR3/T4 FRS seals during Major servicing."* (emphasis added)

8.10 The Harrier EA's letter was sent to (amongst others) the MOD's Inspectorate of Flight Safety (IFS). On 17 July 1989, the IFS issued a letter entitled "*Servicing of Fuel System Couplings*"[2] in which it requested that other aircraft types consider the applicability of the Harrier EA's changes to their FRS coupling servicing schedule to their own type. This letter was circulated to Headquarters Strike Command who would then have been responsible for deciding whether further distribution to Groups (including 18 Group, the then operators of the Nimrod) was necessary. The IFS's letter stated as follows:

> *"The accident to Harrier GR3 XW921 in Aug 88 followed engine stagnation and an airborne fire. Although the precise mechanism for these pre-crash occurrences could not be positively determined, inter alia, the Board of Inquiry recommended that the Harrier EA investigate the integrity of the FRS couplings in the aircraft fuel system. As a result of their investigation, at the Reference (enclosed), the Harrier EA tasked the CSDE Schedules Flight with amending the Topic 5 series for the Harrier GR3 and T4 to introduce replacement of all FRS – the more commonly used name – coupling seals during Major servicing. … I understand that FRS couplings are installed on a number of other aircraft types; you may wish to consider whether the Harrier EA's policy is relevant to your aircraft EAs."* (emphasis added)

8.11 The two letters above, issued pursuant to the Harrier BOI recommendation on FRS couplings, appear to demonstrate a coherent and structured organisation attempting to ensure that an issue raised during the investigation of the loss of one type of aircraft was carried over to other aircraft types. However, neither of the two subsequent letters refer to the Harrier BOI's suggestion to consider "*geometric checks of the coupling on fitment*". Although not explicitly referenced, it is clear that this recommendation stemmed from a concern that couplings not assembled within the strict FRS parameters might leak.

8.12 A subsequent internal MOD Minute dated 26 July 1989, addressed to the engineering officer with responsibility for Nimrod and Shackleton, stated: "*Please see the attached copy of reference A, which reports the Harrier EA's decision to replace all FRS coupling seals during Majors as a result of a previous accident. Do we use similar couplings on the Nimrod and Shackleton? If so, please investigate to see whether we should follow the same policy. If not, are our seals analogous, and should we therefore consider introducing this policy? I would appreciate your response by the end of Sep.*" (emphasis added)

8.13 The Review's investigations revealed that the internal Minute referred to above was copied internally to other specialist Nimrod engineering staff, asking for advice in relation to the Nimrod. Following receipt of a data printout on fuel coupling leaks covering the period March 1987 to February 1989, the specialist staff advised that there were approximately 30 such leaks per year on Nimrods and noted that:[3]

> *"[You] will wish to consider the more difficult question of the Nimrod seals. Perhaps an AEDIT task is called for to look more closely at the fault history to identify whether any particular types of coupling seals fail more frequently and establish the potential dangers involved in fuel leaks where the couplings are located. This may narrow down a range of seals which could justify replacement at Major".*

[2] D/IFS(RAF)/48/32/64.

[3] Strike Command Minute sheet – file STC/13004/10, Part 8, minute sheet.

8.14 In the event, however, it was considered that the low rate of 30 leaks per year did not warrant any further action. It would appear that, after a brief consultation with the Nimrod Major Servicing Unit and Nimrod Line engineers at RAF Kinloss, it was agreed that there was no need to change the extant maintenance policy for the Nimrod fleet.[4]

8.15 In my view, there is much that is worthy of note in relation to the Harrier GR3 XW921 incident. First, it is significant that the Harrier BOI considered that the alignment of fuel pipes and couplings was important and recommended "geometric checks", mirroring those made later for the Nimrod aircraft as a result of incidents following the loss of XV230 (see **Chapter 5**). This reflected similar concerns over pipe misalignment as a cause of leaks. It is also noteworthy that, as the sequence of correspondence developed (see above), the recommendation of a "geometric check" was apparently overlooked. It is also interesting to note the comments by the Harrier EA to the effect that this was a safety issue and that the drying-out of seals during Major maintenance was also a factor. As explained in **Chapter 5**, these were all points that came to be recognised again in the aftermath of the loss of XV230.

8.16 It is clear from the documents I refer to above that there was an attempt, following the loss of XW921, to consider the accident's implications for other fleets. However, the Harrier BOI's recommendation was diluted (undoubtedly unintentionally) and the subsequent analysis for the Nimrod was based solely on whether the current leak rate was acceptable or not. It would appear that one of the Nimrod engineering officers considered that some deeper analysis might be warranted in order to ascertain if any of the couplings were failing regularly and, if so, whether they were in locations which could constitute a hazard to the aircraft (see above). Unfortunately, this was not agreed and the decision was taken that the perceived low frequency of coupling leaks (30 per year) did not justify further action. At no future time do any of the Nimrod documents seen by the Review make any mention of the Harrier BOI recommendations (other than the Ground Incident Report considered below).

8.17 It should also be noted that, in 1988, the fuel leak rate for the Nimrod was believed to be 30 leaks per year. This was well above the figures used by those who compiled the Nimrod Safety Case (NSC) some 15 years later (see **Chapter 10**). In more recent discussions with Nimrod engineers at RAF Kinloss a figure of a leak a fortnight (not including wing leaks) was suggested for operational aircraft. It is equally important to note that such a rate was not considered excessive. However, one should bear in mind the point later made by the XV230 BOI and in this Report that any factor which might contribute to a fire should be minimised. In relation to the Nimrod, it was the increase in leak rates over time which should have provoked at least the consideration of remedial measures, not necessarily the absolute number of leaks. This sort of safety-related decision requires maintenance of comprehensive records throughout the life of a platform and, equally importantly, an ability to interrogate them effectively (see the Recommendations in **Chapters 21** and **22**).

(2) c.1999: Nimrod XV249 – history of fuel coupling leaks in Rib 1 area

8.18 Nimrod XV249 was converted from a Nimrod MR2 to a Nimrod R1 in order to replace XW666, lost on 16 May 1995. The aircraft subsequently suffered from a continuous series of fuselage fuel leaks, which eventually led to an extensive investigation and rebuild of the fuselage fuel system. Nonetheless, whilst the aircraft's leaks were eventually cured, it proved impossible to isolate a single system as the point of failure. Analysis of the faults highlighted, *inter alia:* fuel couplings that leaked in flight, but not on the ground; fuel pipes that moved in flight, provoking leaks; and fuel pipes of the same part number, but different construction and lengths. It is noteworthy that fuel leaks originating to the rear of the Rib 1 area (the proximity of the No. 7 Tank Dry Bay) were observed to track to the rear of the wing root, the pannier bay (equivalent to the MR2's bomb bay) and the tail cone. Fuel leaks were also noted to be associated with Air-to-Air Refuelling (AAR) sorties, although not exclusively so. As the XV230 BOI observed, although XV249's problems were attributed principally to its conversion from an MR2 to an R1, coupled with the fact that it had been stored outside for some time prior to conversion: "it does illustrate the potential for complex fault scenarios within the Nimrod's fuel system and the fact that the leaking fuel can potentially find its way to many areas of the airframe."[5]

[4] Ibid.

[5] BOI Report, Annex E [E-2].

8.19 On 26 January 1999, BAE Systems issued a report[6] into the persistent fuel leaks on XV249. It pointed to four potential differences between ground and flight conditions, one of which was that *"there will be structural movement due to flight loads and cabin pressurisation, causing sympathetic movement of the fuel piping and the interconnections."* The BAE Systems report went on to make the following observations:

> *"Past problems with Flight Refuelling couplings leads us inexorably towards understanding the reasons for the system leakage. The catalogue of problems causing fuel leakage due to airframe build difficulties when using FRS110 couplings relate back to the Lancaster, Vulcan, Lightning, AEW MK3 Nimrod, and VC10 CMK1. The Hawker Siddeley Engineering Standard SO8 sets the FRS standard for the manufacture of pipes, the beading of pipe ends and the gap tolerance between mated pipes. The integrity of the coupling demands that these criteria are met at each and every joint, a difficult achievement for the Nimrod airframe especially when each production aircraft has build differences that exceed the permitted tolerance banding for the couplings. …".* (emphasis added)

8.20 The BAE Systems report went on to suggest two particular causes of the problems. First, the fact that XV249 had been placed in storage and was subject to conversion in 1996: "*Couplings previously wetted by fuel and then allowed to dry out, will suffer from deterioration of the rubber, especially if the cycle was repeated again…*". Second, BAE Systems concluded that maintenance work may have led to *"assembly stresses"* being built into the system. Therefore, some seven years before the loss of XV230 and the consideration subsequently given to the lifing of seals, there was already a recognition of some of the factors I discuss in **Chapter 5**, i.e. that the 'drying out' of seals may present a problem and the difficulties of actually fitting the FRS couplings on the Nimrod within the required tolerances.

8.21 It would nonetheless appear that, once the specific problem of the fuel leaks on XV249 was satisfactorily addressed, no wider thought was given to these issues in the context of the Nimrod fleet as a whole. For example, no steps were taken to address the 'drying out' issue during Major Maintenance. Rather, and notwithstanding that the precise cause of the leaks on XV249 was never identified, once XV249 had been proved to operate satisfactorily, the matter was considered closed. Thus, a report on the fuel leak problems on the XV249 by No. 51 Squadron's Senior Engineering Officer, dated 23 July 1999,[7] concluded:

> *"Over the past 6 months, XV249 has undergone extensive investigations to identify an elusive and potentially hazardous major fuel leak, accumulating over 500 manhours maintenance effort. Despite the extent of this work, it has not been possible to pinpoint a specific component within the fuel system as being the sole cause of the leak. However, it can be stated that … the fuel system [has been] completely overhauled. Furthermore, the test flights using fuel dye and with couplings bagged were highly successful in identifying couplings which leak only in the air and allowed correctly targeted rectification to be carried out."*[8]

(3) 13 September 2000: Nimrod XV245 incident – leak from FRS coupling during AAR

8.22 On 13 September 2000, midway through an AAR sortie, the Tristar tanker reported that XV245 was venting fuel from the underside of the fuselage. After landing, fuel was found to be covering the rear fuselage and to be leaking from the No. 6 tank defuel valve outlet FRS coupling. Further investigations revealed that the seal was split. An Incident Report[9] was raised. In the section for Further Actions/Comments, it was noted "*NLS Prop TM [Trade Manager] reports that this is an isolated incident and there is no history of leaks from the subject valve. This statement is supported by both the seal Range Manager and EA who confirm that there is no history of faults with the subject seal.*" The AV(Spey) Remarks/Recommendations then went on to state: "*This incident occurred following a fuel leak resulting from a split coupling seal. Discussion with NLS and confirmed by the seal EA indicates there is no history of leaks associated with this seal. Closed*".

[6] BAe letter PJP/AF/402, dated 26 January 1999: "Nimrod XV249 Persistent Fuel Leaks" (BOI Report, Exhibit 35).

[7] 51S/402/1/1/Eng (BOI Report, Exhibit 26).

[8] Ibid, paragraph 18.

[9] Incident Report KIN/103/00, dated 13 September 2000.

8.23 Again, evident here are the signs of a somewhat 'closed-loop' thinking, i.e. the analysis of events in terms of their perceived frequency, as opposed to in terms of their potential outcome or seriousness, such as to provoke a deeper safety analysis. This was clearly not just a small fuel leak, confined to the immediate area of the coupling.

(4) December 2000: Nimrod XV229 incident – leak from FRS coupling onto hot duct

8.24 Just three months after the above incident, there was a further incident in December 2000 on XV229. Ground crew were conducting ground engine runs while attempting to trace leaks in the SCP's pressure regulating and shut off valve (PRSOV). To do so, they had removed the insulating muff. During the ground runs, fuel began to leak from an FRS coupling in the "*stbd rib 1 rear spar compartment . As the fuel dropped onto the PRSOV and associated ducting it began to smoke*". Investigation revealed that fuel was leaking from the FRS coupling on the No. 6 tank transfer fuel pipe, rib 1, starboard side above the hot air duct. The FRS coupling seal was found to be split and deformed, "*presumably due to ageing, thus allowing fuel to leak out*". A Ground Incident Report was raised[10]. In the section for Further Actions/Comments, it was noted:

> *"Leak attributed to ageing seal and seal has been replaced. However, no trend of ageing seal related faults apparent at 1st Line or through IRD(F&F) Report. This occurrence suspected to be isolated incident and EA will monitor for future occurrences. AC has flown several sorties without related incident and no further action is considered necessary."* (emphasis added)

8.25 In the section for AV(Spey) remarks/Recommendations, it was then noted that:

> *"FRS couplings are susceptible to leakage if misaligned, fitted incorrectly or overtorqued, and whilst we have no explicit evidence of these in this particular incident, we do believe these causes are more likely than ageing. Furthermore, there is evidence on other airframe types (Harrier) of FRS seals leaking due to causes other than ageing. Therefore, other than monitor future arisings for trending [sic], the incident is closed."* (emphasis added)

8.26 In this report, therefore, one sees an awareness of some of the issues that I discuss in **Chapter 5**, namely the fact that seals age and that FRS couplings may leak if incorrectly fitted or misaligned. Once again, however, the incident was treated as an isolated one, without (it would appear) any detailed investigation of any earlier incidents being made. Nor would it appear that the 'smoking duct' (which was admittedly uninsulated at the time) caused anybody to think more widely about the potential risks posed by fuel dripping from a leaking coupling onto one of the hot air ducts or perhaps penetrating the insulation.

(5) May 2002: Tornado GR4 ZA599 Incident – coupling fuel leak ignited by bleed air pipe despite insulation

8.27 In terms of ignition sequence, the incident most similar to the fire which occurred on XV230, was the loss of a Tornado GR4A ZA599 on 17 May 2002, as a result of a coupling fuel leak ignited by a bleed-air pipe.

8.28 Tornado GR4 ZA599 was flying from RAF Marham on a routine low level flying mission when it suffered multiple control failures. Fortunately, the crew managed to eject successfully before the aircraft crashed into the River Humber. The Tornado ZA599 Board of Inquiry (Tornado BOI) found that the aircraft had suffered a mechanical control rod failure as a result of a fuel fire in the spine of the aircraft in Zone 23. The fuel source was a fuel leak, caused by an incorrectly sealed elastomeric 'O' ring in a vent line, dripping and pooling onto the spine floor in Zone 23. The ignition source was the bleed-air Hot Intercooler Ejector Pipe, which was insulated with a two-piece Refrasil jacket which was not liquid or vapour proof. The insulation was found to be particularly vulnerable where there were muffs over bellows attached with spring clips or locking wire.[11] Tests showed the lagging was impregnated with fuel residues.[12]

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[10] Ground Incident Report KIN/142/00.

[11] BOI Report into Tornado ZA599 17 May 2002 incident, paragraph 41(a); and see Annex W: "Interim Evaluation by the Tornado Maintenance School", paragraph 21.

[12] BOI Report into Tornado ZA599 17 May 2002 incident, Annex T: BAE Systems Report BAE-WME-RP-TOR-CHM-300940, dated September 2002.

8.29 A report commissioned by the Tornado ZA599 Board of Inquiry concluded:[13]

> *"Most of the sections of bleed air pipe are insulated with Refrasil material ... Anecdotally the stainless Refrasil jackets are frequently damaged during maintenance activities ... Assuming that a fuel leak either drips or is splashed onto the pipe the fuel will ignite if the temperature is hotter than 240C. There will be an ignition delay time while pre-ignition reactions take place. This is about 4 minutes at 240C but rapidly reduces as the temperature increases (for example it is about 20 seconds at 400C). Of course the same fuel has to be held in contact with the hot pipe for this time but this does not seem to present a problem because the fuel can easily be trapped in damaged Refrasil or under the PTFE grommets. In some ways, in spite of the longer delay time, the lower temperature is the most threatening because the fuel remains liquid and stays in contact with the hot surface rather than quickly evaporating into the passing airflow."* (emphasis added)

8.30 The Tornado thermal insulation or Refraisal blanket appears to have been similar to that used on the Nimrod fleet. It was described in the AAIB report into the incident to the Tornado BOI as comprising "*a fibrous insulating material sandwiched in a thin stainless steel jacket*" which completely enclosed the intercooler ejector supply pipe. However, the AAIB expressly noted that it was "*not designed to be fluid or vapour tight*".[14] This was confirmed by the Design Authority, BAE Systems, who said it was not intended within the design requirement that the Tornado muffs be hermetically sealed so they did not provide a liquid-proof seal[15] (see also **Chapter 4)**.

8.31 The ignition sequence for the Tornado incident would, at first glance, appear to be directly comparable to the loss of XV230. This therefore raises the obvious question why information gained (by both the MOD and BAE Systems) as a result of the Tornado incident was not read across to the Nimrod fleet (and other fleets), *i.e.* why did the Tornado incident not prompt anyone to consider the fire risk in the No. 7 Tank Dry Bay given the presence of fuel couplings above similar hot pipes covered with Refrasil insulation? Why did the Tornado incident not prompt anyone to question the effectiveness of the insulation in the No. 7 Tank Dry Bay and whether it provided a liquid-proof seal in the event of a fuel leak?

8.32 In both its oral and written evidence to the Review, BAE Systems sought to dispute that the findings of the Tornado BOI (and its own reports appended thereto) were "*directly applicable*" to the Nimrod fleet. Its primary basis for doing so was that the type of insulation covering the hot intercooler ejector pipe on the Tornado was different from that utilised on the Nimrod (other than within the engine bays), in that the former comprised two 'half shells' secured together with a spring clip, the ends of which were not secured and did not overlap with other fixed insulation. Be that as it may, it seems to me that this response somewhat misses the point and again highlights the dangers of assessing incidents on an individual basis, without anyone taking a more global, holistic view of the lessons that can be learnt from that incident. If any of those responsible for carrying out the Hazard Analysis of the risks present in the No. 7 Tank Dry Bay and preparing or checking the NSC in 2003 and 2004 had read a copy of the Tornado BOI report, the contents of the report would (or should) have caused them to consider more acutely the risk presented by the presence of the SCP elbow in the No. 7 Tank Dry Bay. It is apparent that no-one connected with the NSC did (see **Chapter 10**).

(6) November 2004: Nimrod XV227 incident – SCP duct failure leading to near catastrophic loss

8.33 As discussed in **Chapter 7**, on 23 November 2004, Nimrod MR2 XV227 suffered a potentially catastrophic in-flight failure of an expansion bellows in the SCP system. This expansion bellows is located immediately aft of, and just below, the No. 7 Tank Dry Bay, enclosed in a fairing external to the fuselage. The Unit Inquiry (UI) into the event concluded that the expansion bellows had failed due to corrosion and that the failure had probably occurred some 20 to 40 minutes before the SCP was closed down. This leak of air at up to 420°C caused, *inter alia*, a significant weakening of the rear spar, damage to aileron and flap control cables and pulleys, the melting

[13] BOI Report into Tornado ZA599 17 May 2002 incident, Annex S: QinetiQ, Examination of Fire-Damaged Components from Tornado ZA599, paragraph 4.0 on Ignition Sources

[14] BOI Report into Tornado ZA599 17 May 2002 incident, Annex X: AAIB Report, page 15.

[15] BOI Report into Tornado ZA599 17 May 2002 incident, Annex Y: BAES report BAe-WAW-RP-TOR-PDS, dated February 2003.

or destruction of a multitude of hydraulic pipeline fairleads, damage to the front face of the No. 7 fuel tank, extensive damage and melting to numerous fuel seals, damage inside the bomb bay and damage to the Rib 1 and rear spar temperature indicator looms. As the XV230 BOI observed, "*Although this particular pipe was replaced throughout the Nimrod fleet, and is thus unlikely to have contributed to XV230's loss, the incident illustrates the extensive effects of heat damage concomitant on the spread of hot gases within this area*."[16] A recommendation was made by the XV227 UI to incorporate a hot air leak detection system, to ensure that all possible duct failures were covered. The recommendation was not enacted because the IPT believed that such a modification was not practicable in view of the Nimrod's Out-of-Service Date (OSD).

8.34 I explain in **Chapter 7** why, in my view, the loss of XV230 was not caused by a hot air leak of the type experienced on XV227 and why the fitting of the hot air leak warning system proposed by the XV227 UI would not have made any difference to the outcome of XV230's fire. It must nonetheless be recognised that the XV227 incident (and the earlier history of corrosion problems experienced with the hot air ducts, discussed in **Chapter 7**) presented an opportunity, which was missed, properly to assess the risks posed to the Nimrod aircraft by the hot air duct system (see **Chapter 4**). As one Nimrod line maintenance engineer put it to the Review, there is no doubt that XV227 should have been a "*wake up call*" for everyone, in particular to those compiling the NSC (see further **Chapter 11**). It is highly regrettable that it was not.

8.35 The manner in which the subsequent actions related to the XV227 investigation were handled betrays a worrying lack of 'corporate memory' on the part of both BAE Systems and the Nimrod IPT. There seemed to be collective amnesia about the fact that Nimrod bleed-air ducts had suffered from systemic corrosion and fatigue problems since the early 1980s onwards. This problem seems to have been slowly 'forgotten'; as time wore on the original resolve to replace all of the ducts ebbed. Indeed, whilst the documentary evidence provided to the Review was replete with references to corrosion in the ducts in the 1980s,[17] such references disappear almost entirely in the 1990s and the issue did not resurface again until BAE Systems reviewed its earlier reports of 1982 and 1984 when preparing its report of June 2005. It is particularly striking, as I discuss further in **Chapter 11**, that the NSC prepared in the meantime does not contain a single reference to any of BAE Systems' earlier reports, or indeed even to the existence of the earlier corrosion problems experienced with the ducts.

8.36 XV227 also, in my view, again illustrates a worrying tendency on the part of both the Nimrod IPT and BAE Systems, to look at problems in isolation, and in their own particular compartments, rather than taking a more holistic view. As BAE Systems correctly identified in the 1980s, the corrosion problem with the ducts was systemic. Notwithstanding BAE Systems' advice to this effect, however, when incidents occurred, they tended to be approached as 'one-off', without anybody delving back into the earlier history. Indeed, even in respect of the XV227 incident itself, the IPT Leader, Group Captain (now Air Commodore) George Baber stated in a letter to BAE Systems, dated 3 March 2006, that: "*following the failure of the Secondary Cooling Pack (SCP) duct the hazard was still assessed as an Incredible risk as it was considered to be a one off event*".[18]

8.37 Of course, the real tragedy of the XV227 incident is that the opportunity to appreciate the general fire hazard represented by the SCP was missed. I refer elsewhere in this Report to the dangers of embedded design defects, such as those arising in the case of the SCP. Over the years, a number of very competent and experienced engineers looked into, or worked in, the No. 7 Tank Dry Bay and failed to spot the (with hindsight) obvious risk presented by the close proximity of the SCP duct and fuel pipes in that area. It was the elephant in the room, which nobody saw because nobody was looking for it. The XV227 incident, however, directly focused the attention of the Nimrod IPT, BAE Systems and indeed all those working on the Nimrod on the potential risks presented by a failure of the SCP duct. It is clear both from the initial fault reports and the UI report into the incident (see **Chapter 7**) that it was widely appreciated that, as a result of the leak from the hot air pipe, significant damage had been sustained not only to the primary structure of the aircraft, but also to fuel seals in the adjacent pipelines. Nonetheless, no real thought appears to have been given to the potential for any leaking fuel as a result of such damage meeting a source of ignition; either the ruptured duct itself or another area of the hot air system. Indeed, it may be said to constitute a short mental step to go from registering the risk of a

[16] BOI Report, Exhibit E [E-2].

[17] For example, the minutes of the meetings of the Nimrod Structural Integrity Working Party show that the problem of the cracking of the ducts was regularly discussed at the meetings between 1980 and 1982.

[18] DLO(Strike)(Wyt) 512725/27/6/1.

duct failure in the No. 7 Tank Dry Bay threatening the integrity of adjacent couplings, to recognising the risk of a coupling failure causing fuel to touch a hot air duct. Nonetheless, and notwithstanding that XV227 itself illustrated the stark fact that a single failure (of a hot air duct) could in itself provoke a fuel leak,[19] it appears that nobody took that step.

8.38 It is instructive to note the following response by one of the Nimrod IPT desk officers during interview:

> "***MR HADDON-CAVE QC:*** *The risk that the hot ducts posed to the fuel system was obviously considered carefully as a result of 227 incident. Why was the obverse not thought of, namely, the risk of fuel leaking on to hot ducts, or equally considered, do you think?*
>
> ***NIMROD IPT DESK OFFICER:*** *We were responding to the fire that we had. There was nothing to arouse our suspicion that we had a particular problem in those areas with fuel leaks."*

8.39 It is relevant to note that, following the incident on XV227, the flexible expansion bellows that had failed on XV227 were replaced on every aircraft in the Nimrod fleet, including the one on XV230 which was replaced on 4 July 2005. The replacement of these bellows necessitated the removal (and subsequent refit) of the Refrasil™ insulation covering the SCP elbow (i.e. the most likely ignition source for the fire on XV230).

8.40 The XV227 should have been a '*wake up call*' but appears not to have been. It came too late to affect BAE Systems' production of the NSC (which was handed over in September 2004) but not too late to affect the Nimrod IPTs subsequent checking and 'ownership' of the NSC. As I explain in **Chapter 9**, the very rationale of a Safety Case is to ensure that risks, which might not otherwise be identified, are not only identified, but assessed and mitigated appropriately. As I explain later, Hazard H73 in the NSC expressly identified the risk inherent in the No. 7 Tank Dry Bay with "*so many components in close proximity*" as a fire/explosion risk. XV227 showed just what a risk this was but nobody sat up and thought through the implications. They should have done. This sort of thought process was the very purpose of a 'hazard' analysis. Although XV227 was referenced in CASSANDRA, little thought was given to its real implications. I explain in **Chapters 10** and **11** just how and why the NSC failed in its objective in this respect and why it is so important to take into account all known evidence when assessing risks.

(7) August 2005: Nimrod XV229 – hot air duct failure

8.41 Following the incident on XV227, on 8 August 2005, XV229 suffered a failure of its Port Bomb Bay Air Supply Duct (Part No. 6M4V235A), consisting of a small amount of material loss and cracking in the duct. The fault was detected during an engine ground run. No detection systems were activated by the leak during the ground run, but the expelled air would have been below the 230°C activation temperature. It should be noted that the failure of the duct on XV229 was within the engine bay of the aircraft and there was, in this case, no evidence of any resultant damage to the aircraft structure. BAE Systems' investigation into the incident[20] concluded that there was little evidence of corrosion and that the cause of the failure was fatigue, possibly provoked by mechanical damage.

8.42 The failures on XV227 and XV229 were therefore not directly related, but the important fact remains that there were two duct failures within a period of just nine months. Further, both failures, being attributable to corrosion and fatigue respectively, must in my judgment, be viewed, if only in part, as being age-related failures. In view of the ever-increasing age of the Nimrod fleet, common sense would suggest that such failures were likely to become more common.

8.43 In the MOD Form 761 relating to the incident on XV229, BAE Systems pointed out that the potential for this type of failure in the engine bay was recognised by way of Hazard H66 in the NSC, which had been ascribed a probability of 'Incredible' by the Nimrod IPT in its letter to BAE Systems of 16 March 2005 (see further **Chapter 10**). BAE Systems went on to recommend that, in view of the second failure of a duct, the probability of Hazard H66 hazard should be reviewed by the Nimrod IPT and "*should be reassessed to IMPROBABLE or more likely REMOTE*".

[19] The No. 7 tanks of XV227 were empty at the time so little fuel was released on that occasion.

[20] Investigation into failure of Nimrod duct assembly (AFT/NIMROD/700) CHD-TFM-R-ISA-MB1434, dated 17 February 2006.

8.44 It is not entirely clear exactly what investigations, if any, the Nimrod IPT carried out following receipt of BAE Systems' report of 17 February 2006, and the MOD Form 761. In a letter dated 3 March 2006 entitled: "*Hot Air Ducts" – Nimrod Hazard NM/H66*", the IPT Leader, George Baber, wrote to BAE Systems, referring to the second duct failure on XV229 and stating, *inter alia*, as follows:

> *"Following consideration by the relevant subject matter experts within the Nimrod IPT, Nim (ES)AV(A)3 and Nim(ES)Safety , the effect of the failure is to remain at Catastrophic but the probability is to be raised to Improbable (Remote likelihood of occurrence to just one or two aircraft during the operational life of a particular fleet).*
>
> *You are requested to amend hazard NM/H66 accordingly and set it to Managed."*

8.45 As I explain further in **Chapter 11**, it is important to note that this change in probability was only applied to the hazard linked to the aircraft engine bay (Hazard H66) and not to any other area with hot air ducts. The No. 7 Tank Dry Bay was of course an area particularly vulnerable, should a hot air leak occur. However, neither this area nor any of the other areas containing hot air ducts are recorded as having been reassessed in the light of the new concerns over the second duct failure. In my judgment, the decision process remained myopic and failed to consider all the implications arising from the incident, and the earlier duct failure on XV227.

Conclusion

8.46 In conclusion, the above represented significant incidents in the years before the loss of XV230 which contained warning signs of some of the problems and issues which were to affect XV230.

8.47 These incidents represented missed opportunities to spot risks, patterns and potential problems, and for these lessons to be read across to other aircraft.

8.48 No-one was taking a sufficient overall view.

PART III:
NIMROD SAFETY CASE

PART III: NIMROD SAFETY CASE

Introduction to PART III

1. Part III of this Report covers the Nimrod Safety Case.

2. Safety Cases were mandated by regulations. The purpose of a Safety Case is to identify, assess and mitigate potentially catastrophic hazards which might occur to an aircraft or other platform.

3. The Nimrod Safety Case was produced between 2001 and 2005, primarily by BAE Systems, with involvement from the Nimrod Integrated Project Team and QinetiQ acting as 'independent advisor'. The Nimrod Safety Case comprised a series of reports and a hazard database on the Nimrod MR2 and R1 fleets.

4. Nimrod MR2 and R1 aircraft had, from their inception, contained inherent design flaws (see **Part II** of this Report). These flaws should have been picked up by the Nimrod Safety Case. They were not. The reasons why not are set out in **Chapters 10A, 10B** and **11**.

5. The Nimrod Safety Case, in fact, represented the best opportunity to capture the serious design flaws in the Nimrod MR2 and R1 that had lain dormant for the decades before the accident to XV230.

6. A careful Safety Case would, and should, have highlighted the catastrophic risks to the Nimrod fleet presented by the Cross-Feed/Supplementary Conditioning Pack duct and the Air-to-Air Refuelling modification.

7. If the Nimrod Safety Case had been properly carried out, the loss of XV230 would have been avoided.

8. Unfortunately, the Nimrod Safety Case was a lamentable job from start to finish. It was riddled with errors. It missed the key dangers. Its production is a story of incompetence, complacency and cynicism.

9. The best opportunity to prevent the accident to XV230 was, tragically, lost.

10. **Part III** has four Chapters:

    - **Chapter 9: BACKGROUND TO SAFETY CASES**
    - **Chapter 10A and Chapter 10B: NIMROD SAFETY CASE: THE FACTS**
    - **Chapter 11: NIMROD SAFETY CASE: ANALYSIS AND CRITICISMS**

CHAPTER 9 – BACKGROUND TO SAFETY CASES

Contents

Chapter 9 answers the following questions:

- What was the origin of 'Safety Cases' and their history and development?
- When and how were they adopted by the RAF?
- What are the military regulations regarding 'Safety Cases'?
- What, if any, guidance was available regarding their production?
- What procedures did the Nimrod Integrated Project Team have in place in relation to 'Safety Cases'?

Summary

1. The origins of 'Safety Cases' can be found in the 1984 CIMAH Regulations,[1] implementing the 1982 EC Directive on major industrial accidents.[2] Lord Cullen in the *Piper Alpha* Report in 1988 highlighted the importance of Safety Cases in the oil and gas industry and required their application to off-shore (as well as on-shore) installations.
2. Safety Cases were first discussed in a military context in the Man S (Org) Study in 1994[3]. Safety Cases were, however, not formally adopted as a military platform requirement until the 4th Edition of Joint Service Publication (JSP) 318B in September 2002.
3. The requirements for Safety Cases for military platforms, including aircraft, are laid down in JSP553 (formerly JSP318B), Defence Standard (Def-Stan) 00-56 and Business Procedure (BP) 1201.
4. A Safety Case itself is defined as *"a structured argument, supported by a body of evidence, that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment"*.[4]
5. The basic aims, purpose and underlying philosophy of Safety Cases were clearly defined, but there was limited practical guidance as to how, in fact, to go about constructing a Safety Case.
6. The Nimrod Integrated Project Team's Safety Management Plan contained detailed procedures for the preparation and maintenance of a Safety Case. It is regrettable that these procedures were not followed in relation to the preparation of the Nimrod Safety Case, and the sentencing of risks, during the period 2001-2005.

[1] Control of Industrial Major Accidents Hazards Regulations 1984 (CIMAH Regulations).

[2] European Commission Directive 82/501/EEC *"on the major-accident hazards of certain industrial activities"*, issued in 1982 (known as the 'Seveso Directive').

[3] Management Services (Organisation) Division Study No. 773: Equipment Safety Assurance dated March 1994.

[4] Def-Stan 00-56, paragraph 9.1.

History of Safety Cases

> *"The ability of an aircraft or other airborne equipment or system to operate without significant hazard to aircrew, ground crew, passengers (where relevant) or to the general public over which such airborne systems are flown."*[5] (JSP553, Military definition of 'airworthiness')

The Public Inquiry into the Piper Alpha Disaster

9.1 There is no better starting point for an understanding of the Safety Case philosophy than the report of Lord Cullen into the *Piper Alpha* disaster, in which 167 men died as a result of a series of explosions on 6 July 1988.[6]

9.2 In the *Piper Alpha* report, published in 1990, Lord Cullen examined the (then) existing United Kingdom off-shore and on-shore safety regimes. He concluded that operators of both types of installations should be required by regulation to carry out a formal safety assessment of major hazards, the purpose of which would be to demonstrate that the potential major hazards of the installation and the risks to personnel thereon had been identified and appropriate controls provided. The aim of this regulation was twofold: to assure the operators that their operations were safe and to fulfil a legitimate expectation of the workforce and public that operators should be required to demonstrate this to the regulatory body.[7]

9.3 Lord Cullen's conclusion was thus that 'Safety Cases' should apply equally to installations in the off-shore industry as they did in the on-shore industry, *i.e.* that operators should demonstrate that the hazards of the off-shore installation had been identified, assessed and controlled and that the exposure of personnel to these hazards had been minimised.[8] The reason for this was clearly stated:[9]

> *"A Safety Case should be required for existing installations. This is the requirement onshore. The risks offshore are clearly no less. <u>It is not acceptable that installations should be operated without a thorough assessment of what those risks are</u>."* (emphasis added)

9.4 In the paragraphs that follow, I examine the background to, the aims, and the effect (in the military context) of Lord Cullen's conclusions.

Health & Safety at Work Act 1974

9.5 The Health & Safety at Work Act 1974 (HSWA) was an important starting point for Lord Cullen's analysis in the *Piper Alpha* report. Lord Cullen noted[10] that the HSWA arose out of the report of the Robens Committee in 1972 (Cmnd 5034),[11] which identified a number of defects in the then existing statutory system for the advancement of safety and health, namely: (1) there was too much law; (2) too much of the existing law was intrinsically unsatisfactory, largely through problems created by unintelligibility and obsolescence; and (3) the relevant administrative jurisdictions were fragmented and there was a lack of a clear and comprehensive system of official provision for safety and health at work. Many of these lessons are equally relevant in the current context of the MOD (see **Chapter 20**).

9.6 The HSWA aimed to remedy these deficiencies, by progressively replacing the specific Acts and instruments relating to health and safety with a new system of regulations and approved codes of practice. The new style of regulations was intended to *"specify principles rather than solutions"* and was intended to *"encourage*

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[5] Military definition of 'airworthiness', JSP553, Change 5, Notes to Users, paragraph 2.

[6] The Public Inquiry into the Piper Alpha Disaster, Cullen, The Honourable Lord, HM Stationery Office, 1990 (*Cullen*).

[7] *Cullen*, paragraph 1.17.

[8] *Cullen,* paragraph 17.37.

[9] *Cullen,* paragraph 17.44.

[10] *Cullen*, paragraph 16.7.

[11] The Robens Committee were appointed in May 1970 by Barbara Castle, Secretary of State for Employment, to review the provision of health and safety in the UK. The committee reported in 1972, from which report the HSWA was born.

innovation on the one hand but be effective against lack of precaution on the other".[12] Such regulations are known as *"goal-setting regulations"*[13] since this is what they do, rather than prescribe solutions. In explaining why goal-setting regulations are to be preferred to prescriptive rules, Lord Cullen expressed himself to be in agreement with the following words of the (then) Chairman and Managing Director of Conoco (UK) Ltd:[14]

> *"It is my fundamental belief that safety cannot be legislated, while recognizing that enough legislation or regulation needs to exist to ensure that minimum standards are maintained. Such regulation should impose a duty on the operator to do everything reasonable to achieve a safe operation. By and large, safety has to be organized by those who are directly affected by the implications of failure. These people are in the best position to determine the detailed measures necessary on their own particular installation to achieve the safety objective. Imposition of detailed requirements cannot anticipate all the variances of differing practice, location, organization and size that exist. In fact, prescriptive regulation or over-detailed guidance may at times result in the overall objective actually being compromised. Innovation, on-going improvement and objectivity will be stifled; and the more prescriptive the regulation the more unclear it is who has the responsibility for total safety. Compliance becomes the overriding objective. Sight is lost of the more realistic and overall intent that all reasonable steps should be taken to achieve the total safety of the installation."* (emphasis added)

9.7 This "goal-setting" approach finds legislative expression in sections 2 and 3 of the HSWA. These impose on an employer a duty "*to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his employees"* and *"to conduct his undertaking in such a way as to ensure, so far as is reasonably practicable, that persons not in his employment who may be affected thereby are not thereby exposed to risks to their health or safety"* (emphases added). Herein lies the origin of the principle, discussed further below, that risks should be reduced to a level that is as low as reasonably practicable (ALARP).[15]

9.8 The HSWA established the Health and Safety Commission (HSC) as the body responsible for effecting the general purposes of the Act and the Health and Safety Executive (HSE) as the body generally responsible for the enforcement of health and safety legislation and for exercising on behalf of the HSC such of its functions as the HSC directed it to exercise. I refer below to some of the guidance that has since been produced by the HSE in relation to Safety Cases and the application of the ALARP principle.

Formal Safety Assessment

9.9 In the *Piper Alpha* report, Lord Cullen provided a detailed description of what he meant by a *"formal safety assessment"* (FSA), explaining that it involved the identification and the assessment of hazards over the whole life cycle of a project from the initial feasibility study through the concept design study and the detailed design to construction and commissioning, then to operation, and finally to decommissioning and abandonment. The techniques available to be used were said to include hazard and operability (HAZOP) studies; quantitative risk assessment (QRA); fault tree analysis (FTA); human factor analyses; and safety audits. Lord Cullen explained that the need for FSA arose because the combinations of potential hardware and human failures are so numerous that a major accident hardly ever repeats itself. A strategy for risk management is, therefore, required to address the entire spectrum of possibilities.[16] Lord Cullen was, however, not prescriptive as to how precisely an FSA should be carried out in any particular case.

9.10 The first regulations in the United Kingdom to refer to such a formal safety assessment in the form of a 'Safety Case' were the Control of Industrial Major Accidents Hazards Regulations 1984 (CIMAH Regulations), which

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[12] *Cullen*, paragraph 16.36.

[13] *Cullen*, paragraphs 17.63 and 21.39

[14] *Cullen*, paragraph 21.4.

[15] It should be noted that the HSWA does not apply to aircraft in flight: see section 15(9) of the HSWA. As explained below, however, the MOD has nonetheless adopted the ALARP principle.

[16] *Cullen*, paragraph 17.3.

implemented European Council Directive 82/501/EEC[17] *"on the major-accident hazards of certain industrial activities"*, issued in 1982 (known as the 'Seveso Directive'). The CIMAH Regulations were later superseded by the Control of Major Accident Hazards Regulations (COMAH Regulations), which came into force on 1 April 1999 by way of implementation of European Council Directive 87/216/EEC,[18] which amended the Seveso Directive (known as the 'Seveso II Directive'). The COMAH Regulations (as amended) apply mainly to the chemical industry and impose upon operators a duty to take all measures necessary to prevent major accidents and limit their consequences to persons and the environment (s.4) and to prepare, and keep under review, a "safety report" (s. 5).

9.11 At the time that they were in force, the CIMAH Regulations applied to on-shore major hazard installations and, pursuant to Regulation 7, required the operators of such installations to provide the HSE with a written report on the safety of the installation. Lord Cullen in the *Piper Alpha* report explained that this written report was commonly called the 'Safety Case'. Its contents were specified in Schedule 6 of the CIMAH Regulations. The four main headings related to information on: (1) every dangerous substance involved in the activity; (2) on the installation itself; (3) on the management system; and (4) on the potential major accidents.

Lord Cullen's Approach to Safety Cases

9.12 Having reviewed the CIMAH Regulations, Lord Cullen explained that the Safety Case was, first and foremost, *"the means by which an operator demonstrated to itself the safety of its activities"*.[19] Its central feature was that of ensuring that every company produced an FSA, in order to assure itself that its operations were safe and that it gained the benefit of an FSA. Whilst the Safety Case had a further role in demonstrating this to the regulatory body, this latter function was a matter of only secondary importance,[20] albeit that it met the legitimate expectation referred to above.

9.13 Lord Cullen expressed the view that the Safety Case should normally be prepared primarily by the company personnel.[21] He accepted the force of the comments in the guidance notes to the CIMAH Regulations[22] in relation to the level of expertise required that *"A partial answer is to suggest that if a manufacturer was unable to meet most if not all of the aims of the Safety Case set out in para 106 by using his own staff, doubts would arise about his competence to manage a major hazard activity …".* He further considered the involvement of the company's own personnel to be the best way to obtain the full benefits of the Safety Case within the company. In particular, it was desirable that the operator should deal itself with the QRA aspects of the Safety Case rather than contract them out. Familiarity with the system was essential for good QRA and, moreover, the use of company personnel would allow expertise to be built up in-house. [23] It is appropriate to note here that, in the event, one of the major reasons for the failure of the Nimrod Safety Case (NSC) was the lack of relevant operator input.

9.14 Lord Cullen also considered that the use of the company's own personnel would help to promote an effective dialogue with the regulators. He emphasised that the Safety Case should be seen not as a one-off exercise, but as part of a continuing dialogue between the operator and the regulatory body. [24] He further recognised that his proposal to assign a central role in a safety regime to FSA in general, and the Safety Case in particular, had obvious implications for the regulatory body. This was because the regime that he envisaged was one in which the regulator's focus would move to an audit of the operator's systems, with the Safety Case providing the starting point for such an audit. The regulatory body would therefore need to be not only able to evaluate the Safety Case, but also to be at ease with the whole approach.[25]

[17] OJ No. L230, 5.8.82, p. l.

[18] OJ No. L85, 28.3.87, p. 36.

[19] *Cullen*, paragraph 17.11.

[20] *Cullen*, paragraphs 17.34 – 17.35.

[21] *Cullen*, paragraph 17.40.

[22] At paragraph 114.

[23] *Cullen*, paragraph 17.40. On the other hand, Lord Cullen did recognise that consultants have a role in bringing an independent perspective and assisting with novel and specialist techniques.

[24] *Cullen*, paragraph 17.46.

[25] *Cullen*, paragraph 17.70.

Guiding Principles of Lord Cullen's Approach

9.15 It should be clear from the above that Lord Cullen appears to have anticipated an active process of risk assessment by the operators of installations. The overriding theme that emerges from his report is that he wanted organisations to think more clearly and logically about the risks which existing installations presented. He saw a Safety Case as a sensible means of achieving this end, albeit not an end in itself. Lord Cullen expressly stated that a regime should not rely solely on the Safety Case, which should be complemented by other regulations dealing with specific features, especially regulations which set goals rather than prescribing solutions. [26]

9.16 Dealing with the wider picture, Lord Cullen made a number of observations and emphasised some important features of an effective safety regime:

9.16.1 Safety is crucially dependent on management and management systems. One of the things that the Safety Case should demonstrate (amongst other things) is that the company has a suitable safety management system. [27]

9.16.2 However, whilst an effective safety system is necessary, it is not of itself sufficient. Lord Cullen explained that it was not enough to set up a systematic approach to safety and put it into operation; it requires continual review and audit. [28] The primary object of the regulator's audit or inspection is to *"stimulate the operator to carry out his duty to maintain safety"* and *"an inspector's immediate purpose in visiting is to satisfy her or himself that systems exist that are likely to lead to the identification and prevention by management of significant faults and that the attitude of management is conducive to this".*[29]

9.16.3 That said, the regulator cannot be expected to assume direct responsibility for the ongoing management of safety, which for all practical purposes remains in the hands of the operators.[30]

9.16.4 Lord Cullen highlighted the importance of a safety culture and the importance of a chain of command for safety, in particular the significance of leadership from the top. The establishment of a safety culture included the *"systematic identification and assessment of hazards and the devising and exercise of preventative systems which are subject to audit and review".*[31]

Guidance on QRA and the ALARP Principle

QRA

9.17 Lord Cullen emphasised that Quantitative Risk Assessment (QRA) is only one tool, and should not be used in isolation or as an automatic mechanism for risk assessment:[32]

> *"QRA is an element that cannot be ignored in decision-making about risk since it is the only discipline capable, however imperfectly, of enabling a number to be applied and comparisons of a sort made, other than in purely qualitative kind. That said, the numerical element must be viewed with great caution and treated as only one parameter in an essentially judgmental exercise."*[33]

9.18 This warning was reiterated by the HSE in their later guidance document entitled *"Reducing Risks, Protecting People"* published in 2001 (R2P2). The HSE pointed out that, whilst QRA is a powerful tool, care needs to be taken in selecting: (1) the accident/incident sample; (2) the time period; and (3) the statistical method used. It

[26] *Cullen*, paragraph 17.63.
[27] *Cullen*, paragraph 17.36.
[28] *Cullen*, paragraphs 21.10 and 21.13.
[29] *Cullen*, paragraph 16.37.
[30] *Cullen*, paragraph 21.4.
[31] *Cullen*, paragraphs 21.9 – 21.10.
[32] *Cullen,* paragraph 17.38. This is a view endorsed by the HSE (see *Cullen*, supra).
[33] *Cullen,* paragraph 17.49 ff.

expressly stated that *"the use of numerical estimates of risk by themselves can ... be misleading and lead to decisions which do not meet adequate levels of safety"*. Thus, in general, qualitative learning and numerical risk estimates from QRA should be combined with other information from engineering and operational analyses in making an overall decision.[34]

ALARP

9.19 I have referred above to the ALARP principle, derived from sections 2 and 3 of the HSWA, *i.e.* the principle that risks should be reduced to "As Low As Reasonably Practicable". In the *Piper Alpha* report, Lord Cullen illustrated this principle using the (carrot) diagram[35] depicted in Figure 9.1 (from which, in due course, the tables in BP1201 that I set out below were derived).

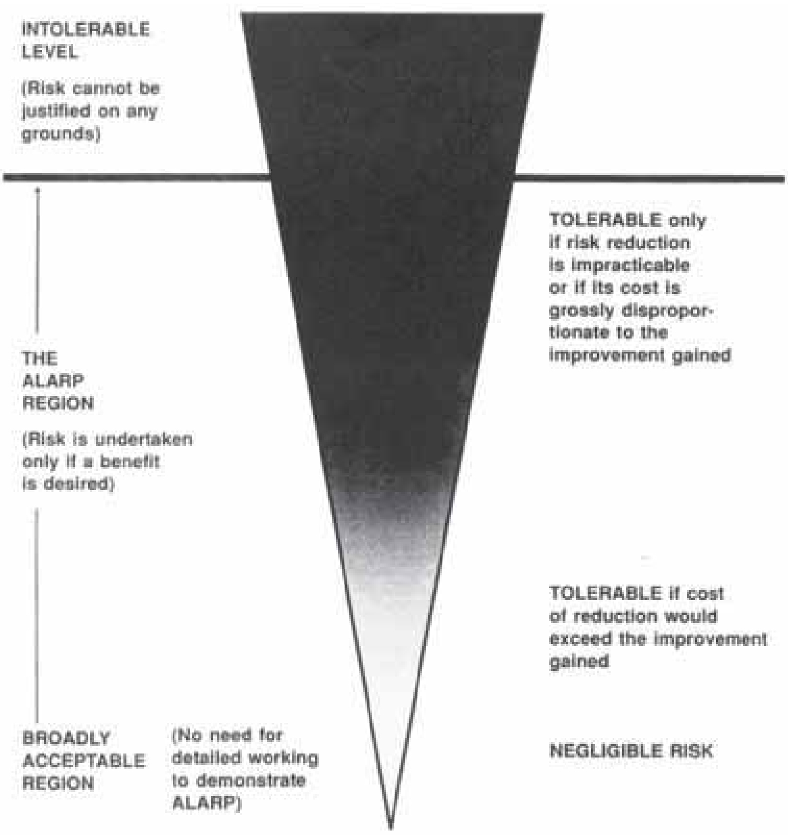

Figure 9.1: Lord Cullen's ALARP diagram

9.20 A similar diagram re-appeared in the HSE R2P2 document. What the diagram seeks to illustrate is the principle that, above a certain level, a risk is regarded as intolerable and cannot be justified on any grounds, except perhaps in extraordinary circumstances (the '*Intolerable*' level). At a lower level, a risk can be regarded as broadly acceptable when the risk becomes truly negligible in comparison with other risks that the individual or society runs (the *'Broadly Acceptable'* region). Between the broadly acceptable and intolerable regions an activity is allowed to take place provided that the associated risks have been made ALARP ('*Tolerable*').

9.21 In R2P2,[36] the HSE set out its guidance as to what was meant by reducing risks to a level that was ALARP.[37] The HSE referred, in this respect, to the key case of *Edwards v National Coal Board* [1949] 1 KB 704, in which the Court of Appeal held that *"… in every case, it is the risk that has to be weighed against the measures necessary to eliminate the risk. The greater the risk, no doubt, the less will be the weight to be given to the factor of*

[34] HSE Publication *"Reducing Risks, Protecting People"*, 2001, page 31.

[35] *Cullen,* fig 17.1. The diagram was introduced to the *Piper Alpha* Inquiry by Dr. M. S. Hogh, Manager of Projects and External Affairs, Group Safety Centre, BP International.

[36] See paragraph 9.18 above.

[37] See also the HSE's subsequent publication *"Principles and guidelines to assist HSE in its judgment that duty-holders have reduced risk as low as reasonably practicable"* dated 13 December 2001.

cost"[38] and that a computation must be made in which the quantum of risk is placed on one scale and the sacrifice, whether in time, money or trouble, involved in the measures necessary for averting the risk is placed in the other; and that, if it be shown that there is a gross disproportion between them, the risk being insignificant in relation to the sacrifice, then the person upon whom the duty is laid discharges the burden of proving that compliance was not reasonably practicable.[39]

9.22 The HSE has endorsed this test of 'gross disproportion', namely, that in any assessment as to whether risks have been reduced to ALARP, measures to reduce the risk can be ruled out only if the sacrifice involved in taking them would be grossly disproportionate to the benefits of the risk reduction.[40] The HSE summarises matters by stating: *"Thus, determining that risks have been reduced ALARP involves an assessment of the risk to be avoided, of the sacrifice (in money, time and trouble) involved in taking measures to avoid that risk, and a comparison of the two."*

9.23 The 'R' in ALARP thus has a financial, temporal and trouble component.

Development of Safety Cases in the RAF

Management Services (Organisation) Division Study (1994)

9.24 The requirement for Safety Cases within the MOD can be traced back to the Management Services (Organisation) Division Study No. 773 – Equipment Safety Assurance, dated March 1994 (Man S (Org) Study), which in large part grew out of the findings and conclusions of the *Piper Alpha* report.

9.25 The Man S (Org) Study was sponsored by the Deputy Under Secretary of State (Defence Procurement) (DUS(DP)) and had a number of specific tasks which included: (1) examining the existing and planned arrangements for ensuring that equipment procured by the Procurement Executive (PE) for its customers was safe for use by reference to contemporary standards and legislative support; and (2) establishing whether such arrangements reflected latest thinking and best practice in safety and risk management and took account of statutory requirements and applicable MOD standards governing safety in Defence equipment.[41]

9.26 The Man (S) Org Study found that, in relation to procurement strategy, there were some concerns that safety was not addressed as a specific item requiring attention as part of the overall process. The central concerns related to the lack of visibility and accountability regarding equipment assurance and the lack of a coherent safety policy. These concerns gave rise to the following recommendations (amongst others):[42]

9.26.1 That safety management should be addressed as part of the procurement strategy process.

9.26.2 The establishment of a safety directorate to define policy, set standards, give advice and liaise with, for example, the HSE. The Man S (Org) Study shared Lord Cullen's view that a 'goal-setting' approach should be adopted.

9.26.3 The creation of a central safety management office and safety management board.

9.26.4 The implementation of a Safety Case regime in the procurement process, its objective being *"to provide a well organised and resourced justification of the acceptability of the System's safety"*. The Man (S) Org Study noted that the essential features of a Safety Case were that it must fully describe the system, identify the hazards, identify the risks and indicate the safeguards and describe the safety management system arrangements.

9.26.5 The development of Def-Stan 00-56 to address the whole safety system (see further below).

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[38] Per Tucker LJ, at page 710.

[39] Per Tucker LJ, at page 712. And see further the report of Adelard on *"Numerical Criteria for Airworthiness"* dated 30 September 2002, produced for ALTG.ADRP1 under contract MAP2b/1351.

[40] HSE Document *"Principles and guidelines to assist HSE in its judgment that duty-holders have reduced risk as low as reasonably practicable"*, paragraph 24.

[41] Man S (Org) Study, at pages A1-A2.

[42] See the Summary of Recommendations at page 85 of the Man S (Org) Study.

9.27 The findings and recommendations of the Man S (Org) Study were made following a review of 'best practice' as set out by the HSE, Industry and foreign Ministries of Defence, using WS Atkins Consultants Ltd to review industry practice. A review of the Man S (Org) Study itself suggests that this review was comprehensive and that the authors of the study had firmly embraced the Safety Case concept and philosophy as expounded by Lord Cullen in the *Piper Alpha* report. In particular:

9.27.1 The Man S (Org) Study commented that discussions between the study's authors and the HSE had revealed that the MOD was considered to be a 'reactive' organisation which needed to change its approach to safety to being 'pro-active'.

9.27.2 The Man S (Org) Study echoed Lord Cullen's views as to the importance of a safety culture and the importance of audit and review, with a clear line of accountability to the head of the organisation. Such audit and review was especially important within an organisation such as the MOD, which acted as both a regulator and operator.

9.27.3 The Man S (Org) Study emphasised the need for the customer to define safety requirements, imposing on the contractor an obligation to take responsibility for the product and not allowing the contractor to transfer responsibility back to the customer.

9.27.3 The Man S (Org) Study shared Lord Cullen's view that Safety Cases should generally be produced by the operator,[43] who should take responsibility for them, with the ultimate responsibility resting at board level where a director responsible for safety can be identified.

9.28 On 23 August 1995, the Deputy Chief of Defence Procurement (Operations) (DCDP (Ops)) produced a paper[44] (DCDP (Ops) Paper) with the aim of identifying the required restructuring of the (then) current procedures for Design Certification of Airworthiness for military air systems in light of the Man S (Org) Study. The RAF received a copy of this paper in December 1995.[45] The DCDP (Ops) Paper identified three key points of the Man S (Org) Study as applying directly to the procurement of air systems:

9.28.1 The need to establish a "Safety Focus" for air systems, with responsibility for airworthiness policy, procedures and standards;

9.28.2 The introduction of formal "Safety Case" procedures in the procurement arrangements for new or modified military air platforms, associated weapons, and airborne equipment to ensure a satisfactory audit trail; and

9.28.3 The taking of steps to ensure adequate airworthiness expertise was maintained in the Air Project Directorate, with specialist support available to back up the procurement teams.

9.29 The DCDP (Ops) Paper was thus procurement-focused; it expressly sought to introduce Safety Cases in the procurement arrangements for new or modified systems, but did not discuss the application of Safety Cases to legacy aircraft.

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43 The Man S (Org) Study recognised that there were exceptions in the civil aviation industry, where the responsibility for the preparation and submission of a safety case rests with the aircraft designer/manufacturer.

44 Entitled 'Airworthiness Certification for Military Aircraft' (Ref: DCDP(Ops)/115/10).

45 RAF Minute in relation to the DCDP (Ops) paper, dated 9 January 1996.

Military Regulation of Safety Cases

JSP318B

9.30 One of the key recommendations of the DCDP (Ops) Paper was that the existing "Controller Aircraft Release"[46] procedures for military air systems should be revised and published in a new *"Safety Handbook for Air Systems"*, which would form part of Joint Service Publication (JSP)318B.[47] Adelard[48] was subsequently contracted by the MOD[49] to produce a study for the re-structure and re-write of JSP318B, with a view to applying the principles of modern safety management to military airworthiness. Adelard's analysis dated 22 January 1998 led to the following proposals (amongst others):

9.30.1 JSP318B should be based upon an explicitly defined Safety Management System for military aircraft.

9.30.2 An independently assessed Safety Case should become the central justification for military aircraft airworthiness and a record of safety analysis activities.

9.30.3 In order to provide a single focus for airworthiness and maintenance of the Safety Case throughout an aircraft's lifecycle, a single MOD Project Director with responsibility for acquisition and in-Service activities, known as the Aircraft Design Approval Authority, should be nominated.

9.30.4 The report stressed the importance of centres of excellence and corporate memory in ensuring structural integrity, and the need for them in other areas relevant to safety, including Safety Case development.

9.30.5 The ALARP principle should be applied to military airworthiness and appropriate guidance provided. Adelard recognised that there are significant problems in implementing ALARP in a military context and that technical guidance and policy decisions on the method of application were required.

9.30.6 Internal and external audits and corrective action should be implemented

9.31 Following Adelard's report, JSP318B was duly amended and published as "Regulations of the Airworthiness of Ministry of Defence Aircraft", JSP318B, 4th Edition, dated September 2002. The foreword to the new JSP318B stated that it applied to all UK military aircraft and that it described *"the Safety Management System adopted by the Ministry of Defence for the management and regulation of military aircraft airworthiness"*, in accordance with the policy and associated arrangements agreed with the Defence Aviation Safety Board (DASB).

9.32 JSP318B is a lengthy document which contains a good deal of encouraging rhetoric about Safety Cases but little in the way of practical guidance as to how actually to implement the policies and principles it promulgates.

9.33 It is nonetheless fair to say that the objectives of the Safety Management System (SMS) were clearly stated[50] as being to: (1) establish and maintain an effective management structure and organisation for implementing and promulgating airworthiness policy; (2) assess the safety performance of the equipment and the safety management system itself by measurement and audit; (3) provide for the documentation of the evidence for airworthiness in a Safety Case; and (4) establish mechanisms for learning from the MOD's and others' experience in safety and airworthiness.

9.34 Chapter 2 of JSP318B dealt with the "Safety Management System for Military Aircraft Airworthiness". It provided[51] that the Safety Management System (SMS) for a project was to be described in a Safety Management Plan (SMP) and that the Safety Case was to provide the *"objective justification for the airworthiness of the*

[46] The formal certification of the airworthiness of the aircraft design within stated flight limitations and operational configurations. This also formed the basis of the formal "Release to Service" in accordance with JSP318B.

[47] The Joint Service Publications (JSPs) are tri-Service regulations.

[48] An independent consultancy specialising in *inter alia* safety management systems and safety cases.

[49] Contract MAP2b/1351.

[50] JSP318B, 4th Edition, Chapter 2, paragraph 2.2.

[51] Ibid, Chapter 2, paragraph 2.42.

aircraft",[52] adopting the HSC's definition of a Safety Case as *"A suite of documents providing a written demonstration that risks have been reduced as low as reasonably practicable. It is intended to be a living dossier which underpins every safety-related decision made by the licensee"*. JSP318B further provided that: (1) the Safety Case should clearly describe the evidence and arguments used to justify the safety of the system;[53] and (2) that it was the responsibility of the IPT leader (IPTL) to ensure that the Safety Case was supported by a safety analysis in accordance with Def-Stan 00-56 (see further below)[54] and that it was independently assessed, in order to *"overcome possible conflicts of interest and oversights that may arise from the use of a single organisation"*.[55] Such independent assessment was to consist of two elements: audit against the safety plan and technical evaluation of the Safety Case and supporting analyses.[56]

9.35 Chapter 4 of JSP318B dealt with the "Management of Airworthiness During Procurement". Despite its title, paragraph 4.50 prescribed that IPTLs of projects involving legacy aircraft and equipment that did not already have a Safety Case were to undertake as much of the analysis prescribed in JSP318B as was *"reasonably practicable given the available safety records"*. Further guidance on the safety analysis of legacy systems was said to be contained in Def-Stan 00-56, Part 2, Annex D, discussed below.

9.36 In 2003, JSP318B, 4th Edition (as amended) was re-published, renamed JSP553 "Military Airworthiness Regulations" and incorporated into the JSP550 series of publications forming the Military Aviation Regulations Document Set (MARDS). The substance of the regulations in relation to Safety Cases remained unchanged.

Def-Stan 00-56

9.37 Defence Standards are used by the MOD as contractual requirements with Industry.

Issue 1 of Def-Stan 00-56

9.38 Def-Stan 00-56 Interim Issue 1[57] was published by the MOD on 5 April 1991 to give the MOD a consistent approach to the contracting of Safety Management requirements. It was, however, primarily focused on computer based systems. As referred to above, the Man S (Org) Study recommended the development of Def-Stan 00-56 to address the whole safety system.

Issue 2 of Def-Stan 00-56

9.39 Issue 2 of Def-Stan 00-56 entitled "Safety Management Requirements for Defence Systems" was duly published on 13 December 1996. It provided *"uniform requirements for implementing a system safety programme in order to identify hazards and to impose design techniques and management controls to identify, evaluate and reduce their associated risks to a tolerable level"*.[58] These requirements were set out in some considerable detail in the Def-Stan. In particular:

9.39.1 Paragraph 4.6 provided for a Hazard Log to be established to act as a directory for the safety justification, or Safety Case, and to provide a summary of all safety activities throughout the project life. The Hazard Log was to be employed as the principal means of establishing progress on resolving the risks associated with the identified hazards.

9.39.2 Paragraph 4.7 stated that the Hazard Log alone was unlikely to be acceptable as a Safety Case, which was to be constructed using information from the Hazard Log. The Safety Case was to provide a well-organised and reasoned justification clearly showing that the proposed system was acceptably safe.

[52] Ibid, ntroduction, paragraph 9 and Chapter 2, paragraph 2.43.
[53] Ibid, Chapter 2, paragraph 2.45.
[54] Ibid, Chapter 2, paragraph 2.56.
[55] Ibid, Chapter 2, paragraphs 2.47 and 2.58.
[56] Ibid, Chapter 2, paragraph 2.59.
[57] Entitled "Hazard Analysis and Safety Classification of the Computer and Programmable Electronic System Elements of Defence Equipment".
[58] Def-Stan 00-56 (Part 1)/Issue 2, paragraph 0.2.

9.39.3 Section 5.3 of the Def-Stan detailed the key appointments in the system safety programme, including a Project Safety Manager and Engineer, Project Safety Committee and Independent Safety Auditor.

9.39.4 The responsibilities of the Independent Safety Auditor included auditing of the project for compliance with the Standard[59]and the audit was to be documented in an Independent Safety Audit Report which was, amongst other things, to approve the completeness of the Hazard Log.[60]

9.39.5 Whilst Def-Stan 00-56 did not seek to explain precisely how a risk analysis was to be carried out, it did specify in some detail: (1) the required contents of the Hazard Log;[61] (2) the required activities of a preliminary hazard analysis and system hazard analysis, and the contents of a preliminary hazard analysis and system hazard analysis reports;[62] and (3) provided (amongst others) a table of probability ranges and a table of risk classifications.

9.40 It will be clear from the above that Issue 2 of Def-Stan 00-56 was rather prescriptive, an approach somewhat at odds with that of the 'goal-setting' approach advocated by Lord Cullen and the HSE. This was in due course recognised by the MOD who, on 17 December 2004[63] published Issue 3 of Def-Stan 00-56, as part of its drive to make military standards as *"civil as possible, as military as necessary*.[64]

9.41 Before turning to Issue 3, it should be noted that Annex D of Issue 2 of Def-Stan 00-56 sought to provide guidance on the retrospective application of the Standard to projects involving legacy systems. This guidance included the following:

9.41.1 The retrospective application of the Standard should be flexible, its utmost objective being the collection and collation of as much safety related information as reasonably practicable (para. D.1.1).

9.41.2 A Safety Programme Plan should be prepared and maintained in all cases. Retrospective application of the Standard was said to require *"judicious and justified tailoring of the project safety programme"* and clarification of a number of basic issues, including: (a) the process and safety standards used to design and build the system; (b) the accident and near-miss history of the system; and (c) the existence of a prior safety case for the system. This existing information was then to be supplemented with further analyses and/or by the use of service history (paragraph D.1.2).

9.41.3 A Hazard Log should be established and maintained for all systems. In the case of legacy systems, it was recognised that the information contained in the Hazard Log could originate from: (a) previous safety assessments; (b) existing safety certification data; (c) previous design activity quality assurance records and audits; and (d) experience from service history. It was further noted, however, that the Safety Case should provide justification for using information from any of these sources as well as explicit arguments explaining how the Safety Case was supported by such evidence. In particular, if service history was to be used, all safety related incidents and near-misses should be recorded in the Hazard Log and mitigating circumstances explained in the Safety Case (paragraph D.1.6).

9.41.4 If a system had previously been certified as compliant with other standards, it may be necessary to supplement the existing certification data in order to satisfy the requirements of the Standard (paragraph D.2.2).

9.41.5 Use of service history may allow validation of a safety requirement by comparison to the safety requirements of similar, in-service certified systems (paragraph D.2.3).

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59 Ibid, paragraph 5.3.4.8.

60 Ibid, paragraph 5.3.4.9.

61 Ibid, paragraphs 5.8.7 and 5.8.9.

62 Ibid, paragraphs 7.2.3 and 7.2.4.

63 By this time, as I explain in **Chapter 10**, the Nimrod Safety Case had in fact already been signed-off by the IPT.

64 This remains the policy: *"The SofS* [Secretary of State] *safety policy is that civil legislation should be followed unless there is an over-riding imperative to do otherwise; where exemptions to civil legislation are granted, the measures set in place should be '…so far as reasonably practicable, at least as good as those required by legislation'"* (*Directorate of Aviation Regulation and Safety Annual Report for 2007*, page 7, under Legislation).

9.41.6 In all cases of retrospective application of the Standard, the Safety Case should contain well organised and reasoned justification clearly showing that: (a) existing or supplemental analysis is sufficient to demonstrate that the system is tolerably safe; and (b) service history is applicable and changes to the referenced system configuration have been appropriately controlled and documented (paragraph D.3).

Issue 3 of Def-Stan 00-56

9.42 As explained above, Issue 3 of Def-Stan 00-56 was issued in December 2004. It purported to abandon the prescriptive approach of earlier issues in favour of a 'goal-based' approach (although the change of approach is not readily apparent save for the covering words to Part II that *"THIS GUIDANCE IS NOT MANDATORY"*). Part 1 of Issue 3 set out mandatory key safety management requirements, including over-arching objectives and principles and Part II, which was not mandatory, provided guidance on establishing a means to comply with the requirements of Part I.

9.43 The MOD explained to the Review that Issue 3 was intended to reflect a review of project safety management issues and incorporate changes in MOD policy and safety management good practice, and to take account of lessons learnt from Issue 2. The key changes introduced in Part 1 'Requirements' (Issue 3) were said to be as follows:

(1) The adoption of the ALARP principle for managing risks.[65]

(2) The introduction of an MOD Duty Holder who has specific responsibilities for Safety Management of the system.[66]

(3) The setting of objective and specific requirements to enable the acquisition of equipment that is compliant with both safety legislation and MOD safety policy.[67]

(4) The adoption of the principle of safety management requirements as opposed to the safety programme requirements used in Issue 2. Effectively, Issue 3 no longer mandated the procedures to be used.[68]

(5) The provision of a definition of what a system is considered to be and the application of Def Stan 00-56 to all acquisition scenarios and all systems.[69]

(6) Placing the requirement on the contractor to demonstrate compliance.[70]

(7) Placing the onus on the contractor to identify all the safety legislation, regulations, standards and MOD policy relevant to the safety of the system.[71]

(8) The introduction of the requirement that, if the duty holder or a delegated representative does not chair the Safety Committee, then the Safety Committee can only make recommendations to the Duty Holder, *i.e.* formal Duty Holder agreement is required before proceeding on ALARP judgments.[72]

(9) Placing the requirement on the contractor to produce a Safety Case for the system on behalf of the Duty Holder.[73]

(10) The introduction of the need to establish tolerability criteria for forming the basis for assessing whether a risk is broadly acceptable, or tolerable and ALARP.[74]

(11) The appointment of an Independent Safety Auditor.[75]

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65 Def-Stan 00-56 (Part 1)/Issue 3, paragraph 0.1.
66 Ibid, paragraph 0.2.
67 Ibid, paragraph 0.3.
68 Ibid, paragraph 1.1.
69 Ibid, paragraph 1.2
70 Ibid, paragraph 1.7.
71 Ibid, paragraph 6.
72 Ibid, paragraph 7.4.2.
73 Ibid, paragraph 9.2.
74 Ibid, paragraph 10.7.1.
75 Ibid, paragraph 4.3.3.

9.44 The Introduction to Issue 3 of Def-Stan 00-56 specified 13 key objectives underlying the Def-Stan's requirements, as follows:

(1) All relevant safety legislation, regulations and MOD Policy should be identified.

(2) All activities and products should comply with the identified legislation, standards, MOD Policy and specific contractual requirements.

(3) Safety should be considered from the earliest stage in a programme and used to influence all activities and products. It is essential that safety risks and project risks are managed together.

(4) Tasks that influence safety should be carried out by individuals and organisations that are demonstrably competent to perform those tasks.

(5) Safety Management should be implemented as a key element of a harmonised, integrated systems engineering approach.

(6) An auditable Safety Management System should be implemented that directs and controls the activities necessary to ensure safety throughout the programme life (i.e. the acquisition cycle).

(7) A Safety Case should be developed and maintained that demonstrates how safety will be, is being and has been, achieved and maintained.

(8) Safety Case Reports, that summarise the Safety Case and document the safety management activities, should be delivered as necessary for effective oversight of safety management;

(9) All credible hazards and accidents should be identified, the associated accident sequences defined and the risks associated with them determined.

(10) All identified risks should be reduced to levels that are broadly acceptable or, when this is not possible, tolerable and ALARP, unless legislation, regulations or MOD Policy impose a more stringent standard.

(11) Interfaces between Safety Management Systems, Safety Cases, systems and organisations should be identified and effectively managed.

(12) Changes to the operational, technological, legislative and regulatory environment, and any other changes that may have an impact on safety, should be monitored and managed.

(13) Defect/failure reports and incident/accident/near miss reports should be monitored; remedial actions necessary to ensure continued safety should be identified and implemented.

9.45 A Safety Case itself was defined in Def-Stan 00-56 as *"a structured argument, supported by a body of evidence, that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment".*[76] Whilst Issue 3 of Def-Stan 00-56 no longer included Annex D, paragraph 9.2.2 of the Guidance in Part 2 of Def-Stan 00-56 (which is non-mandatory) provided that a Safety Case was required for all systems, whether being acquired or already in-service. Paragraph 9.3.1. of the Guidance recognised that the development of a Safety Case for a pre-existing system could be a costly process, both in time and financial terms, and that effective planning, management and contracting were required to enable the implications to be understood and addressed early in the project. Paragraph 9.5 of the Guidance provided that, whilst all Safety Cases contain an implicit safety argument, Def-Stan 00-56 required an explicit argument; usually expressed in terms of a defined hierarchy of safety claims and sub-claims supported by a body of evidence. The explicit argument was required to be structured and contain references to the documented evidence (paragraph 9.5.3 of the Guidance). It appears, therefore, that whilst non-mandatory, the Guidance to Def-Stan 00-56 recommended an explicit Safety Case.

9.46 In relation to the Hazard Log, paragraph 10.5.1 specified that the Contractor was to carry out Hazard Identification and Hazard Analysis to identify credible hazards and accidents associated with the system and to determine the related accident sequence. Paragraph 10.5.2 went on to provide that the Contractor was to demonstrate the adequacy of the Hazard Identification and Hazard Analysis process and the suitability of the techniques employed.

[76] Ibid, paragraph 9.1.

9.47 In terms of the evidence required to support the Safety Case, Issue 3 of Def-Stan 00-56, required *"compelling"* and *"diverse"* evidence but made it clear that the quantity and quality of evidence should be *"commensurate with the potential risk posed".* It provided as follows:

> *"11.3.1. Within the Safety Case, the Contractor shall provide compelling evidence that safety requirements have been met. Where possible, objective, analytical evidence shall be provided. The quantity and quality of the evidence shall be commensurate with the potential risk posed by the system and the complexity of the system. For safety requirements that lead to the realization of mitigation strategies, the quantity and quality of the evidence shall be commensurate with the level of Risk Reduction from that safety requirement.*
>
> *11.3.2. The Contractor shall provide diverse evidence that safety requirements have been met, such that the overall safety argument is not compromised by errors or uncertainties in individual pieces of evidence. The strategy for providing diverse evidence shall be agreed with the Duty Holder.*
>
> *11.3.3. The Contractor shall integrate within the Safety Case the evidence that shows that safety requirements have been met for elements of the system, to demonstrate that the overall safety requirements have been met."*

9.48 It appears that some may have taken or mistaken the definition of a Safety Case as something of a green light to undertake what was, in effect, an 'archeological' document trawl into the original design documents. This, however, was not an appropriate, sensible or fruitful use of time or resources and tended to detract from the key element of a safety analysis for legacy aircraft, namely the carrying out of a thorough Hazard Analysis. I discuss this issue further in **Chapter 11**. In my view, it is important that the evidence to support a safety case is (a) proportionate and (b) relevant to current risks.

Issue 4 of Def-Stan 00-56

9.49 The latest version of Def-Stan 00-56 is issue 4 which was issued on 1 June 2007. The Part 2 guidance is again said not to be mandatory, as before.

Appointment of ISA

9.50 The appointment of an *"Independent Safety Auditor"* (ISA) in relation to the preparation of a Safety Case was mandated by JSP553 to ensure that the Safety Case was independently assessed. It required both an audit to ensure compliance with the Safety Management Plan (SMP) and a technical evaluation of the Safety Case Report. The assessment was to be carried out by an *"Independent Safety Auditor"* (ISA) in accordance with Def-Stan 00-56, or an alternative independent competent organisation (see JSP553, Chapter 2, paragraph 2.58). There was also a requirement under Def-Stan 00-56 that an ISA was to be formally tasked in all cases where a Preliminary Hazard Analysis identified class A or B risks (and class B risks were deemed tolerable) and that terms of reference for the ISA and an audit plan should be drawn up (see Def-Stan 00-56, paragraph 5.3.4). I discuss this issue further below.

BP1201

9.51 As indicated above, JSP318B and Def-Stan 00-56 were essentially procurement focused, *i.e.* aimed at the Defence Procurement Agency (DPA). Whilst they both indicated that the Safety Case concept should also be applied to older systems and mature or 'legacy' aircraft, this was not their primary focus, which was the application of the Safety Case concept to all new or modified systems. This reflected the ideal that a Safety Case should be developed concurrently with the design of an aircraft to ensure that the design is influenced by the Safety Case. Applying Safety Cases to a legacy aircraft obviously does not offer the same opportunity. Pursuant to JSP318B, however, all IPTs were required to adopt an Equipment Safety Management System and

JSP318B further prescribed that its requirements should be applied to mature systems as far as was *"reasonably practicable"* (see above). With this in mind, Equipment Support (Air) (ES(Air)) within the Defence Logistics Organisation[77] published ES(Air) Business Procedure 1201 (BP1201) to provide direction to the in-service IPTs.

9.52 BP1201 set out the mandatory core content of a Safety Management System (SMS) and prescribed that all IPTLs were to ensure that Project Engineers (PEs) were to produce and maintain an Equipment SMP (ESMP) for all equipment for which they had airworthiness and safety responsibility.[78] It also provided for a Project Safety Working Group (PSWG) to be formed within each IPT to support each Project SMS and to co-ordinate the ESMP.[79] Every SMS was also to be subject to assurance and audit processes to provide evidence that safety was being properly managed.[80] Annex E detailed the essential elements of the audit regime, providing for either internal self audit, internal independent audit or external audit at least twice a year.

9.53 In relation to Safety Cases, BP1201 provided that a Safety Case: (1) was to remain the responsibility of the Project Engineer (PE); (2) was to be maintained throughout the life of the equipment; and (3) was to continue to provide the justification that the equipment remained tolerably (targets achieved and ALARP demonstrated) safe.[81] It set out a pyramid structure for a *"credible, complete, consistent, and comprehensible Safety Case"*, which comprised four levels:

9.53.1 *Safety Evidence*: This is the foundation of the Safety Case and includes the Hazard Log. Safety evidence includes safety targets, standards, design and development data, analysis, simulation and modelling, test results and service experience.

9.53.2 *Safety Argument*: The analysis and justification that the Safety Evidence is sufficient to demonstrate that the equipment is tolerably safe.

9.53.3 *Safety Case Report*: A summary of the Safety Argument that supports the Safety Statement, includes all salient issues from the Safety Argument and includes recommendations for future work.

9.53.4 *Safety Statement*: The certificate by the IPTL that the equipment is *"tolerably safe"*.

9.54 BP1201 explained that all hazards identified from any source were to be managed through the Hazard Log, which was fundamental to the Safety Case. The setting of accident severity categories and probability categories was to be based on those in Def-Stan 00-56 but categories were to be chosen that permitted the adoption of the Risk Classification Table at Annex D to BP1201 (see further below).[82]

Legacy Aircraft and 'Implicit' Safety Cases

9.55 Regrettably, it may be said that it was in BP1201 that the seeds of a fundamentally flawed approach to the application of Safety Cases to legacy platforms were sown.

9.56 BP1201 recognised that most aircraft in (then) current service did not enjoy a formal Safety Case and further stated that it was not necessary for a full retrospective safety case to be prepared, for much of the effort would be nugatory. It permitted, therefore, what it called an *"implicit Safety Case"*, namely, that the PE responsible for the legacy system could accept the current Release to Service (RTS) as an implicit Safety Case by conducting a general safety assessment to assure that there were no known reasons not to accept the current clearances and underlying safety evidence.[83] In other words, the fact that an aircraft had been built to a standard applicable at its build date, had received the necessary clearances and operated satisfactorily since then could be taken as acceptable *in lieu* of an explicit Safety Case, provided that a general safety assessment did not reveal any evidence to the contrary.

[77] See **Chapter 12**.
[78] BP1201, paragraph 5.
[79] Ibid, paragraph 6.
[80] Ibid, paragraph 11.
[81] Ibid, paragraph 7.
[82] Ibid, paragraph 8.
[83] Ibid, paragraph 9.

9.57 BP1201 recognised that such an 'implicit' Safety Case was less desirable than an 'explicit' one and set out in Annex C a strategy for the safety assessment of legacy systems. The 'strategy' laid down in BP1201 comprised four phases:

9.57.1 *Phase 1 – Form a strategy for constructing the Safety Case*: This phase was to culminate in the completion of an ESMP for the Safety Case which had been reviewed and endorsed by the PSWG.

9.57.2 *Phase 2 – Form a strategy for managing the acceptability of safety throughout the aircraft's operational life*: This would rely upon the implicit Safety Case and subsequent changes being acceptably demonstrated within an explicit Safety Case.

9.57.3 *Phase 3 – Construct the Safety Case*: The explicit Safety Case structure was to contain the following components: (i) Safety Management Plan; (ii) (Limited) Safety Assessment; (iii) Hazard log; and (iv) Safety Case Report. It was to contain a safety assessment which provided an assurance that all the top level hazards presented by the aircraft had been satisfactorily managed during its operational life.

9.57.4 *Phase 4 – Manage the acceptability of safety throughout the aircraft's operational life*: Current airworthiness related management systems, i.e. change control and reporting procedures, would have to be adapted to support the explicit Safety Case.

9.58 In my view, there are a number of fundamental problems with, or objections to, the notion of an '*implicit*' Safety Case. First, it is something of an oxymoron: one either prepares a proper 'Safety Case' or one does not. Second, the concept of an *"implicit Safety Case"* does not comply with Lord Cullen's concept of a *"thorough assessment"* of the risks posed by a platform. This is because, in effect, the notion assumes that a legacy aircraft is safe merely because it was built to design and has been operating without mishap for a number of years. Third, the very fact that BP1201 expressly permitted such an assumption is, perhaps, undesirable in itself, because it may tend to undermine the resolve of those carrying out the Safety Case.[84] It is also troubling that the 'Phase 1 strategy' in Annex C of the original BP1201 referred to above included the statement: *"make the basic assumption that the aircraft is already operating to acceptable levels of safety and determine that level of safety."* Any genuine assessment should, however, be a matter of engineering judgment, not assumption. Otherwise, the process is self-defeating.

9.59 It should be noted that Issue 2 of BP1201, published in September 2002, did not include the guidance contained in the former Annex C, although it continued to endorse the notion of an implicit Safety Case for legacy systems. Otherwise, it largely followed the original BP1201, with the addition of the further comment that the purpose of a hazard Log was *"to provide a 'corporate memory' for IPT managers, and potentially, operators, of the hazards, associated safety risks and mitigating action"*.[85]

[84] *C.f.* the reference to the NSC being *"underpinned"* by the in-service history in BAES Equipment Safety Case Baseline Report No. MBU-DEF-C-NIM-SC0713 dated September 2004, page 4.

[85] BP1201, Issue 2, paragraph 14.

9.60 Issue 2 of BP1201 also included at Annex B a revised Safety Risk Classification Table,[86] as follows:

		Accident Severity Categories			
		Catastrophic	Critical	Marginal	Negligible
Accident Probability Categories	Frequent	A(1)	A(3)	A(7)	B(13)
	Probable	A(2)	A(5)	B(9)	C(16)
	Occasional	A(4)	B(6)	C(11)	C(18)
	Remote	B(8)	C(10)	C(14)	D(19)
	Improbable	C(12)	C(15)	D(17)	D(20)

Risk Classification	
A	**Unacceptable** – Urgent management action required since such risk cannot be justified save in extraordinary circumstances.
B	**Undesirable** – Requires management action to introduce control measures to reduce risk and shall only be accepted when risk has been reduced to ALARP.
C	**Tolerable** – The residual risk is tolerable only if further risk reduction is impracticable or requires action that is grossly disproportionate in time, trouble and effort to the reduction in risk achieved.
D	**Broadly Acceptable** – The level of residual risk is regarded as insignificant and further effort to reduce risk not likely to be required as resources to reduce risks likely to be grossly disproportionate to the risk reduction achieved.

9.61 Annex B provided that the responsibility for the categorisation of safety risk lay with the IPTL, taking the advice of the PE as required. The IPTL was responsible for determining when a particular equipment safety risk had been reduced to ALARP, and all safety risks were to be regularly reviewed to reassess the validity of ALARP.

Deadline

9.62 Issue 2 provided a number of deadlines by which each IPT was required to have implemented its requirements. In particular, the initial safety management planning activity was to be completed by 31 December 2001 and IPTs were to have in place an SMS and have completed a review of the implicit Safety Case and issued a risk-based Safety Case Report by 1 April 2004. A Safety Management Timeline at Annex D included as the last stage of the process an Independent Assessment following the construction of the Safety Case report. These requirements and timings were reiterated in Issue 3 of BP1201 dated August 2003[87], which largely replicated Issue 2, save for the following:

9.62.1 It incorporated a new diagram of the structure of the Safety Case, *in lieu* of the pyramid diagram in Issue 2[88]. This new diagram showed *"assumptions"* leading to *"reasoned arguments"* which in turn led to *"safety claims"*. *"Analysis"* was shown as one of the evidential factors which, amongst others, was to form part of the reasoned argument.

[86] Annex B also included tables explaining the probability and severity bands that feature in the Risk Classification table.

[87] Issue 3 was in due course replaced by the Military Air Environment Handbook (MAE) BP1201 in August 2006. Issue 4 dealt with the Acquisition Safety and Environment Group (ASEG), a dual accountable organisation set up to operate the Acquisition Safety and Environmental Management System (ASEMS) (with a view to overcoming the difficulties experienced in the transfer of projects between the Defence Procurement Agency and the Defence Logistics Organisation).

[88] BP1201, Issue 3, paragraph 11 and see above.

9.62.2 Another change was to the Risk Classification Table contained in the annexes – the newer edition included a further Accident Probability Category of *"Incredible"*.

9.62.3 Issue 3 also included in the annexes a Generic Hazard Log Flowchart which set out a generic process that IPTs should adopt to ensure that the information recorded within the hazard log was correct.

Guidance for Safety Cases

9.63 Given the deadline in Issues 2 and 3 of BP1201, just what guidance was available to the Nimrod IPT as to how *in fact* to implement the requisite SMS, carry out the required risk analysis, and ultimately produce the Safety Case?

9.64 As indicated above, in terms of practical guidance (*i.e.* explaining how to actually produce a Safety Case), the relevant military regulations dealing with Safety Cases were somewhat thin, focusing instead on the aims of the Safety Case and the guiding principles to be applied. Indeed, in paragraph 0.4 of Issue 2 of Def-Stan 00-56, it was expressly stated *"This Standard assumes a working knowledge of the techniques for hazard analysis and safety assessment"*. This 'assumption' is perhaps what led Frank Walsh (the Nimrod IPT Safety Manager) to complain to ES(Air) in relation to a draft version of Issue 3 of Def-Stan 00-56 about the *"lack of a hazard assessment framework"* and *"the lack of any suggested Hazard Log format"*.[89] That said, arguably the best practical guidance in terms of the relevant military regulations was in fact to be found in the Guidance in Part 2 of Def-Stan 00-56, Issue 2 which, amongst other things:

- Provided a suggested Hazard Log structure and a breakdown of the information that it should include;[90]
- Sought to explain how to carry out Hazard Identification, including explaining the concepts, tasks and requirements involved in Preliminary Hazard Analysis, System Hazard Analysis, Functional Analysis and Zonal Analysis;
- Sought to explain the objective, formulation and application of safety criteria, including the different severity and probability categories; and
- Sought to explain risk estimation, including how to identify accident sequences and how to categorise accidents.

9.65 Whilst this Guidance was undoubtedly more helpful than the very limited contents of JSP318B, the reader could be forgiven for still wondering how best to go about actually performing *e.g.* a functional or zonal analysis. The same may be said of earlier, non-regulatory guidance, such as the "Guidance for the provision of an aircraft Safety Case"[91] produced by the Defence Evaluation and Research Agency (DERA)[92] and issued back in March 1998.[93] Again, this identified the guiding principles and purpose of a Safety Case but did not specify just *how* one was to go about identifying the possible hazards which could arise. A balance needs to be struck between pure 'goal-based' regulations and overly prescriptive regulations.

9.66 It is nonetheless clear that, at least by 2002, there was an understanding within (at least parts of) the MOD of the fundamental aims and philosophy that should underpin a Safety Case. The very least that can be said is that there was material available which set out the aims of Lord Cullen's recommendations in the *Piper Alpha* report. Most notably in this respect, in 2002, Advantage Technical Consulting under contract to the MOD produced Issue 1 of *"An Introduction to System Safety Management & Assurance"*. This has come to be known as the 'White Booklet' and is still freely available today (as amended)[94] on the MOD intranet,[95] described as an *"entry-level reference for system safety management"*, its stated purpose being to provide an introduction to system safety management concepts, terms and activities.

[89] Email from Frank Walsh to ES(Air), dated 1 March 2004.

[90] Def-Stan 00-56 (Part 2), Issue 2, paragraph 5.8.

[91] DERA/AT&E/MC/TR0005/1.0.

[92] Forerunner to QinetiQ.

[93] See, in a similar vein, *"Scoping Study for a Generic Specification on the Retrospective Application of Safety Cases to UK Military Helicopters"*, Report Number 305E287/1, dated June 1999, prepared by BMT Reliability Consultants Limited for the Defence Helicopter Support Authority.

[94] The current edition is Issue 2, dated July 2005, which expands slightly upon the earlier version.

[95] http://www.mod.uk/DefenceInternet/AboutDefence/CorporatePublications/DefenceEstateandEnvironmentPublications/ASEG/TheWhiteBookletAnIntroductionToSystemSafetyManagementAndAssurance.htm

White Booklet

9.67 This description arguably does not do the White Booklet (2002) justice, for it in fact included a number of highly pertinent observations from which it is clear that its authors fully recognised and appreciated the fundamental requirements of an effective safety system, as expounded by Lord Cullen. These observations included the following:

9.67.1 Accidents are indications of failure on the part of management and that, whilst individuals are responsible for their own actions, only managers have the authority to correct the attitude, resource and organisational deficiencies which commonly cause accidents.[96]

9.67.2 The user must be involved in safety throughout the lifecycle, from setting appropriate safety requirements through to managing residual risk and feeding back information on shortfalls experienced in service use.[97]

9.67.3 The definition of a Safety Culture is *"that assembly of characteristics and attitudes in organisations and individuals which establishes, as an overriding priority, that safety issues receive the attention warranted by their significance"* (as per the International Nuclear Safety Advisory Group).[98]

9.67.4 Safety assessment must not be viewed as a one-off exercise: people should be continuously trying to make things safer. A strong safety culture with the necessary simulation from audits, incidents and suggestions will ensure that safety improves.[99]

9.67.5 The non-occurrence of system accidents or incidents is no guarantee of a safe system. Safety monitoring and safety audit are the methods used to ensure that the safety system does not die but is continually stimulated to improve the methods of risk control and safety management. To maintain safety integrity across large and/or high risk projects, it is advisable that an Independent Safety Auditor be appointed to ensure that MOD contracted safety requirements are being met by the Contractor.[100]

9.67.6 *"Like a case in law, the Safety Case is a body of evidence presented as a reasoned argument. Unlike most areas of the law, the activities are not presumed innocent until proven guilty: the Safety Case must <u>prove</u> that a system is safe"* (emphasis added). In this context, the MOD is the 'operator', but also the 'regulator'. The regulator function must be organisationally distinct within the MOD, so that one area is not responsible both for preparing the safety case argument and declaring it adequate. The MOD may contract out the production of the Safety Case, but it is still owned by the MOD.[101]

9.67.7 *"A Safety Case can be defined as a structured and documented body of evidence that provides a convincing and valid argument that a system is adequately safe for a given application in a given environment. A simple way of understanding the Safety Case is to consider four basic questions:*

- What could go wrong? (hazard identification and analysis)
- How bad could it be? (risk assessment)
- What has been done about it? (hazard control, supporting evidence)
- What if it happens? (emergency and contingency arrangements)

The Safety Case should answer these questions for the whole system under consideration for the uses defined."[102]

[96] White Booklet, 2002, page 1.
[97] Ibid, Page 6.
[98] This is my favoured definition of Safety Culture (see **Chapter 27**).
[99] Ibid, page 10.
[100] Ibid, pages 12 – 13.
[101] Ibid, page 16.
[102] Ibid, page 16.

9.67.8 The Safety Case is a *"live, working document and shouldn't just gather dust in a cupboard"*. Further, not all Safety Cases are good. The HSE has reviewed many real safety cases in its role as a regulator and some of the problems it has found with poor examples include: (i) they contain assertions rather than reasoned argument; (ii) there are unjustified and implicit assumptions; (iii) some major hazards have not been identified and are therefore never studied; and (iv) ownership of the Safety Case is not always clear.[103]

9.67.9 The MOD has a policy of requiring a retrospective assessment of safety for existing systems. This assessment should be documented in a format which is essentially the same as for a Safety Case.[104]

9.68 The White Booklet, therefore, provided useful general guidance as to what was required and expected with respect to a Safety Case.

Nimrod Safety Management Plan

9.69 As explained above, pursuant to JSP318B, each platform was required to develop a Safety Management Plan (SMP). In relation to the Nimrod IPT, the preparation of a SMP was regarded as a priority by the previous IPTL. He delegated the task of drawing it up to the then Head of Air Vehicle, who explained in evidence that he used the Jaguar/Canberra SMP as a template and as evidence of 'best practice'. He felt he needed time to concentrate on the task and so devoted part of his annual holiday to drawing it up. Leaving aside the assumption of safety that I refer to below, he did a creditable job. The Nimrod SMP, which was issued by the IPTL in February 2002, comprised a detailed and comprehensive set of rules and procedures for the safe management of the Nimrod. It defined the Safety Management System (SMS) for ensuring the safety of the platform and set out: (1) the IPT philosophy and system for safety; (2) the IPT SMS, including organisation, committees, documents and processes through which hazards are identified, evaluated, managed and monitored; (3) the Safety Case and strategy for the platform, setting a baseline for the legacy aircraft and a structure for ongoing safety development; (4) the audit programme by which the SMS efficacy would be monitored; and (5) a programme of work to implement the SMS. The SMP's treatment of topics is outlined in further detail below. The Nimrod SMP was revised in August 2003 by Frank Walsh on his appointment as Safety Manager (see further below).

9.70 The Executive Summary of the SMP stated:[105]

> *"By virtue of a range of traditional methods, there is a high level of corporate confidence in the safety of the Nimrod aircraft. However, the lack of structured evidence to support this confidence clearly requires rectifying, in order to meet forthcoming legislation and to achieve compliance with JSP 318B."* (emphasis added)

9.71 Lord Cullen explained that a Safety Case was, primarily, a matter of a company assuring itself that its operations were safe, and only secondarily a matter of demonstrating this to the regulatory authorities.[106] The problem was that those involved in producing the NSC embarked on the process believing the Nimrod type was safe (*c.f.* the repeated statements by the Nimrod IPT and BAE Systems that *"...there is a high level of confidence in the safety of the Nimrod..."*). For this reason, therefore, there was no real need for them to assure themselves of something that they assumed to be the case, *i.e.* that the Nimrod was safe. This attitude was unfortunate and served to undermine the integrity and rigour of the Safety Case process itself (see further **Chapter 11**).

[103] Ibid, pages 16–17.
[104] Ibid, page 17.
[105] Nimrod SMP, Executive Summary, page 3.
[106] Cullen, paragraph 17.35.

Philosophy of the SMP

9.72 The SMP's philosophy was that the overall safety of the platform was to be demonstrated through a Safety Case, detailing the necessary supporting evidence and providing a sound argument as to how safety requirements had been met. Where hazards were identified, they were to be managed to a level at which they were deemed to be ALARP.[107] To ensure that valid operating assumptions were made when assessing hazards, Service Operating Branch (SOB) representatives would be called upon as part of the Platform Safety Working Group (PSWG). Additionally, the following would be consulted at the hazard identification stage: (a) IPT members with SOB experience; (b) the Nimrod Aircraft Engineering Development and Investigating Team (NAEDIT) for maintenance aspects; and (c) Aircraft and Programmes and Airworthiness (APA) staff for operational aspects.[108]

9.73 Annex A to the SMP set out the SMP safety organisation, describing the safety roles and responsibilities of the key personnel/bodies, including the following:

9.73.1 *IPTL:* The IPTL's responsibilities included (amongst others) the production of the SMP, maintenance of the NSC (including the Hazard Log), the management and identification of the necessary competence within the IPT and an audit regime. The IPTL also assumed the responsibilities of the Project Engineer (PE).

9.73.2 *Head of Air Vehicle Branch (Nim(ES)Av):* Nim(ES)Av's responsibilities included acting as a *"Safety Advisor"* to the IPT, advising the IPTL on safety matters (as appropriate), chairing the Aircraft Safety Reviews (see below), ownership of the NSC and Hazard Log and identifying the safety evidence necessary to support the Nimrod air vehicle from equipment suppliers (Contractors and other IPTs), and setting appropriate safety requirements.

9.73.3 *Safety Manager (Nim(ES)Av(S)):* Although not an airworthiness Letter of Delegation (LOD) holder, NIM(ES)Av was to play a role in the efficacy of the Safety Management System (SMS), primarily through interfacing with equipment contractors.

9.73.4 *Independent Safety Assessors (ISA):* ISAs were to be appointed, where necessary, as identified by the PSWG. QinetiQ was included in the approved list of ISAs. The SMP referred to the guidance given in Def-Stan 00-56 and stated that an ISA should be *"strongly considered"*, *inter alia*, to assess complex safety evidence provided by a contractor for a product.

[107] Nimrod SMP, paragraph 8.

[108] Ibid, paragraph 13.

9.74 These roles and responsibilities were further depicted pictorially in the following organogram:

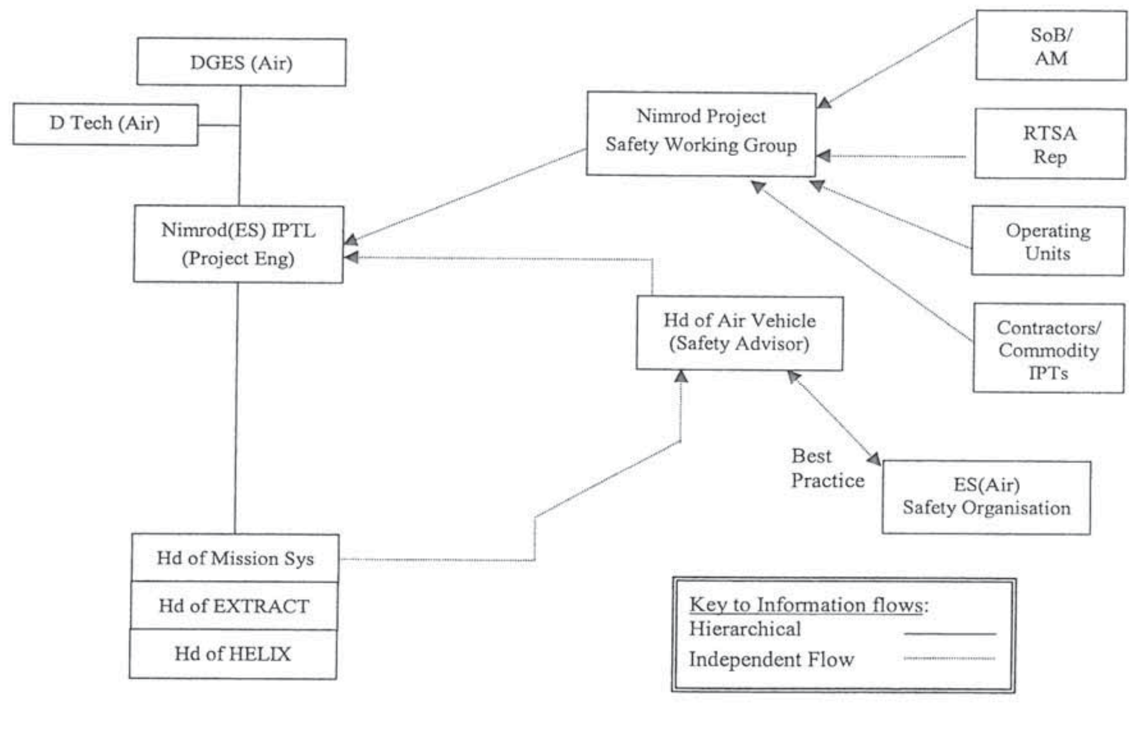

Figure A1 – IPT Safety Organisation

9.75 It should be noted that the SMP organogram envisaged 'Operating Unit' representation on the PSWG**.** The Review was informed, however, that whilst there was good attendance by representatives from both RAF Kinloss and RAF Waddington at the early PSWG meetings, the attendance from RAF Kinloss waned somewhat from mid-2003 onwards. However, it had been agreed at the first two meetings of the PSWG that 'operational' risks would be more appropriately dealt with at the separate Joint User Working Group. This decision, coupled with the lengthy travelling time from RAF Kinloss to RAF Wyton, may well have been the cause of the decline in Kinloss operators' attendance. A concomitant result of this was that Kinloss no longer received copies of the meetings' minutes and would not have been aware of forthcoming PSWGs. Following the loss of XV230, RAF Kinloss was added once more to the distribution list and their attendance resumed.

9.76 Paragraph 20 of Annex A to the SMP noted that a 'safety culture' was an essential requirement for the IPT. Such a culture could not be imposed, but was to be fostered through: (1) communication; (2) training; (3) the setting of personal objectives; and (4) *"as broad an involvement of IPT members as possible"*, to foster the common 'ownership' of safety processes and to ensure that the process was ultimately workable and effective. It is regrettable that these laudable aims were never successfully implemented in practice during the production of the NSC. Indeed, it transpired that few of the members of the IPT were more than vaguely aware that the NSC was being prepared at all.

The Safety Committees and Hazard Management Process

9.77 The SMP provided that the review and endorsement of the platform safety issues managed by the IPT would take place through a two-tier committee system, a high level PSWG and lower level Aircraft Safety Reviews (ASR).[109] It mandated the following process for hazard management:

Hazard Management Process	**Aircraft & Engine Safety Reviews**	**Nimrod Project Safety Working Group**
Period – Daily basis	Period – Six-monthly (staggered to fit between PSWGs)	Period – Six-monthly
IPT members – Raise 'Draft' hazards & accidents **LoD holders -** Review Drafts and raise as 'Open' with proposed risk categorisation or 'Deleted' with reasons **Engineering HOBs** 'Approve' all hazards & accidents, risk categorisation and establish controls. Can declare risks up to Cat 'C' as 'Managed' (Controls in place) or 'Closed' (ALARP). **PE/IPTL –** Can declare risks up to Cat 'A' as 'Managed' (Controls in place) or 'Closed' (ALARP).	Chaired by Hd of Air Vehicle Review all hazards & accidents, including 'Draft', for risk categorisation and controls. All Cat 'A' & 'B' risks passed up to PSWG. Unusual or borderline Cat 'C's nominated also. Can declare risks up to Cat 'C' as 'Managed' (Controls in place) or 'Closed' (ALARP)	Chaired by IPTL/PE. Review overall risk statistics (Cat 'A' to 'D'). Review efficacy of SMS. Review all Cat 'a' & 'B' and nominated 'C' risks. Endorse categories and controls. Can declare risks up to Cat 'A' as 'Managed' (Controls in place) or 'Closed' (ALARP).

Table A1-1 – Aligning the Safety Committees with ongoing Hazard Management

9.78 The SMP Hazard Management Process thus envisaged a tiered, three-stage process:

9.78.1 *Stage 1*: LOD holders were to give 'proposed' risk categorisations to draft hazards after advice from the Engineering Heads of Branch (HOB) (with HOB being able to declare risks as 'managed' or 'closed' up to Category 'C' and the PE/IPTL being able to declare risks up to Category 'A').

9.78.2 *Stage 2*: All risk categorisations and controls were to be reviewed by the ASR (with the ASR being able to declare risks up to Category 'C', but passing all Category 'A' and 'B' and borderline 'C' risks up to the PSWG).

9.78.3 Stage 3: All Category 'A' and 'B' and nominated 'C' risks were to be reviewed by the PSWG (with the PSWG being able to declare risks up to Category 'A').

9.79 Risks of Category 'C' and above required more than simply a discussion between the instigating IPT member and LOD holder. They required a formal Preliminary Hazard Analysis as directed by the Head of Air Vehicle or the ASR, *i.e.* detailed discussion, 'brainstorming' sessions, structured HAZOP techniques, or assistance from specialist industry. For risks of Category 'A' or 'B', risk classification of 'Open' and 'Approved' hazards/accidents by NIM(ES)AV or the ASR was subject to endorsement by the IPTL/PE. As to which, it was contemplated by the SMP that the PE/IPTL's categorisation of risk could and would, on occasion, be done ex-committee. However, it appears also to have been envisaged by the SMP that, in any event, all 'A' and 'B' and borderline 'C' risks categorisations would nevertheless still require to be reviewed, first by the ASR and then by the PSWG.[110]

[109] Ibid, Appendix 1 to Annex A, paragraph 1.

[110] Ibid, Appendix 1 to Annex A, paragraphs 6 and 10.

Risk Assessment

9.80 As regards risk assessment, the SMP provided that this would be made on the basis of the potential severity of the accident and the probability of the hazard condition occurring. It was specifically stated that such quantification *"must support, not replace, sound judgment"* and that *"probabilities must not be 'tweaked' to artificially move hazards or accidents into a more favourable category"*[111]. Where the indications were borderline, *"the more stringent criteria should always be applied to ensure appropriate management action is taken"*.[112] As explained above, risk assessment within the IPT was to be undertaken by Nim(ES)Av and the ASR, with endorsement of risks above Category C by the PE/IPTL and the PSWG. Risk assessment undertaken by contractors and external agencies was similarly to be subject to review by the PE/IPTL.[113] Ultimately, the overall safety argument was to be documented in a Safety Case Report and a Safety Statement certificate was to be issued by the PE/IPTL to the RTSA that the aircraft was tolerably safe.[114]

Risk Classification

9.81 Appendix 1 to Annex C of the SMP set out accident, hazard and risk criteria. In terms of risk classification, the A, B, C & D categories, in terms of broad bands of acceptability, corresponded to the following Def-Stan 00-56 classifications:[115]

9.81.1 *"Intolerable risk"*: Required urgent action, including reporting in accordance with Chief Engineers Notice 44.

9.81.2 *"Undesirable risk"*: Required management action and was only to be accepted by the PE/IPTL and PSWG when risk reduction was impracticable.

9.81.3 *"Tolerable risk"*: Could be accepted with the endorsement of Nim(ES)AV/ASR.

9.81.4 *"Broadly acceptable risk"*: Could be accepted with the endorsement of the normal project reviews.

ALARP principle

9.82 The SMP also adopted the ALARP principle, stating that its achievement required an evaluation (qualitative or quantitative) of the net risk, against a clear view of the cost of any risk reduction measure, in terms of money, time, physical difficulty, operational imperative and availability.[116] In accordance with the HSE guidance (see above), the standard was that the expense must be *"grossly disproportionate"* to the risk for an ALARP decision to be justified.[117] As part of the SMS, ALARP decisions would be documented to record the basis of 'reasonableness' and together with supporting evidence, and would be retained to form an audit trail.[118]

9.83 As I explain later, it is a matter of concern to me that the ALARP principle appears not to be properly understood by many, including QinetiQ. It is the 'R' in ALARP that is important. The notion of ALARP is founded on the important principle of proportionality.

Audit

9.84 As to audit, the SMP provided very clearly that the SMS was to be subject to assurance and audit processes to provide evidence that equipment safety was being properly managed. Indeed, an audit regime was said to be *"an essential feature of the SMP"*.[119] The IPT was to carry out a rolling audit over each 12 month period and the IPT SMS was itself to be audited once every 12 months, by one of the following organisations in rotation:

[111] Ibid, Annex C, paragraph 27.

[112] Ibid, Annex C, paragraph 27.

[113] Ibid, Appendix 3 to Annex C, paragraph 5.

[114] Ibid, paragraph 58.

[115] Ibid, Appendix 1 to Annex C, para 13.

[116] Ibid, paragraph 19.

[117] Ibid, Reference P.

[118] Ibid, paragraph 20.

[119] Ibid, Annex D, paragraph 1.

(1) cross-audit by another IPT; (2) D Technical; and (3) Airworthiness Design Requirements and Procedures (ADRP).[120] Internal audits were to include assessment of compliance with, *inter alia,* JSP318B, Def-Stan 00-56 and BP1201, and also assessment of risk management, including hazard capture and identification, risk analysis and identification, and risk control and elimination. The audits that were carried out, however, tended to be of process rather than product.

The Safety Case and Hazard Log

9.85 As indicated above, the Head of Air Vehicle (Nim(ES)Av) had a pivotal safety role under the SMP. His responsibilities included acting as "Safety Advisor" and it was Nim(ES)Av who 'owned' the Safety Case. He was also the 'Key Administrator' appointed to facilitate implementation of the SMP and to carry out risk assessments and progress control and mitigation actions for hazards and accidents.[121] In terms of the availability of the Safety Case, the IPTL was required to ensure that its content, including the Hazard Log, was available to all those who had a requirement to use it, including the Release to Service Authority (RTSA), members of the PSWG, other IPTLs responsible for similar platforms, commodity IPTs and unit staff, i.e. the operator. In actual fact, however, the NSC was never made available to unit staff. Indeed, those at RAF Kinloss were unaware of its very existence until learning about it after the XV230 accident.

Appointment of Safety Manager in 2003

9.86 In August 2003, Frank Walsh was appointed to the post of Nimrod Safety Manager (Nim(ES)Safety). He subsequently amended the SMP to reflect this appointment. The organogram set out above was amended to insert Nim(ES)Safety as *"Safety Advisor" in lieu* of Nim(ES)Av. Paragraph 24 of Annex C was also changed so that the first reference to *"Nim(ES)AV"* was changed to *"Nim(ES)Safety"* but the other references remained. This meant that the job of raising a document to record a decision by the IPTL ex-committee signing off a Category 'A' or 'B' risk would no longer be carried out by a LOD holder, the Head of AV, but by the more junior Safety Manager, who was not a LOD holder. This was a significant downgrading of an important step in the safety process.

9.87 As I shall explain in more detail later, it is regrettable that the detailed procedures laid down in the Nimrod SMP were not followed in relation to the NSC and the sentencing of risks.

Conclusion

9.88 The drawing up of a Safety Case for the Nimrod fleet was mandated by the military regulations in force in 2001. As I explain in **Part II** of this Report, Nimrod MR2 and R1 aircraft contained inherent design flaws which gave rise to serious fire risks. These were precisely the sort of embedded hazards which the Safety Case process was intended to capture and control. These design flaws should have been identified by the NSC which was drawn up in the period 2001-2005. They were not. The reasons why not are set out in **Chapters 10** and **11.**

[120] Ibid, Annex D, paragraphs 1, 3, 5 and 7. See further **Chapter 12**.

[121] Ibid, Annex C, paragraph 23.

CHAPTER 10A – NIMROD SAFETY CASE: THE FACTS (PHASES 1 AND 2)

"There was an element of the blind leading the blind."
(Former senior RAF officer)

Contents

Chapters 10A and **10B** set out the detailed chronological facts regarding the preparation of the Nimrod Safety Case. They answer the following questions:

- Who was responsible for drawing up the Nimrod Safety Case?
- When, how and by whom was it produced?
- What roles did each of the particular organisations and individuals play?
- How long did it take and how much did it cost?
- What did it comprise and what happened during its production?
- What was the end result?

Chapter 10A deals with Phases 1 and 2 of the Nimrod Safety Case.

Chapter 10B deals with the Third Phase.

Summary

1. The purpose of Safety Cases is to identify, assess and address serious risks to equipment and installations before it is too late.

2. The Nimrod Safety Case should have identified the potential for the catastrophic fire which caused the loss of Nimrod XV230 in September 2006. It singularly failed to do so. The best opportunity to prevent the accident was, therefore, lost.

3. The Nimrod Safety Case took a total of nearly four years to produce (April 2001 to March 2005) and cost in excess of £400,000.

4. Three organisations were involved in drawing up the Nimrod Safety Case:

   - BAE Systems, which was the 'Design Authority' for the Nimrod aircraft and formally tasked by the Nimrod IPT to draw up a Safety Case for the two aircraft types, Nimrod MR2 and R1;
   - The Nimrod IPT, which was the 'Integrated Project Team' within the MOD Defence Logistics Organisation with specific responsibility for the Nimrod MR2 and R1 fleets; and
   - QinetiQ, which acted as 'Independent Advisor' to the Nimrod IPT in relation to the Nimrod Safety Case.

5. The Nimrod Safety Case was drawn up in three phases:

   5.1 Phase 1 conducted by BAE Systems (April 2001 to April 2003): Following initial scoping and formalisation of Phase 1 of the Nimrod Safety Case task, BAE Systems carried out zonal inspections of Nimrod aircraft at RAF Kinloss and RAF Waddington and delivered a 'hazard identification' Report to the Nimrod IPT in April 2003.[1]

[1] BAE Systems Nimrod MR Mk2-Baseline Safety Case (Phase 1) Zonal Hazard Analysis Report Reference: MBU-DEF-R-NIM-FS00538, dated April 2003.

5.2 Phase 2 conducted by BAE Systems (August 2003 to September 2004): Following scoping and formalisation of Phase 2 of the Nimrod Safety Case task, BAE Systems conducted 'hazard analysis' and 'hazard mitigation' exercises at its offices at Chadderton, culminating in the population of a database (CASSANDRA) and the delivery of six written Reports to the Nimrod IPT, comprising its completed work on the Nimrod Safety Case, in September 2004.[2]

5.3 Third Phase conducted by the Nimrod IPT (September 2004 to March 2005): Following handing over of the Nimrod Safety Case Reports by BAE Systems to the Nimrod IPT and the 'signing-off' of the task (supported by QinetiQ), the Nimrod IPT then proceeded to sentence the remaining hazards left "*Open*" by BAE Systems, and the Nimrod Safety Case for both Nimrod MR2 and R1 was declared completed in March 2005.[3]

6. I deal with Phases 1 and 2 in **Chapter 10A** and the Third Phase in **Chapter 10B**.

7. All three phases of the Nimrod Safety Case were fatally undermined by an assumption by all the organisations and individuals involved that the Nimrod was 'safe anyway', because the Nimrod fleet had successfully flown for 30 years, and they were merely documenting something which they already knew. The Nimrod Safety Case became essentially a paperwork and 'tick-box' exercise.

8. The Phase 1 work by BAE Systems comprised superficial zonal inspections of the aircraft and 'hazard identification' with little detailed analysis.

9. The Phase 2 work by BAE Systems suffered increasingly from planning, management, execution, resource, time and attitude problems, which seriously affected the quality of the work done. The task was not completed by the 31 August 2004 deadline. The end product was both seriously deficient and defective in three principal respects:

(1) BAE Systems' final Reports contained a big hole: over 40% of the hazards remained *"Open"* and over 30% of the hazards remained *"Unclassified"*. All these hazards had a potential severity rating of *"Catastrophic"*.

(2) BAE Systems' 'hazard analysis' and 'hazard mitigation' exercises (summarised in documents called 'Pro-Formas' which underpinned, but did not accompany, the final Reports) contained numerous, systemic errors of fact, analysis and risk categorisation.

(3) BAE Systems failed properly to assess and address the critical fire hazard relating to the Cross-Feed/SCP duct in the starboard No. 7 Tank Dry Bay which probably caused the loss of Nimrod XV230 (Hazard H73). BAE Systems' provisional assessment of Hazard H73 as *"Improbable"*, *i.e.* as a Class C 'tolerable' risk, was seriously erroneous. Hazard H73 was, however, included in the large block of *"Unclassified"* and *"Open"* hazards in the final Reports because of the lack of time for BAE Systems' Electrical Systems Department to complete their assessment.

10. At a two-day meeting with the Nimrod IPT and QinetiQ to present the results of its work on 31 August 2004 to 1 September 2004 (and at a subsequent meeting on 10 November 2004), BAE Systems represented that it had completed the task satisfactorily, that all hazards had been 'appropriately identified, assessed and addressed', and that the Nimrod MR2 and R1 could be deemed *"acceptably safe to operate"* and ALARP, subject to the carrying out of specific recommendations. This was not a full or accurate picture: BAE Systems deliberately did not disclose to its customer at the meeting the known figures for the large proportion of hazards which it had left *"Open"* and *"Unclassified"* (many with only vague recommendations that 'further work' was required) or otherwise draw attention to the large gaps remaining in its analysis.

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[2] Including, in particular, BAE Systems Nimrod MR MK2 Equipment Baseline Safety Case Report: Reference: MBU-DEF-C-NIM-SC-0713, dated September 2004; and Nimrod MR MK2 and RMK 1 Equipment Baseline Safety Case Report Fire/ Explosion Hazard Assessment Reference: MBU-DEF-C-NIM-SC-710, dated August 2004.

[3] E-mail from Frank Walsh to BAE Systems on 16 March 2005.

11. The Nimrod IPT and QinetiQ were content simply to accept that BAE Systems had completed the task and to agree to 'sign off' the final Reports without sufficient inquiry, or asking for any underlying material, or even carefully reading the final Reports themselves (which would have alerted them to the substantial proportion of *"Open"* and *"Unclassified"* hazards and large amount of work remaining to be done).
12. Once the Nimrod IPT appreciated the number of *"Open"* hazards, it subsequently proceeded to sentence the remaining 43 out of 105 hazards which had been left *"Open"* by BAE Systems (including Hazard H73) on a manifestly inadequate, incorrect and unsatisfactory basis.
13. At no stage during the Nimrod Safety Case process did BAE Systems, the Nimrod IPT or QinetiQ, ever properly identify, assess or address the serious and long-standing catastrophic risk to the Nimrod fleet represented by the Cross-Feed/SCP duct and the Air-to-Air Refuelling modification.
14. The best opportunity to capture these serious design flaws in the Nimrod fleet, that had lain dormant for the decades before the accident to the XV230, was squandered.
15. The production of the Nimrod Safety Case is a long, complex and involved story. In order to understand why it failed, and the precise roles and responsibilities of the organisations and individuals involved, it is necessary to examine in considerable detail the facts of what took place in the course of its development during the period 2001 to 2005.

Introduction

BOI findings

10A.1 The XV230 Board of Inquiry (BOI) found significant errors in the Nimrod Safety Case (NSC):

> *"…The NSC states that the cross-feed duct is only pressurised during engine start, not taking into account the lengthy periods it can be pressurized (at a working temperature of up to 420°C) when feeding the SCP. Furthermore, the NSC notes, as mitigation for the Zone 614 hazards, the provision of an aircraft fire detection and suppression system: neither exist within Zone 614. These inaccuracies led to an overly optimistic assessment of the hazards related to Zone 614, which in turn affected the assessment of the probability of the loss of an aircraft to an uncontrolled fire/explosion – given as 'Improbable'… … Had the NSC's inaccuracies been noticed earlier, the Board consider that a more intense review of the hazards concomitant on airframe fuel leaks might have been instigated. Moreover, the higher risk, which necessarily would have been attributed to such a hazard, would have required sanction at a higher level of management, or active mitigation, such as not using the SCP."*[4]

10A.2 In light of the BOI's findings, the Review conducted a detailed investigation of the NSC, and the history of its development. The story of the NSC which emerged has proved to be a central part of this Report and holds important lessons for the future.

10A.3 This Chapter contains the Review's findings of fact as to the NSC and its development during the period 2001-2005. These findings of fact are based on months of painstaking work by the Review, piecing together the story from a large volume of documents, lengthy written submissions from the organisations and individuals involved and numerous witness interviews. The documents remained incomplete, recollections imperfect and the parties' and witnesses' versions of events were often at odds with each other. I am satisfied, however, that the following represents an accurate and detailed picture of the long, complex and involved history of the development of the NSC and its interstices.

[4] BOI Report, page 2.23.

NSC took four years and cost in excess of £400,000

10A.4 The development of the NSC formally commenced on 11 April 2001, when the Nimrod Integrated Project Team (IPT) first contracted BAE Systems to begin the process of developing 'safety cases' for both the Nimrod MR2 and R1 types.[5] The drawing up of platform safety cases was mandated by Joint Service Publication (JSP)318B. The task was initially expected to be completed by 31 December 2002, *i.e.* within 20 months.[6] In fact, the whole process was to take until March 2005, *i.e.* nearly four years.[7] It was to cost in excess of £400,000.

NSC failed to capture the risk which led to the loss of XV230

10A.5 Despite the length of time the NSC took to complete and the substantial cost involved, the NSC singularly failed to achieve its purpose: to identify, assess and address all serious risks to the Nimrod fleet. The NSC failed, in particular, to capture the serious catastrophic fire and explosion risks which the Cross-Feed/Supplementary Conditioning Pack (SCP) duct and the Air-to-Air Refuelling (AAR) modification posed to the Nimrod fleet. If it had been carried out properly and carefully it would have captured these risks. Had it done so, the loss of XV230 in September 2006 would have been prevented.

Organisations involved in NSC

10A.6 Three organisations were involved in the process of developing the NSC during the period 2001-2005:

- **BAE Systems**, which was the Design Authority (DA) for the Nimrod aircraft and formally tasked by the Nimrod IPT to draw up the NSC for the two aircraft types, with offices at Chadderton.
- **The Nimrod IPT**, which was the 'Integrated Project Team' within the Defence Logistics Organisation (DLO), with specific responsibility for the Nimrod MR2 and R1 fleets, with offices based at RAF Wyton.
- **QinetiQ**, which acted as 'independent advisor' to the Nimrod IPT in relation to the NSC, and whose main office for the purpose of the safety assessment of military aeroplanes is based at Boscombe Down.

Key individuals involved in NSC

10A.7 The key individuals involved in the development of the NSC were:

- At BAE Systems: The three key figures in BAE Systems in charge of managing Phases 1 and 2 of the NSC task: (1) Chris Lowe, Chief Airworthiness Engineer; (2) Richard Oldfield, NSC Task Leader; and (3) Eric Prince, Flight Systems and Avionics Manager.
- At the Nimrod IPT: The three key figures in the Nimrod IPT with responsibility for airworthiness and safety and the NSC: (1) Group Captain (now Air Commodore) George Baber, as the Nimrod IPT Leader (IPTL) and Project Engineer with overall responsibility for airworthiness; (2) Wing Commander Michael Eagles, as Head of Air Vehicle with general responsibility for the production of the NSC under the Safety Management Plan (SMP); and (3) Frank Walsh, as Safety Manager and primary point of contact with the BAE Systems' NSC team to whom the task of managing the NSC project was delegated.
- At QinetiQ: The two key figures at QinetiQ who had responsibilities in respect of the NSC were: Martyn Mahy, the designated Task Manager during the majority of Phase 2 of the NSC project; and (2) Colin Blagrove, Technical Assurance Manager.

[5] PDS Task Request Form number AV(PDS)814 drafted by the Nimrod IPT (NIM(ES)AV(PDS), SPTO).

[6] PDS Task AV(PDS)814, dated 11 April 2001.

[7] Letter from Nimrod IPT Leader, Group Captain George Baber: DLO (Strike)(WYT)5 12725/27/1 Nimrod, dated 22 February 2005; followed by e-mail from Frank Walsh, the Nimrod IPT Safety Manager, dated 16 March 2005.

Chronology – three phases

10A.8 The chronology of what took place during the drawing up of the NSC conveniently falls to be considered in three phases:

(1) Phase 1 conducted by BAE Systems (April 2001 to April 2003): following the initial scoping of the NSC task, the carrying out of the hazard identification task by BAE Systems (Phase 1).

(2) Phase 2 conducted by BAE Systems (August 2003 to September 2004): the carrying out of the hazard analysis and hazard mitigation tasks by BAE Systems, and the handing over of the six NSC Reports by BAE Systems to the Nimrod IPT (Phase 2).

(3) Third Phase conducted by the Nimrod IPT (November 2004 to March 2005): Following handing over of the NSC Reports by BAE Systems to the Nimrod IPT and the 'signing-off' of the task (supported by QinetiQ), the Nimrod IPT then proceeded to sentence the remaining hazards left *"Open"* by BAE Systems, and the NSC for both Nimrod MR2 and R1 was declared completed in March 2005.[8]

Phase 1 conducted by BAE Systems (April 2001 to April 2003)

10A.9 The Nimrod IPT determined early in 2001 to develop an 'explicit' Safety Case for the Nimrod fleet, and to task BAE Systems to draw it up. Whilst, technically under BP1201, the Nimrod IPT could have relied on the Military Airworthiness (MA) Release as an 'implicit' Safety Case,[9] it was clearly desirable for a 'legacy' platform of the age of the Nimrod to have an 'explicit' Safety Case. BP1201 provided that a Safety Case must provide a *"credible"* justification of safety and must be *"consistent, complete and comprehensible"*.[10]

10A.10 The scope of the NSC task to be carried out by BAE Systems was initially laid down by the Nimrod IPT in a Post Design Services (PDS) Task Request Form sent to BAE Systems on 11 April 2001.[11] This outlined the respective responsibilities within the IPT and RAF for the NSC, the strategy to be employed, and the scope of BAE Systems' involvement:

10A.11 As to responsibilities, the following were to said to have key roles in developing the NSC: (1) all IPTs were required to establish a Platform Safety Working Group (PSWG) *"to develop and maintain"* a platform Safety Case; (2) the Nimrod IPTL would chair the PSWG and was responsible for the NSC; (3) the Nimrod Head of Air Vehicle (NIM(ES)AV) was responsible for managing the development of the NSC on behalf of the IPTL; and (4) the Fixed Wing Airworthiness Management Group (FWAMG) would *"monitor"* the implementation of the NSC on behalf of the Defence Aviation Safety Board (DASB). I discuss later the extent to which, if any, of the above, in fact, had any real involvement in the development of the NSC.

10A.12 As to strategy, it was envisaged there would be four phases for Safety Cases for 'legacy' platforms: (1) Phase 1: develop a strategy to construct the Safety Case; (2) Phase 2: develop a strategy for the ongoing risk management of the Nimrod; (3) Phase 3: construct the Safety Case; and (4) Phase 4: manage the safety of the Nimrod throughout its operational life.

10A.13 As to BAE Systems' involvement, it was envisaged that much of the work would be based on BAE Systems' information as the aircraft DA. It was expected that BAE Systems Chadderton would *"assess the level of information currently available to it"* and provide: (a) an initial *"hazard assessment"* carried out at system level; (b) a detailed *"Fault Tree"* analysis at system level; and (c) a *"safety assessment"* detailing the findings of the studies and assessing the risk of functional failures.

10A.14 BAE Systems was given two initial tasks. First, to provide an initial assessment of the current availability of appropriate Hazard Data and Fault Tree Analysis data, *i.e. "how much data is readily available within the ADA for the Nimrod Platform"*. Second, to provide a business strategy to develop a Safety Case by 31 December 2002 and costings within 60 days, the overall scope of the work being envisaged as *"considerable"*. The second task was carried out. The first was not.

[8] E-mail from Frank Walsh to BAE Systems, dated 16 March 2005.

[9] BP1201, paragraph 12.

[10] Ibid, paragraph 9.

[11] PDS Task Request Form number AV(PDS)814 drafted by the Nimrod IPT (NIM(ES)AV(PDS), SPTO).

10A.15 The essential aim of the NSC was straightforward, as the Nimrod IPT explained to BAE Systems at an early meeting on 1 August 2001: *"A Safety Case should be a safety argument which highlights risks."*

4 October 2001: Internal BAE Systems meeting

10A.16 On 4 October 2001, an internal BAE Systems meeting was held at Warton to discuss the requirements of PDS Task AV(PDS)814.[12] The file note of that meeting[13] records a number of points of discussion. First, the MOD were looking to spend only c. £100,000 – £200,000 over a period of six months on the NSC, whereas the Harrier 'Safety Case' cost £3 million and took over two years. This apparent concern as to the limited budget did not seem to be taken further. Second, it was agreed that BAE Systems should assist the MOD to develop 'strategies' for the development of the NSC. Third, it was agreed that BAE Systems should suggest to the MOD that the PDS Task ought to be re-written to read: *"Construct the explicit Safety Case by documenting the Implicit Safety Case, using the Strategy developed in 1a above."* This amendment was never, in fact, made; but it does encapsulate BAE Systems' essential (flawed) approach to the task (see further below). Fourth, hazards with '*seemingly unacceptable*' Hazard Risk Indices could be considered '*acceptable*' based on 20 years historical evidence '*as per the Harrier Safety Case*'. Fifth, it '*may be possible*' to use the Nimrod MRA4 Hazard Log and Accident Model as a starting point for the NSC.

10A.17 Three of these suggestions are of particular concern, and bear the seeds of the flawed approach to the NSC adopted by BAE Systems which was subsequently to bedevil its production:

10A.17.1 First, the suggestion that the PDS Task ought to be re-written to read *"Construct the explicit Safety Case by documenting the Implicit Safety Case..."*[14] is illuminating. It indicates that, from the very beginning, BAE Systems viewed the process of constructing an *"explicit"* Safety Case as one of just documenting the *"implicit"* Safety Case, *i.e.* it was essentially a documentary or paperwork exercise, in which the hazards were more theoretical than real, the object being merely to populate the 'CASSANDRA' database.[15]

10A.17.2 Second, the suggestion that hazards with *"seemingly unacceptable"* Hazard Risk Indices could nevertheless *"be considered for acceptance based on 20 years historical evidence, as per Harrier Safety Case"*, gives cause for concern. It indicates a flawed mindset for legacy aircraft: 'if it has not happened in the past, it is unlikely to happen in the future'. Further, as will be seen, the Nimrod fleet did not have sufficient total flight hours to provide a satisfactory historical incident base.

10A.17.3 Third, the suggestion that it might be possible to use the Nimrod MRA4 Hazard Log as a *"starting point"* for a Safety Case for the MR2 and R1 was misconceived. The Nimrod MRA4 was a new build prototype. It was based on the Nimrod fuselage but was essentially a new aircraft. Its systems had little in common with the MR2 and R1 and it was unlikely to prove a reliable basis for a safety case for its 30-year-old predecessors (as, indeed, Chris Lowe of BAE Systems himself later acknowledged).[16]

9 October 2001: QinetiQ Task Review Meeting

10A.18 At a QinetiQ Task Review Meeting (TRM) on 9 October 2001,[17] it was suggested that the Nimrod IPT might task QinetiQ to review the draft Nimrod SMP and take on the role of an *"Independent Safety Auditor"*. An *"Independent Safety Auditor"* was defined in Defence Standard (Def-Stan) 00-56 (Part 1)/3 Annex A (Definitions), dated 19 December 2004 as:

[12] BAE Systems Task No. 16-3151.

[13] File Note written by the Airworthiness/Regulations Manager – FSTA, 4 October 2001.

[14] Strategy item 1c on the PDS Task AV(PDS)814.

[15] Cassandra (Κασσάνδρα) was the beautiful daughter of King Priam and Queen Hecuba of Troy. Apollo granted her the gift of prophecy but, when she spurned his love, he placed upon her the curse that no-one would ever believe her predictions.

[16] At the First PSWG Meeting on 18 March 2003.

[17] QinetiQ Task Review Meetings were held regularly (mostly quarterly) between QinetiQ and Nimrod IPT representatives at Boscombe Down to monitor QinetiQ's numerous on-going tasks for the Nimrod IPT.

> *"An individual or team, from an independent organization, that undertakes audits and other assessment activities to provide assurance that safety activities comply with planned arrangements, are implemented effectively and are suitable to achieve objectives; and whether related outputs are correct, valid and fit for purpose."*

10A.19 It does not appear, however, that QinetiQ was subsequently ever formally tasked with the role of Independent Safety Auditor. QinetiQ was tasked, however, and *de facto* assumed, a role as 'independent advisor' in relation to the development of the NSC and was at all material times assumed by the Nimrod IPT and BAE Systems to have such a role (see further below).

4 December 2001: BAE Systems agree to issue proposal

10A.20 It was not until eight months later, following a meeting with the Nimrod IPT at RAF Wyton on 4 December 2001, that BAE Systems formally agreed to issue a proposal for the production of a baseline safety argument with firm costs to be presented at the first Platform Safety Working Group (PSWG) meeting due early 2002.[18]

27 January 2002

10A.21 On 27 January 2002, the Nimrod IPT wrote to BAE Systems confirming the MOD's decision that the Nimrod MR2 and R1 were to be treated as *"combat aircraft"* for the purpose of safety management. This meant that the MR2 and R1 Nimrods were expected to meet the military standard of safety under Def-Stan 00-56, namely, that no credible failure shall lead to a catastrophic failure in less than 10^{-6} flying hours.[19] They would not be required to meet the higher level of safety (10^{-7}) expected of aircraft derived from civil airliners used by the MOD in a passenger-carrying role.[20] This was, in my judgment, a logical and correct decision. Although derived from the civilian Comet airliner, the Nimrod MR2 and R1 types embodied extensive changes, carried stores and equipment, did not have a passenger-carrying role, were capable of equipment and bomb release, flew in combat zones and therefore had a distinct, offensive military role. The letter concluded: *"Nevertheless, this decision will not prevent us aiming for the highest possible standards of safety that can reasonably be achieved, given the age and complexity of the platform and the operating environment concerned".*[21]

10A.22 On the same day, the then Head of Air Vehicle at the Nimrod IPT wrote thanking BAE Systems for an early draft of BAE Systems' Feasibility Study[22] (see further below) and stating that he was extremely pleased with it. He went on to explain that, whilst the MOD decision to classify the MR2 and R1 as *"combat aircraft"* provided a more *"realistic"* basis for safety considerations for the remaining life of the Nimrod platform, *"I stress that there is no intention for any relaxation of approach"*. It should be noted that the draft Feasibility Study suggested the involvement of the Aircrew Standards and Evaluation Unit (STANEVAL) in the Phase 1 process. It is unfortunate that this suggestion was never taken up because it might have meant greater operator involvement in the Safety Case process.

5 February 2002: QinetiQ Task Review Meeting

10A.23 At a QinetiQ Task Review Meeting on 5 February 2002 there was a suggestion that QinetiQ would be asked to play *"a key role"* in Nimrod safety management as the Independent Safety Auditor and that financial provision would be made to this end. It was also noted that BAE Systems had been tasked to produce the NSC and QinetiQ's involvement could be discussed at the next PSWG meeting on 18 March 2002.

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[18] BAE Systems Task Acceptance Form No. 16 3151.

[19] *i.e.* one in a million flying hours.

[20] A troop carrying role was specified in the original RAF Air Staff Requirement but has never been fitted or used

[21] See letter: NIM IPT ES(Air)(WYT)/512707/27/NIM IPT, dated 27 January 2002.

[22] Draft BAE Systems Report MBU-DEF-C-NIM-SC04444, Issue 1, dated January 2002.

March 2002: BAE Systems' Feasibility Study

10A.24 In March 2002, BAE Systems finalised and issued its Feasibility Study on the NSC, drafted by Chris Lowe and approved by Witness A [BAE Systems].[23] It was an optimistic and encouraging document which must have instilled confidence in the Nimrod IPT. The Executive Summary repeated the high level of confidence in the Nimrod which had been stated in the Nimrod SMP:[24]

> *"By virtue of a range of traditional methods (certification and qualification/integrity testing), there is an intrinsic high level of confidence in the prevailing acceptable level of safety of the Nimrod types. However, there is currently a lack of structured argument and supporting evidence formally recorded and maintained in order to support the requirements of forthcoming legislation and to achieve compliance with the requirements of JSP318B Edition 4. Hence the reason for the overall task to compile, record, monitor and maintain an aircraft level SC for the Nimrod MR Mk2 and R Mk 1 types."* (emphasis added)

10A.25 A level of confidence in Nimrod aircraft was both understandable and justified. As the previous NIM(ES)AV explained, the Nimrod fleet had flown for some 30 years and *"very few technical accidents…had occurred on the aeroplane, and the safety record of the aeroplane was extremely good."* Unfortunately, the phrase, *"there is a high level of corporate confidence in the safety of the Nimrod aircraft"*, was to be repeated regularly in the NSC documents produced over the following three years.[25] It became something of a mantra. It was indicative of a widely-held view by those involved in the drawing up of the NSC that the Nimrod was safe anyway, and that the NSC process was one of simply proving or documenting something that was already known. This attitude was unfortunate and corrosive. It served to undermine the integrity and rigour of the Safety Case process itself from the very beginning.[26]

10A.26 The Executive Summary also claimed a high level of confidence in BAE Systems' ability to carry out the task satisfactorily in somewhat bold terms:[27]

> *"The above-mentioned feasibility study concludes that BAE SYSTEMS have a high level of confidence that preparation of both the Safety Case itself and the respective Baseline Safety Case Reports of both types can be undertaken in an effective, competent, expedient and cost-effective manner. This confidence extends to both Safety Case itself and Baseline Report achieving compliance as far as is practicable with forthcoming legislation and MOD Policy aims, together with the broad criteria and requirement of [JSP318B Edition 4, the Nimrod SMP and BP1201 Issue 1]."*[28] (emphasis added)

10A.27 Whether this "*high level*" of confidence was actually justified is, in my view, doubtful. It is far from clear that those at BAE Systems who embarked on the NSC task really knew what they were doing. The people involved had never done a Safety Case before. They had not researched in depth how to conduct a Safety Case exercise. Few, if any, appear to have done a Zonal Hazard Analysis before. They had conducted no 'dry run' on a sample hazard. Contrary to the requirements of the initial tasking, they had not even investigated their archives by this stage to see what useful mitigation evidence was, in fact, readily available. As BAE Systems' Chief Airworthiness Process Engineer and Deputy Head of Airworthiness, Witness A [BAE Systems], accepted in interview with the Review, to call this a '*feasibility*' study was something of a misnomer. As explained below, there appears to have been a considerable element of making it up as they went along. In any event, any confidence proved to be misplaced: the reports that were eventually produced by BAE Systems were far from effective, competent, expedient or even cost-effective.

[23] BAE Systems Report MBU-DEF-C-NIM-SC0444: PDS Task 16-3151 Equipment Safety Management Nimrod MR MK2 and R Mk1. Safety Case and Baseline Report Feasibility Study.

[24] Ibid, Executive Summary, page 3.

[25] See *e.g.* BAES Report MBU-DEF-C-NIM-SC04444. PDS Task 16-3151 Equipment Safety Management Nimrod MR MK2 and R Mk1. SC and Baseline Report Feasibility Study; BAE Report MBU-DEF-C-NIM-SC0538 – Nimrod MR Mk2 – Baseline Safety Case (Phase 1) Zonal Hazard Analysis (April 2003) (BLSC (Phase 1) Report).

[26] It is noteworthy that the Jaguar SMP did not contain a similar recital.

[27] See also the Conclusion, ibid, page 26. The Executive Summary also said that the Feasibility Study proposed *"a practically achievable structure and description of the argument, methodology and format"* for the Nimrod Safety Cases and Baseline Safety Case Reports.

[28] Ibid, Executive Summary, page 3.

10A.28 The Feasibility Study explained that the methodology to be employed was the *"top level down"* approach considered acceptable for legacy aircraft by BP1201 and the Nimrod SMP.[29] Fault Tree Analysis (FTA) was recommended. Goal Structured Notation (GSN) (an illustrative technique which provides a useful structured way of presenting a complex safety argument)[30] would be used to demonstrate the achievement of the relevant goals supported by strategies and evidence. The key goals were:

- Top level goal: *"The aircraft is deemed acceptably safe to operate and maintain within specified contexts"* (Goal 1);
- First sub-goal: *"All identified potential safety hazards risks be demonstrated as having been mitigated to a level that is [ALARP] or eliminated where appropriate"* (Goal 2); and
- Second sub-goal: *"All relevant safety and certification requirements and standards are demonstrated as having been met"* (Goal 3).

10A.29 The Feasibility Study promised a Baseline Safety Case Report (BLSC Report) which would be a 'snapshot in time' in which *"all potential safety hazards will have been identified and appropriately addressed"*.[31] The sub-strategy to achieve the first sub-goal included *"Each potential safety hazard mitigated to a level of ALARP or eliminated where possible."*[32] A three-stage 'iterative' process[33] was envisaged, which Witness A [BAE Systems] explained in interview with the Review was to be based on *"best engineering judgment"*, namely: (a) identify hazard; (b) quantify and assess hazard risk; and (c) mitigate hazard as necessary.

Warning regarding Nimrod in-service statistical data

10A.30 The Feasibility Study sounded a strong note of caution in relation to the use of statistical data in isolation. It warned that the small Nimrod fleet size and low statistical population *"... lead to relatively low confidence levels in any statistical data based on in-service failure rates of a unit or system"*.[34] Regrettably, this warning was eventually ignored by BAE Systems itself and the Nimrod IPT, as explained below.

Joint Working Group

10A.31 The Feasibility Study recommended the setting up of a Safety Case Working Group jointly composed of BAE Systems and Nimrod IPT *"Specialist Engineers close to both projects"*. It was envisaged that the joint Working Group would meet regularly to ensure joint input into all stages of the Safety Case process, i.e. the identification of hazards, determining their cause and effect, the mitigation of all hazards and the consequent population of the hazard log.[35] The setting up of a joint Safety Case Working Group consisting of approximately eight people *"split between BAE Systems and MoD chosen for their genuine specialist knowledge"* to carry out the *"identification and addressing of all hazards",* was subsequently highlighted by Chris Lowe at the Inaugural Nimrod PSWG Meeting on 18 March 2002.[36] Unfortunately, the NSC process turned out to be far from joint: save for the preparation of the Fault Tree Analysis, BAE Systems did all three stages leading to the NSC without significantly involving the Nimrod IPT or Nimrod operators. This was a fundamental mistake.

10A.32 The upbeat tone of BAE Systems' Feasibility Study would have given the IPT further confidence that BAE Systems was indeed ready, willing and able to carry out the NSC task as required. It was understandable that the IPT should have confidence in BAE Systems. It was, after all, the DA for the Nimrod and the Original Equipment Manufacturer (OEM) for both Nimrod types. It retained ownership of the original certification for the civil certification for the Comet, and much of the design data and sub-data that was part of the civil certification. BAE Systems was also carrying out an increasing amount of Nimrod Line 4 (*i.e.* deep)

[29] Ibid, paragraph 2, page 7.
[30] www.yellowbook-rail.org.uk/site/events/ybug2007/yellow%20book%20gsn%20presentation%20-%20kelly.ppt
[31] Ibid, paragraph 3, page 7.
[32] Ibid, paragraph. 6.6
[33] Ibid, page 9.
[34] Ibid, paragraph 8.1.3.
[35] BAE Systems Proposal to Nimrod (ES) IPT – Nimrod Baseline SC (Phase 1) (August 2002) (and see paragraph 10.2 of the Feasibility Study).
[36] Chris Lowe's presentation to the Inaugural Nimrod PSWG Meeting 18 March 2002.

maintenance on behalf of the RAF. BAE Systems also had considerable resources in terms of manpower, and scientific and engineering know-how. It was, therefore, natural and understandable that the Nimrod IPT should have approached BAE Systems to develop the Safety Case for the Nimrod MR2 and R1 at the outset. BAE Systems could be expected to, and was, in my view, required to use its knowledge and experience and all reasonable skill and care in producing the NSC.

18 March 2002: Inaugural PSWG Meeting

10A.33 The first 'Inaugural' PSWG Meeting took place at RAF Wyton on 18 March 2002 and was chaired by the then IPTL (from whom George Baber took over in May 2002). Some 29 people were present, including 12 members of the Nimrod IPT, five representatives of BAE Systems, two representatives of QinetiQ, one from Rolls Royce, two from RAF Kinloss and two from RAF Waddington. Such large meetings were commonplace.

10A.34 The IPTL explained that there was already *"a high level of confidence in Nimrod safety"* but JSP318B required that the IPT *"improve the evidence to support that confidence"* and develop a baseline safety case. The then Head of Air Vehicle[37] explained that the aim of the meeting was to draw together personnel from the Units, Industry, Group, QinetiQ and the IPT *"to discuss the principles and processes of the new* [baseline safety case] *system"* and to ensure that there were no fundamental concerns. He gave a presentation on the safety case principles and processes envisaged and stated that the *"IPT Leader must consider a complete and structured assessment of the risks so that he can formally accept them"*.

10A.35 The BAE Systems Engineering Manager present, Witness B [BAE Systems], paid tribute to the designers, builders, managers, maintainers and operators who had ensured the continued safe operation of the Nimrod *"over the past 30 years",* but warned against *"the dangers of complacency"* and said that BAE Systems would *"enthusiastically embrace the safety case philosophy".* Chris Lowe, the BAE Systems' Chief Airworthiness Engineer, gave a PowerPoint presentation emphasising that mere standards could not replace "*domain expertise and knowledge",* and that in order for the identification and addressing of all safety hazards the PSWG needed to be made up of *"players with genuine expert knowledge"*. The final slide promised that BAE Systems would produce *"a workable and cost effective"* solution for *"completion"* of the baseline safety argument to demonstrate that *"the Nimrod fleet is acceptably safe"*.

Decision that MRA4 data should not be used

10A.36 During the meeting, a QinetiQ representative asked Chris Lowe whether use was going to be made of *"MRA4 hazard data".* Chris Lowe answered "*No*" and that the MRA data was to be kept *"out of* [the] *loop"* because the aircraft were *"significantly different in roles and systems".* Chris Lowe was questioned in interview by the Review about this exchange. His attempt to explain it by suggesting that he and QinetiQ were referring to '*qualification*' data not '*hazard*' data was, in my view, unsatisfactory and unconvincing: QinetiQ expressly referred to *"MRA4 <u>hazard</u> data"* (emphasis added) in the context of data to sentence NSC hazards; and in 2002 the MRA4 was a 'paper' aircraft and would not, therefore, have had much, if any, 'qualification' data. It is noteworthy that two years earlier, Witness A [BAE Systems] had expressed similar concern at using the MRA4 SMP as a basis for the MR2 SMP.[38] I have no doubt that both he and QinetiQ were referring to MRA4 hazard data, and it was clear to everyone at the meeting that it should not be used to sentence MR2 and R1 risks.

10A.37 In these circumstances, it is surprising and regrettable that, in July 2004, BAE Systems subsequently made significant use of generic hazard data used for the MRA4 programme to sentence MR2 and R1 hazards, in order, it appears, to speed up the finalising of the NSC and to meet the 31 August 2004 deadline.

25 April 2002: BAE Systems' internal meeting raises question mark over resources

10A.38 Notwithstanding BAE Systems' external expressions of confidence in its Feasibility Study, concerns were expressed internally from an early stage as to whether there were sufficient manpower resources to deliver the task. At an internal BAE Systems meeting on 25 April 2002, Richard Oldfield expressed concern that BAE

[37] (Wing Commander Michael Eagles' predecessor).

[38] At the Design Authority Safety Working Group (DASWG) meeting held on 19 November 2001.

Systems had *"insufficient resource"*, specifically in the Safety and Certification Department, fully to support the programme. This was echoed by Eric Prince in relation to the workload of the Systems Department on 3 October 2002 at the internal NSC launch meeting. Eric Prince explained in evidence that the department was at the time *"unusually busy"* dealing with Nimrod and VC10 operational modifications, maintenance queries (PDS tasks) and putting together estimates.

10A.39 BAE Systems' personnel were required to operate under tight budgetary constraints. The NSC was a 'non-core' project and, therefore, had to be separately budgeted for and the man-hours monitored. If the man-hours estimate was exceeded, BAE Systems' Commercial Department had to be consulted. In an internal e-mail dated 8 October 2002, BAE Systems' Customer Support warned Richard Oldfield (presciently): *"we mustn't go down the route of excessive planning/ undertaking tasks we have not budgeted for, and therefore will eat away at the hours we have."* Richard Oldfield explained that he and Chris Lowe seemed to have a *"different idea"* from Eric Prince and Witness C [BAE Systems] of what was involved in the project and this needed to be resolved. It is not clear, however, that this was ever resolved.

10A.40 It is regrettable that more thought and planning was not given by BAE Systems at an early stage to the question of resources for the NSC. The issue of inadequate manpower resources was to resurface regularly in the next couple of years and have a significant impact during the latter stages of finalising Phase 2 of the NSC in the summer of 2004.

11 June 2002: QinetiQ Task Review Meeting

10A.41 At a QinetiQ Task Review Meeting (TRM) on 11 June 2002, it was noted that the PSWG had met in March 2002 and, although QinetiQ's role was still to be defined, *"their involvement is not in doubt"*. QinetiQ personnel did indeed remain involved in the NSC throughout, but the nature of their involvement was not what it should have been.

August 2002: BAE Systems' proposal for Phase 1

10A.42 In its formal Proposal for Phase 1 of the NSC dated August 2002, BAE Systems reiterated the theme:

> *"By virtue of a range of traditional methods (certification and qualification/integrity testing), <u>there is already a high level of confidence in the prevailing level of safety of Nimrod types.</u> However, there is currently a lack of structured argument and supporting evidence formally recorded and maintained."* (emphasis added)

10A.43 The Proposal provided that the Zonal Hazard Analysis (ZHA) was to be the same as that for the Jaguar.

10A.44 There were to be two phases to the NSC process: *Phase 1*: the identification and initial assessment of hazards, the production of the Fault Tree and the completion of the ZHA. An important element of this phase was said to be the visit to, and assessment of, an MR2 and an R1; *Phase 2*: The population of the Hazard Log (HL) with evidence 'mitigating' each hazard identified during Phase 1.

BAE Systems' price for Phase 1

10A.45 Due to the short timescale, only one interim review meeting with the Nimrod IPT was proposed for Phase 1. The price quoted by BAE Systems for Phase 1 of the NSC was £118,972, including 12% profit. This was based on an estimate of 1,524 man hours. Richard Oldfield explained in interview with the Review that it was difficult for BAE Systems to quote for the whole task because there were so many unknowns. Accordingly, BAE Systems decided to quote initially for Phase 1 only, before deciding what Phase 2 might entail. (It should be noted that the actual profit made by BAE Systems on Phase 1 was, in fact, 26.1%, primarily due to the man hours allocated to contract risk not being utilised, and the number of project management hours being less than originally estimated. By way of comparison, BAE Systems was in due course to make a loss of 8% on Phase 2, due to the actual number of hours recorded being greater than that estimated).

14 August 2002: Nimrod IPT confirm BAE Systems to be tasked

10A.46 By way of a letter dated 14 August 2002, the Nimrod IPT confirmed its intention in principle to instruct BAE Systems to go ahead with both Phase 1 and Phase 2 of the NSC programme utilising the CASSANDRA software tool.[39] (There had been discussion as to the relative merits of CASSANDRA and SMART software packages as a management tool for the Hazard Log. BAE Systems expressed concerns at the suitability of CASSANDRA and a preference for SMART and a common Hazard Log database with the VC10. But since the VC10 IPT had already chosen CASSANDRA, the decision was taken that it should also be used for the Nimrod.[40] There is no evidence that the choice of software materially affected the quality of the Safety Case that was eventually produced by BAE Systems.)

14 October 2002: Second PSWG Meeting

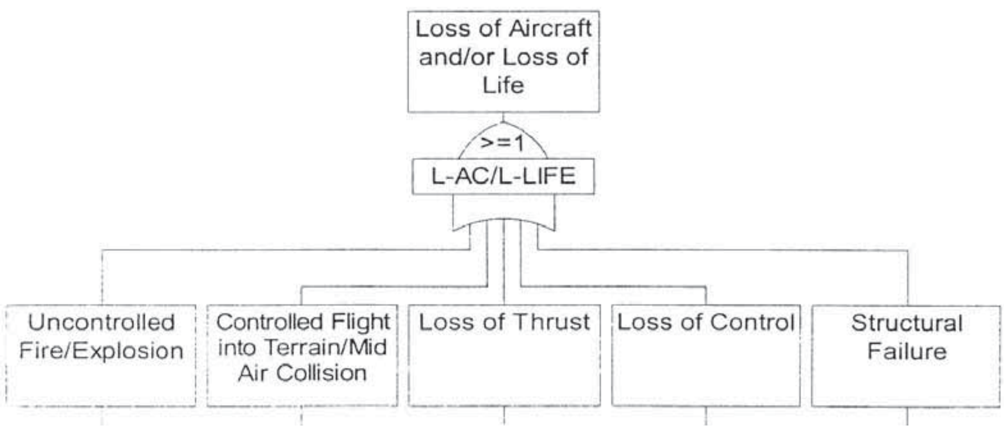
10A.47 At the Second PSWG Meeting on 14 October 2002, Chris Lowe and Richard Oldfield gave a presentation on behalf of BAE Systems on how Phase 1 and 2 of the NSC would be carried out. The meeting was chaired by George Baber. There were 20 people present, including representatives from the Nimrod IPT and QinetiQ.

November 2002: Fault Tree analysis

10A.48 The first substantive step in the NSC process was the preparation of a Fault Tree Analysis (FTA) by the joint NSC Working Group. FTA is a 'top down' Boolean logic model that depicts the relationships between specific events and leads to a final outcome. FTA is a useful and well-known analytical tool and can be used to create an accident loss model. The software used was 'Fault Tree Plus'.

10A.49 The joint Working Group met between 19 and 21 November 2002 at Chadderton and carried out various workshops. There were three members of the Nimrod IPT team: Witness D [MOD] (an RAF officer in the IPT as Nim(ES)AV(A)), Witness E [MOD] (then RTSA and an experienced Nimrod pilot), and Witness F [MOD] (an MOD Civil Servant on the NIM(ES)AV(AV)1 desk)). The BAE Systems team was headed by Chris Lowe. The joint group, of approximately 12 people, sat together in one room working through the various lines of the fault tree, which were then documented using Fault Tree Plus. A print out of these fault trees subsequently formed Annex A to the Preliminary Hazard Identification report provided to the IPT on the completion of Phase 1.[41] It was invaluable having the various specialists from different disciplines and the designers and operators discussing the issues together, in the interests of cross-fertilisation and building up a complete picture of the Nimrod.

10A.50 The FTA identified five main hazards which could cause the loss of a Nimrod or loss of life, including an *"Uncontrolled Fire/Explosion"*:

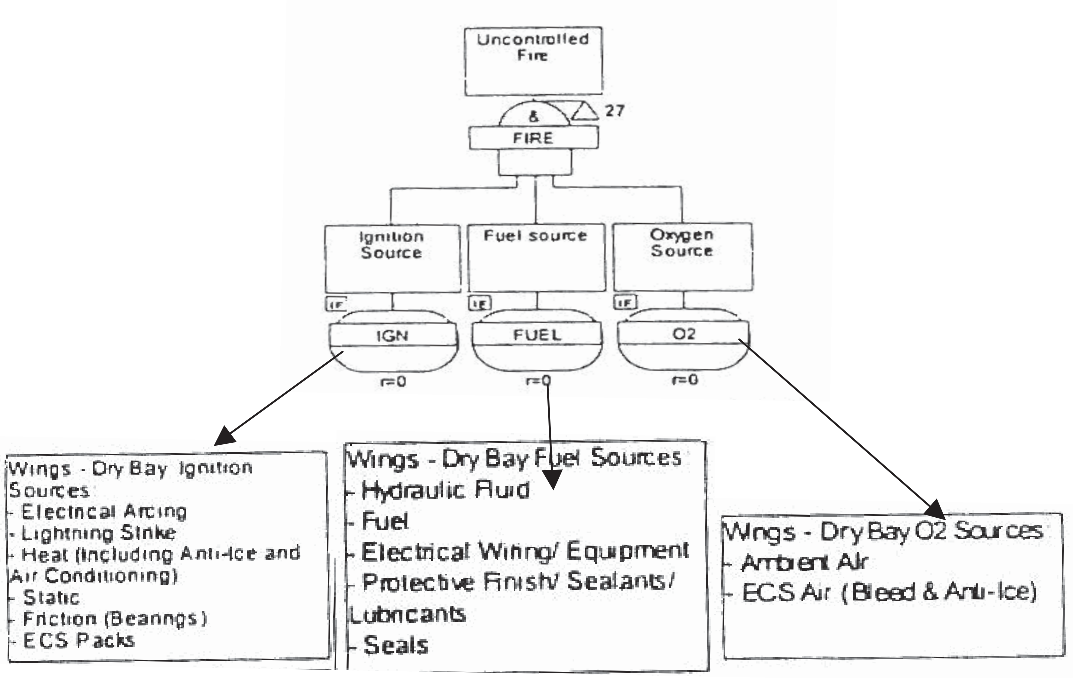


[39] Letter from ES(Air) to Richard Oldfield of BAE Systems re: CASSANDRA Hazard log, dated 14 August 2002.

[40] Internal BAE Systems memorandum, dated 24 April 2002.

[41] Appendix A to BAE Report MBU-DEF-C-NIM-SC0539. Nimrod Task 26-3244 Equipment Safety Management Nimrod MR MK2 and R Mk1. Preliminary Hazard Identification Report – Phase 1 Completion (April 2003).

10A.51 Although a Fault Tree for Uncontrolled Fire/Explosion was included in Annex A, owing to the multitude of causes of fire and explosion throughout the aircraft, it was agreed at the workshop that expanding the Fault Tree below the top level fire and explosion events would not be effective or productive. Instead, it was decided to address the fire hazard by using the alternative ZHA approach. After this ZHA exercise had been undertaken, a more detailed fault tree for Uncontrolled Fire was drawn up in the interests of completeness. This Fault Tree listed the general areas in which an *"Uncontrolled Fire"* might occur, including the fuselage, wings, empennage, APU bay and landing gear bays, and analysed the various ways in which the three necessary ingredients (ignition + fuel + oxygen) might combine in *e.g.* the Wing Dry Bays:



10A.52 The FTA was the only piece of analysis in the entire NSC process that was carried out jointly, *i.e.* with participation by BAE Systems and Nimrod IPT personnel (which included a former Nimrod pilot). It benefitted from this operator input.

25 September 2002: Nimrod IPT formally authorises BAE Systems to proceed with Phase 1

10A.53 On 25 September 2002, the Nimrod IPT authorised BAE Systems to go ahead and produce Phase 1 of the NSC for the price quoted. BAE Systems was tasked by the Nimrod IPT and undertook to produce a Safety Case for the Nimrod MR2 and R1 to achieve compliance with JSP318B (Edition 4).[42] The start date for Phase 1 was November 2002 and the finish date was initially 14 March 2003, but subsequently slipped to 18 April 2003.

December 2002 and March 2003: BAE Systems' zonal inspection visits

10A.54 Zonal inspections were carried out by BAE Systems' personnel at RAF Waddington between 10 and 12 December 2002 and at RAF Kinloss between 11 and 12 March 2003. At RAF Waddington two Nimrod R1 aircraft were inspected: XV249 undergoing a Minor service and XW664 undergoing a modification. At RAF Kinloss three MR2 aircraft were inspected in different states: XV248 on the flight line; XV227 undergoing Minor maintenance; and XV236 undergoing Major maintenance and therefore in a stripped down condition. Given the scale of the task, these zonal inspection visits were short. (It should be noted that the zonal inspection visit to RAF Kinloss in 2008 for the review of the NSC lasted much longer but only involved 11 zones.)

[42] PDS Task 16 3151) BAE Task No. 26-3244 – Nimrod Baseline Safety Case (Phase 1), dated 4 September 2002.

10A.55 The six-man BAE Systems zonal inspection team comprised Richard Oldfield (Project Engineering Team Leader – Nimrod), Witness G [BAE Systems] (Structures Group Leader), Witness H [BAE Systems] (Senior Systems Engineer), Witness I [BAE Systems] (Senior Systems Engineer), Witness J [BAE Systems] (Senior Systems Engineer), Witness C [BAE Systems] (Flight Safety Specialist). The BLSC Phase 1 Report said that the BAE Systems' zonal inspection team had been chosen for *"both their extensive Nimrod knowledge and to give full representation on the Team of the relevant Specialist Departments within the [Design Authority]"*. BAE Systems' claim to have a full spectrum of specialist knowledge was justified: the team included a Flight Safety Manager, a Mechanical Systems Specialist, an Electrical Systems Specialist, an Avionic Systems Specialist, and a Structural Specialist. The claim that the team had *extensive knowledge* of the Nimrod was only justified in the sense that all members of the team had worked with Nimrods over the years (Witness H [BAE Systems] and Witness J [BAE Systems], for 40 and 35 years respectively, and Richard Oldfield for 15 years, as well as being appointed BAE Systems Assistant Chief Engineer Nimrod in 2000). However, this sort of design/office-based experience is markedly different from the detailed, practical, hands-on experience that engineers on the line at RAF Kinloss and RAF Waddington would have had. Witness C [BAE Systems] explained in evidence that he had never actually worked on a Nimrod. Thus, prior to the visits, the BAE Systems team needed to 'familiarise themselves' using the illustrated parts catalogue and the Aircraft Maintenance Manual. This is not something that line engineers would have needed to have done.

10A.56 All six BAE Systems individuals who took part in the R1 and MR2 zonal hazard inspections had attended an internal ZHA course on 17 October 2002 given by a BAE Systems System Safety Technologist and a BAE Systems Eurofighter System Safety specialist.[43] This was no doubt a useful introductory course which explained the background to ZHA and broadly the process involved. It did not, however, cover how in practice a ZHA should be conducted, *i.e.* precisely what steps by way of inspection, recording and analysis should be carried out during the inspection phase. It is noteworthy that at a System Safety Practices Meeting on 4 September 2002, Witness C [BAE Systems] raised the need for more in depth *"level 2"* ZHA and FT courses. It is not clear that this suggestion was ever taken up.

10A.57 The BLSC Phase 1 Report[44] indicates that the team undertook an 'on-aircraft' examination of XV227, XV236 and XV248 and a visual assessment of each zone allocated to them, using a checklist similar to that used for the RAF Jaguar ZHA. The checklist highlighted *e.g.*: "FIRE/EXPLOSION. *Fuel Leaks/ vapour...LEAKS. Junctions in pipes, couplings, 'V' band clamps, manifold blocks/ seals...Fuel tanks...HOT SURFACES. Pipes..."*. The Report said that worksheets were drawn up recording *"the nature of the equipment and hazard within each zone and the likely interactions between them in the event of failures occurring"*, accompanied in many cases by photographs.[45] The results from the worksheets were subsequently entered (by Witness C [BAE Systems]) into the CASSANDRA database.[46]

Zonal inspections of the No. 7 Tank Dry Bays

10A.58 At both the R1 and the MR2 inspections, the six BAE Systems personnel were divided into three two-man teams, each allocated different sections of the aircraft based on the aircraft maintenance zones. Richard Oldfield and Witness C [BAE Systems] covered the wing-to-wing zones, Witness G [BAE Systems] and Witness H [BAE Systems] examined the cabin and the inside of the fuselage, and Witness I [BAE Systems] and Witness J [BAE Systems] inspected the pannier from nose to tail. A member of the Nimrod IPT was present during the R1 inspection at RAF Waddington to give general assistance but played little, if any, part in the actual zonal inspections.

10A.59 The No. 7 Tank Dry Bays, port and starboard, are located at the wing root[47] and are known as Zones 514 and 614, respectively. These zones appear to have been inspected twice: once by Richard Oldfield and Witness C [BAE Systems] when inspecting XV236 and XV248, and once by Witness I [BAE Systems] and Witness J

[43] For at least one member of the BAE Systems team (Witness I [BAE Systems]) this was a refresher course, as he had previously attended a longer Zonal Hazard Analysis course.

[44] Paragraph 2.2 BLSC (Phase 1) Report.

[45] Paragraph 2.3 and 2.4 BLSC (Phase 1) Report.

[46] Reproduced at Appendix F of BLSC (Phase 1) Report.

[47] *i.e.* where the wing joins the fuselage.

[BAE Systems] when inspecting XV236. These two teams appear (unintentionally) to have overlapped at the wing root. Both teams also appear to have recorded the hazards in Zones 514/614 slightly differently in their worksheets (see below).

Worksheets

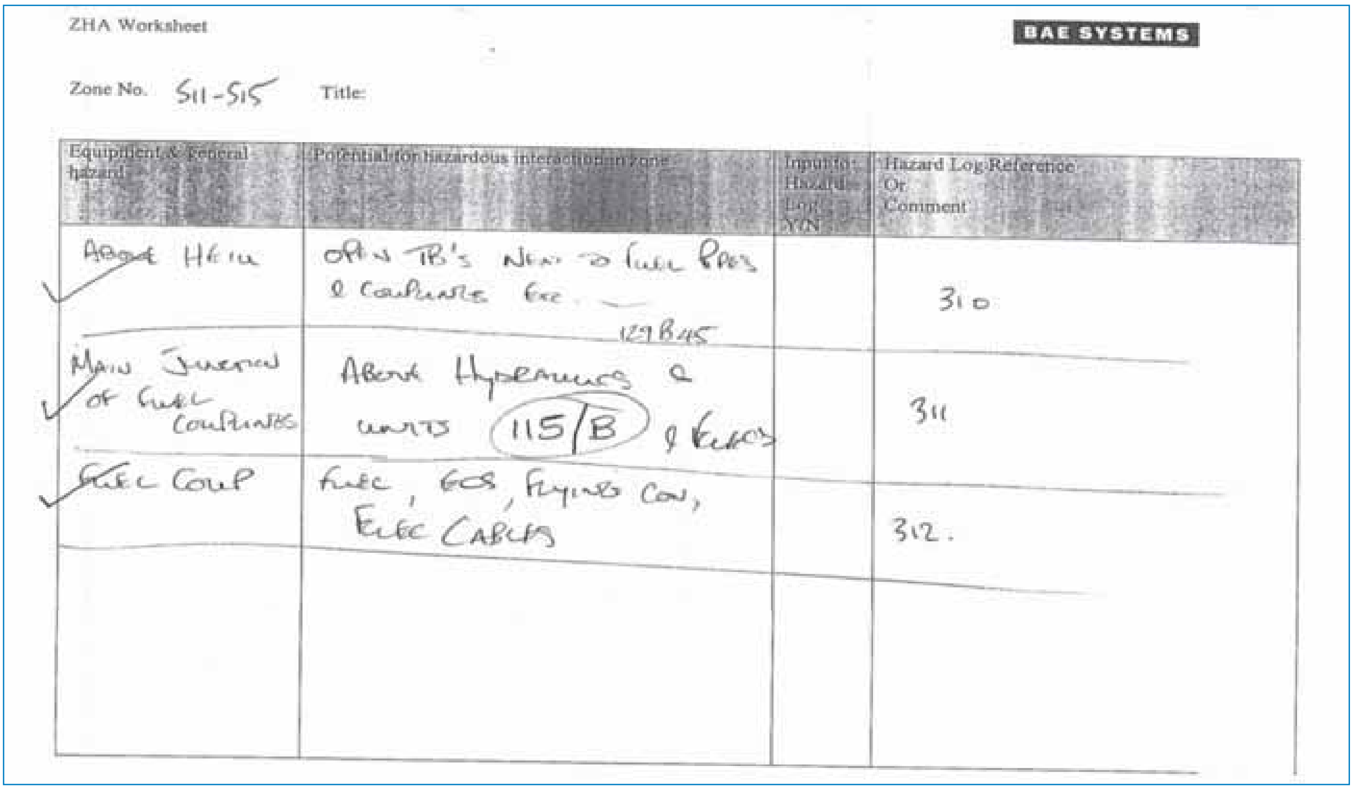
10A.60 The headings on the standard form worksheets used by the teams suggest that some analysis was envisaged at this stage, with one worksheet per zone, namely:

ZHA Worksheet

Zone No. Title:

Equipment & general hazard	**Potential for hazardous interaction in zone**	**Input to hazard Log Y/N**	**Hazard Log Reference Or Comment**

10A.61 Unfortunately, BAE Systems' original worksheets as actually filled in were not available to the Review. Witness C [BAE Systems] recalls leaving the full set in a manila envelope on his desk when he left BAE Systems' employment in April 2008; subsequent careful searches by BAE Systems' lawyers, however, have not located them. Fortunately, photostats of some of the worksheets were found in a separate working file. This included a photostat of the worksheet for Zones 511-515 prepared by Witness I [BAE Systems], reproduced below:


ZHA Worksheet

BAE SYSTEMS

Zone No. 511-515 Title:

Equipment & general hazard	Potential for hazardous interaction in zone	Input to Hazard Log Y/N	Hazard Log Reference Or Comment
Above HEW	Open TB's next to fuel pipes & couplings etc. — 129B45		310
Main junction of fuel couplings	Above hydraulics & units 115/B & elecs		311
Fuel coup	Fuel, ECS, flying con, elec cables		312.

10A.62 The relevant manuscript entry which relates to Zone 514 (the No. 7 Tank Dry Bay port) is the third row of the worksheet, which reads:

FUEL COUP	FUEL, ECS, FLYING CON, ELEC CABLES		312

10A.63 It shows that, at the time of filling out the worksheet, very little actual hazard *analysis* was done, *i.e.* working out precisely how and in what circumstances the various systems might interact to cause a fire or hazard. Indeed, despite the worksheet headings, the worksheets appear to have been used as little more than notepads to record cursory details for a handful of zones. The Jaguar worksheets, by contrast, appear to show more actual analysis being carried out at the zonal hazard inspection stage.[48] Furthermore, it is far from clear that anyone involved in the inspections appreciated that Zones 514 and 614 (*i.e.* the No. 7 Tank Dry Bays port and starboard) were different: namely the MR2's starboard side had the additional SCP pipe at the bottom of the dry bay. It does not appear, however, that the BAE Systems personnel conducting the zonal inspections were instructed or expected to do more than record the bare details. The flowchart summarising the process followed during the ZHA simply states: *"For each zone – utilising checklist identify presence of potential hazardous interactions between systems/components. Input on worksheet"*.

10A.64 Upon returning to Chadderton, Witness I [BAE Systems] and Witness J [BAE Systems] typed up their own worksheets and passed these to Witness C [BAE Systems] for entering into CASSANDRA. The CASSANDRA database entry for Hazard H498 read:

"Hazard Number: *H498*

Hazard Title: *Multiple systems in very close proximity*

…

Source Data References:

134 Photo Dep 312.jpg – Zone 514/614 – Fuel pipes in close proximity to [?F/C flying control] cables, hydraulics and electrics and ECS ducts

…

Description: *In an area closely packed with flight control cables and pulleys, hydraulic services, unprotected electrical cables and hot air ducting there exists a potential for hot air, fuel and hydraulic leaks and possible fire.*

Initial probability: *Remote*

Origin: *Maintenance Zone 514/614*

Hazard type: *Zonal"*

10A.65 There is no surviving worksheet for Hazard H367 prepared by Witness C [BAE Systems] and Richard Oldfield. But the resulting entry for Hazard H367 in the CASSANDRA database read as follows:

"Hazard Number: *H367*

Hazard Title: *Fire/ Explosion – Fuel or hydraulic leak onto Hot Engine Bleed Pipe*

…

Source Data References:

78(?) Photo Doc 0221.jpg. Flap pulley bay – Zone 514. Fire explosion risk due to leaking fuel impinging on hot pipe.

…

Description: *Potential fuel or hydraulic leaks from fuel pipe joint, Flap hydraulic pipelines or No. 7 Tank main feed fuel pipe immediately above the HP, High Temp engine bleed take-off port or associated ducting potentially causing an uncontrollable fire or explosion.*

Initial probability: *Improbable*

Origin: *Maintenance Zone 514/614*

Hazard type: *Zonal"*

[48] See Jaguar Report BAE-WPM-RP-JAG-LEX-1720 DRAFT, dated 28 February 2002.

10A.66 It will be seen, therefore, that in their zonal inspections for Zones 514/614, both Witness C [BAE Systems]/ Richard Oldfield and Witness I [BAE Systems]/Witness J [BAE Systems] identified the relevant hazard, namely, the risk of fire arising from the proximity of fuel pipes and the hot bleed-air piping. They both also described the hazard in general terms. But neither sought to analyse the risks or hazard mechanisms in any detail, *i.e.* as to leak paths, the risk of flammable fluids pooling, the presence of drain holes, the risk of flammable fluids impinging on the surface of the hot pipes, the condition of the insulation, the measurement of gaps etc. Neither sought to analyse or explain in the worksheets in any detail why they formed the view during the inspection that this hazard existed in Zones 514/614, save for the proximity of potential sources of fuel and ignition. Neither appears to have particularly noted or highlighted the significant difference in the configuration of the No. 7 Tank Dry Bays port and starboard: namely the starboard dry bay contained the extra SCP piping and elbow (which given its location at the bottom of the bay presented a particular hazard), whilst the port dry bay only contained the Cross-Feed piping mid-way up the bay. The SCP fairing continues for several feet proud of the fuselage on the starboard side and is, therefore, easily visible. BAE Systems' Phase 1 Report said that such differences in symmetry would be specifically noted and a zonal re-assessment made.[49] Unfortunately, they were not.

10A.67 The extent to which Hazard H498 identified the SCP, in particular, as a risk is not clear because it merely uses the general term *"ECS ducts"*, *i.e.* environmental or engine conditioning ducts, without identification or explanation of the particular part or function of the duct in question. This somewhat vague term *"ECS ducts"* is to be found commonly in the CASSANDRA entries.

10A.68 As regards Hazard H367, Witness C [BAE Systems] said in evidence to the Review that, because the bottom panel had been removed for access, he did not appreciate when drawing up Hazard H367 that the SCP 'elbow' formed part of the No. 7 Tank Dry Bay starboard; he thought that the flat panel extended across the bottom of the bay isolating the SCP duct in a separate fairing underneath. He went on to suggest, however, that it would have made no difference to his assessment of the zonal hazard in this area because he had already recorded the essential risk of fuel or hydraulic leaks onto the bleed-air ducting. In fact, he was probably being unfair to himself: a careful reading of the notes for Hazard H367 suggest that he did identify the risk represented by the SCP at the bottom of the No. 7 Tank Dry Bay starboard, in that his worksheet made explicit reference to *"No. 7 Tank main feed fuel pipe <u>immediately above</u> the HP, High Temp engine bleed take-off port or associated ducting"* (emphasis added). The only engine bleed take-off ducting immediately below the No. 7 tank main fuel feed pipe is the SCP.

10A.69 Any suggestion that the SCP 'elbow' was not technically within the curtelage of the No. 7 Tank Dry Bay starboard is untenable. The SCP and SCP elbow plainly formed part of Zone 614 and have done since the SCP take-off and fairing was added in 1979. In any event, any sensible zonal hazard analysis of Zone 614 would, and should, have taken the presence of the SCP into account. It appears that Hazards H367 and H498 did do so, at least in general terms.

SCP represented serious fire risk

10A.70 The SCP duct presented a particularly serious fire and explosion risk (and a greater risk than even the adjoining Cross-Feed duct) for four reasons. First, the location of the SCP duct at the very bottom of the No. 7 Tank Dry Bay starboard meant that it was vulnerable to fuel dripping on to it from the four fuel pipes and nine fuel seals directly above it. Second, the moulded fuselage panel and fairing around the SCP 'elbow' increased the chances of fuel 'pooling' in this area (and a careful examination would have shown that 'pooling' in panel trays and at the bottom of the fairing was quite possible given its ribbed construction and the fact that there were inadequate drain holes). Third, the laced muff around the SCP elbow was vulnerable to the ingress of fuel (and this would and should have been apparent from a detailed zonal examination). Fourth, there was a gap between the 'muff' and the adjacent Refrasil insulation which was open to any fluid. (See the photographs and analysis in **Chapter 4**).

[49] Page 9, BLSC (Phase 1) Report.

10A.71 Whilst the BAE Systems personnel carrying out the zonal inspections of Zones 514 and 614 identified the general risk presented in the No. 7 Tank Dry Bay starboard resulting from the proximity of fuel pipes and the hot bleed-air piping, they did not particularly highlight the special fire risk represented by the SCP. However, since the task which they appear to have engaged in at this stage was essentially a brief zonal inspection rather than a zonal analysis itself, this is perhaps not altogether surprising. In my view, if they had carried out a detailed and careful zonal inspection and analysis while on site, the serious fire risk that the SCP represented would and should have become apparent. I have concluded, however, that, since the individuals who carried out the zonal inspections were not instructed or expected to do more than record the bare details on the worksheets, it would be unfair to criticise them.

10A.72 The real problem was that the whole approach to the ZHA in Phase 1 was fundamentally flawed: it comprised inspection but no analysis on site.

'Initial probabilities' ascribed

10A.73 Each hazard was ascribed an *"initial probability"*, *i.e.* an initial risk estimate. The *"initial probability"* ascribed to each of Hazards H367 and H498 was different, notwithstanding that they related to the same zone and essentially the same hazard. The initial probability ascribed to Hazard H367 was *"Improbable",* whereas the initial probability ascribed to Hazard H498 was *"Remote"*. This was a difference of one order of magnitude, *i.e.* 10^{-5}-10^{-6} compared with 10^{-6}-10^{-7}. This made a significant difference under the Hazard Risk Index table (HRI)[50]: *"Improbable"* equated to *"Tolerable"* under the HRI, whereas *"Remote"* equated to *"Undesirable"*. It appears that the process of initial probability categorisation was fairly rudimentary. Witness C [BAE Systems] said he or his partner would have categorised Hazard H367 as *"Improbable"* having conducted a word search on the incident database to see if there was any evidence of leaks in that zone. Witness I [BAE Systems] said that he or his partner would have categorised Hazard H498 as *"Remote"* using engineering judgment and because of the *"significant number of interactive systems"* in the zone. These initial probabilities were entered on the CASSANDRA database. (It should be noted that these initial probabilities subsequently proved to be significant because they were in due course seen by the Nimrod Safety Manager, Frank Walsh, when he came to interrogate the database and, it would appear, used by him to sentence many of the remaining risks).

Zonal risk from No. 1 blow-off valve

10A.74 The zonal risk represented by a fuel blow-off during refuelling from No. 1 blow-off valve was not identified during the ZHA. BAE Systems said that the outside of the fuselage was not considered to be a 'zone' and, accordingly, no specific zonal analysis was done on this area on the starboard side forward of the No. 7 Tank Dry Bay starboard. I discuss later in **Chapter 11** whether this approach was, in fact, justifiable.

Photographs

10A.75 Photographs were taken of zones during Phase 1 which were available to those carrying out the later Phase 2 hazard analysis. The problem was that these photographs were often difficult to follow and poorly labelled.

10A.76 The two jpg photographs referred to in the CASSANDRA log entries for Hazards H367 and H498 are reproduced below as Figure 10A.1. They are, however, not particularly informative or easy to follow. Apart from showing a 'spaghetti junction' of different systems in close proximity, they show little else. They give little idea of the angle from which they are taken. In interview, even Witness I [BAE Systems] (who took part in the original zonal inspection of the dry bays) initially thought when questioned by the Review that they were taken from above when, in fact, they were both taken from below looking directly up.

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[50] BP1201

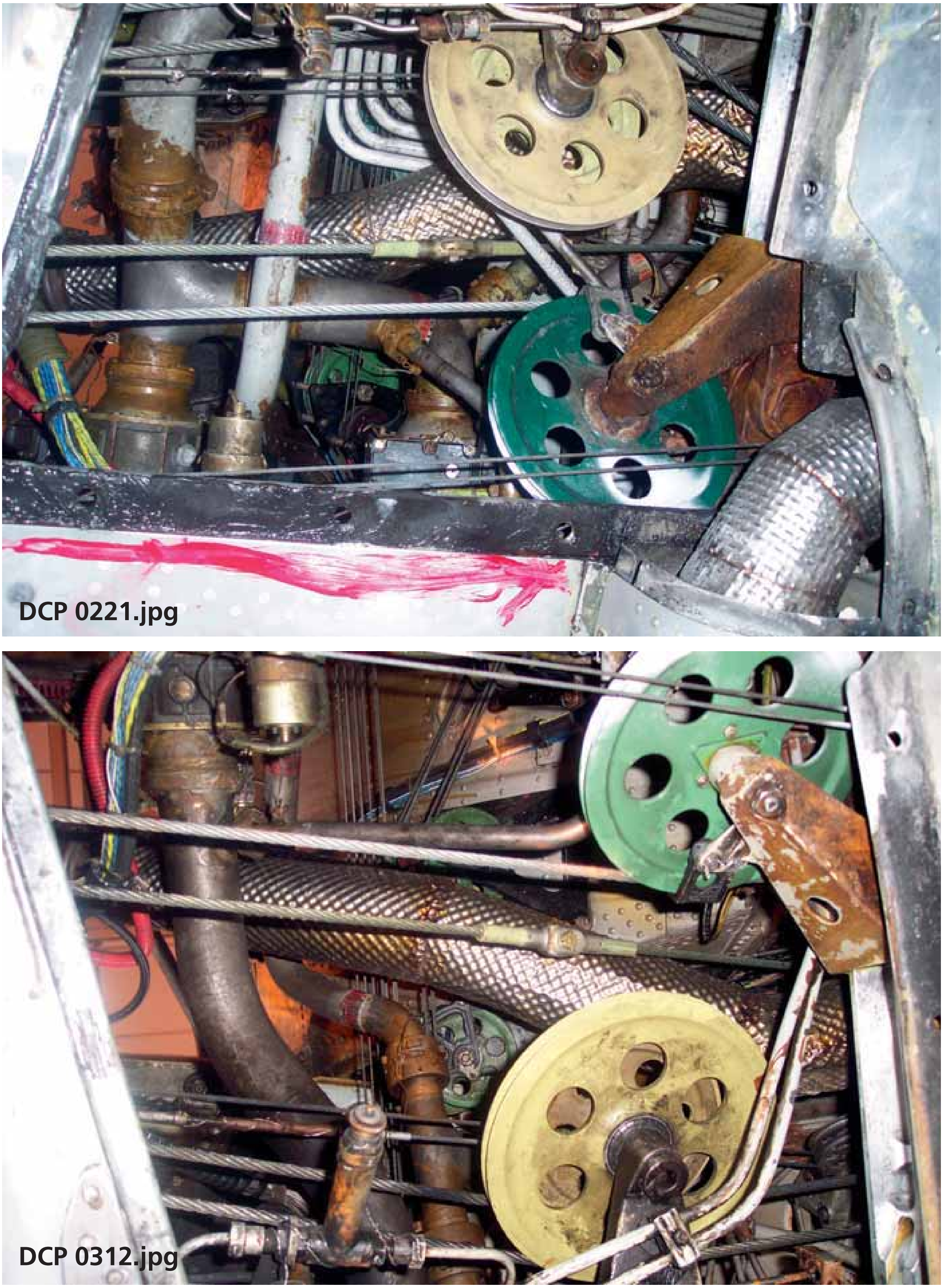

Figure 10A.1: Photographs referred to in the CASSANDRA log entries for Hazards H367 and H498

10A.77 The jpg photographs for hazards H367 and H498 were incorrectly labelled in the CASSANDRA log entries: photo Dcp0221.jpg related to Zone 614 (*i.e.* the starboard No. 7 Tank Dry Bay) not 514; and photo Dcp0312.jpg related to Zone 514 only (*i.e.* the port No. 7 Tank Dry Bay) not both Zones 514 and 614. This meant that a person looking at the photographs later was going to have considerable difficulty in understanding which was which, let alone appreciating that there was a significant difference between the port and starboard No. 7 Tank Dry Bays. Furthermore, the gaps in the insulation and the deterioration in the condition of the insulation are not apparent from the photographs. Indeed, both photographs give the impression that the condition of the insulation of the Cross-Feed pipe and SCP pipe was good. As I explain in **Chapter 4**, however, that was not the case: much of the Refrasil insulation was old and deteriorated throughout much of the Nimrod fleet.

10A.78 Witness K [BAE Systems] was, therefore, right when he subsequently wrote on 7 June 2004: *"Given a zone and a picture, identifying the systems at risk will be a mammoth task."* The poor quality of the initial zonal hazard reports and photos (some of which were not labelled at all and some of which it was difficult to tell whether they were up or down) was the subject of complaint subsequently by those tasked to carry out the analysis and mitigation exercise, such that Richard Oldfield was obliged to offer a further aircraft at RAF Woodford for viewing and the assistance of the BAE Systems' Field Service Representative at RAF Kinloss at a Phase 2 progress meeting on 7 July 2004. This offer was, unfortunately, never taken up.

4 March 2003: QinetiQ TRM confirms QinetiQ will 'review' NSC

10A.79 At a QinetiQ TRM on 4 March 2003, it was noted that BAE Systems hoped to sign off the NSC "*by the end of 2003*", and it was agreed that QinetiQ *"would have the opportunity to review the work done by BAE Systems"*.

April 2003: BAE Systems deliver Phase 1 Nimrod Baseline Safety Case Report

10A.80 In April 2003, BAE Systems delivered its Report on Phase 1 of the Nimrod Baseline Safety Case comprising the Zonal Hazard Analysis (ZHA) of the MR2 and R1 (BLSC (Phase 1) Reports).[51] The BLSC (Phase 1) Report for the MR2 identified some 1,300 hazards. As explained later, this enormous number of 'hazards' is indicative of a lack of understanding by BAE Systems at the time as to what comprised a 'hazard' and what comprised an 'event or cause'. The majority of the 1,300 initial hazards were avionic-related and repeats of each other with small variations. Many were not 'real' hazards in the first place as they assumed, *e.g.*, that a pilot would only look at a single instrument erroneous indication and follow it blindly.

10A.81 The BLSC (Phase 1) Report annexed the CASSANDRA Hazard Log entries for Hazards H367 and H498 set out above. As explained above, these identified the general zonal risk arising from the juxtaposition of fuel pipes and hot bleed-air ducting in Zones 514 and 614 but: (i) contained little analysis or detail; (ii) did not distinguish between the port and starboard sides, and in particular, did not highlight the special risk on the starboard side arising from the SCP pipe and elbow at the bottom of Zone 614; (iii) ascribed different initial probabilities to the same zones and hazard; and (iv) cross-referred photographs that were confusing and difficult to follow. This did not bode well for any subsequent hazard analysis.

10A.82 In an accompanying Phase 1 'Completion' Report, BAE Systems reported that it had completed Phase 1 and recommended that it be tasked to carry out Phase 2.[52]

1 May 2003: Nimrod IPT acceptance of completion of Phase 1

10A.83 By a letter dated 1 May 2003, Frank Walsh (who had joined the Nimrod IPT in January 2003 as Safety Manager) confirmed acceptance of the completion by BAE Systems of Phase 1 of the NSC and acknowledged receipt of a soft copy of the Hazard Log *"populated but not mitigated".* He made arrangements for BAE Systems to be paid for Phase 1 and requested BAE Systems to prepare costings for Phase 2 of the contract *"now the scope of the task is clear."*

[51] BAE Report MBU-DEF-C-NIM-SC0538: Nimrod MR Mk2 – Baseline Safety Case (Phase 1) Zonal Hazard Analysis (April 2003) (BLSC (Phase 1) Report).

[52] BAE Report MBU-DEF-C-NIM-SC0539. Nimrod Task 26-3244 Equipment Safety Management Safety Management Nimrod MR MK2 and R Mk1. Preliminary Hazard Identification Report – Phase 1 Completion (April 2003).

8 May 2003: Third PSWG Meeting

10A.84 At the Third PSWG Meeting on 8 May 2003, the completion of Phase 1 of the NSC by BAE Systems was noted. There was a further BAE Systems presentation on the reasons for, and methodology of, producing Phase 2 of the NSC. QinetiQ was represented by Witness L [QinetiQ], a newly-qualified, keen and rigorous Safety Systems Manager from QinetiQ's heavy aircraft technical evaluation service. The Head of AV asked BAE Systems if it had any objection to QinetiQ being appointed as the Independent Assessor for the Phase 1 work. Witness B [BAE Systems] confirmed that BAE Systems had no objection. It does not appear, however, that QinetiQ was ever formally appointed as 'Independent Assessor' (ISA) in relation to Phase 1 of the NSC. At the meeting, Witness L [QinetiQ] questioned if BAE Systems would be working to BP1201 and asked how they would demonstrate ALARP. After considerable discussion, it was agreed that a meeting would be arranged between BAE Systems, QinetiQ and the Nimrod Safety Mangers *"to discuss the Phase 2 approach".* Witness L [QinetiQ] subsequently said to the Review in interview: *"I felt that I was trespassing in a room where I really wasn't wanted".* He explained in interview with the Review that he was '*shocked*' to find that Phase 1 of the NSC had been produced without the appointment of an ISA, because the appointment of an ISA was a requirement of Def-Stan 00-56 when Class A and B risks were involved.

19 May 2003: Scoping meeting with QinetiQ present

10A.85 On 19 May 2003 the mooted BLSC 'scoping' meeting took place at which Frank Walsh, Witness L [QinetiQ], Witness C [BAE Systems], Witness H [BAE Systems], Chris Lowe and Richard Oldfield were present. There was a detailed discussion on the manner and methodology to be employed for the NSC. In the course of the discussion Witness L [QinetiQ] raised a number of issues. First, whether in relation to Class B hazards, quantitative or qualitative mitigation was to be used. It was suggested that 'numbers' would be included where available and capable of being backed up. Otherwise, qualitative judgments would be made. Second, how it was to be demonstrated that the risks had been mitigated to ALARP. Chris Lowe said that there would be a 'check list' for each hazard to show what had been considered, namely design, testing, analysis, procedures/training and service history. BAE Systems would do the ALARP statement and the IPT would 're-visit' these and agree or amend as appropriate. Third, Witness L [QientiQ] suggested that a statement should be put in the report that past reliability data would not demonstrate future reliability. In the light of the meeting, Witness L [QinetiQ] declared QinetiQ *"happy"* with the suggested way forward.

10A.86 Witness L [QinetiQ] was, however, not given a copy of the BAE Systems' Phase 1 Report. Nor could he take away with him a copy of the CASSANDRA hazard log. QinetiQ did not have a software licence for the CASSANDRA software, even though it was the IPT's preferred software database. Witness L [QinetiQ] tried to persuade his superiors, including Witness M [QinetiQ] and Witness N [QinetiQ], to purchase a licence but this was not done.[53] Printing off a copy of the CASSANDRA log would not have been feasible because the 'hazards' alone numbered 1,300.

10A.87 A few months later, in October 2003, Witness L [QinetiQ] left QinetiQ to take up a post with another company. He was subsequently replaced by Martyn Mahy, who was employed on a permanent basis as a Safety Engineer from July 2004, having been on a sub-contract. Meanwhile, some of Witness L [QinetiQ]'s workload was temporarily given to Witness O [QinetiQ], who had recently joined QinetiQ in September 2003.

13 June 2003: FWAMG Meeting told QinetiQ 'appointed' as ISA

10A.88 At the Thirteenth Fixed Wing Airworthiness Management Group (FWAMG) meeting, a report was presented which was signed by George Baber which stated *"The CASSANDRA Hazard Log has been populated by BAE Systems under Phase 1 work, Phase 2 of the task, scheduled for completion 31 Jan 04 will be to mitigate the hazards. <u>QinetiQ has been appointed as the Independent Safety Assessor</u>"* (emphasis added). This latter statement was incorrect (unbeknown to George Baber). QinetiQ was never formally appointed as ISA for the NSC.

[53] Witness L [QinetiQ] indicated in his evidence to the Review that he thought this would cost approximately £10,000–£14,000 .

15 July 2003: QinetiQ TRM records role as 'independent advisor'

10A.89 At a QinetiQ TRM on 15 July 2003, at which Michael Eagles was present for the first time as the Nimrod Head of Air Vehicle (having joined the Nimrod IPT formally in August 2003), it was noted that QinetiQ had an 'ongoing' task in relation to the Nimrod Safety Management System of *"Attendance at meetings and independent advise* [sic]*"* for which the current charge in the year 2003/2004 stood at £22,165. Witness L [QinetiQ] was recorded as the Task Manager (later replaced by Martin Mahy).

Phase 2 conducted by BAE Systems (August 2003 to September 2004)

10A.90 I now turn to examine the events that took place during Phase 2 of the NSC, conducted by BAE Systems.

13 August 2003: Rationalisation of Hazards from 1,300 to 105

10A.91 At a meeting on 13 August 2003 at Chadderton to scope the work for Phase 2 of the NSC, BAE Systems' heads of departments 'rationalised' the number of hazards from 1,300 to 105 on the basis that there was significant overlap and duplication. It was agreed to cross-refer these hazards and that the reduced number would form the basis of Phase 2. It should be noted that Hazards H367 and H498 identified in Phase 1 relating to the No. 7 Tank Dry Bays port and starboard (Zones 514/ 614) were conflated to become Hazard H73 (see further below).

10A.92 There were two types of hazard: *'Functional'* and *'Zonal'*. Functional hazards were hazards relating to a particular system, *e.g.* the flight direction system. Zonal hazards were hazards arising as a result of the potential interaction between systems in particular zones in the aircraft. These required different treatment. Following the rationalisation, there remained 66 Functional Hazards and 39 Zonal Hazards.

17 September 2003: Internal BAE Systems meeting – 'weasel words'

10A.93 An internal BAE Systems Nimrod Engineering Integration Meeting took place on 17 September 2003, attended by Richard Oldfield, Chris Lowe, Eric Prince and Witness G [BAE Systems]. Richard Oldfield's manuscript notes of the meeting record the following entry: *"Eric Prince to draft some "weasel" words relating to completeness of data-bases."* It is not clear precisely what was contemplated by this suggestion but it is not particularly edifying. Eric Prince subsequently wrote on a draft proposal: *"caveat – completeness RAF databases is not our responsibility"*. In interview Eric Prince sought to suggest to the Review that the phrase *"weasel words"* was *"a fairly innocent expression"* which did not imply anything devious. Richard Oldfield sought to suggest that it meant no more than *"appropriate words"*. I regard both suggestions as disingenuous.[54] The expression *"weasel words"* could be seen as a *leitmotif* for some of the language that was subsequently to be employed by BAE Systems in its NSC presentations and reports to the Nimrod IPT and QinetiQ.

November 2003: Proposal for Phase 2

10A.94 In November 2003, BAE Systems sent its proposals and costings for Phase 2 to the Nimrod IPT.[55] The price quoted was £228,680, payable in two equal tranches. The proposal included the following *"Statement of Work"* by BAE Systems as to how it proposed carrying out the mitigation task. It is worth quoting this in full because it represents the methodology which BAE Systems was (contractually) promising to employ when producing the NSC:

> *"3.2* ***Mitigation (where extant) of each rationalized hazard identified from Phase 1 (WBS Ref: 1.3)***
>
> *This will involve the relevant Specialist Department identifying any existing evidence which can be utilized to mitigate the rationalised number of hazards identified during Phase 1 (see para 3.1) to a risk level that is "As Low As Reasonably Practicable" (ALARP).*

[54] The expression "weasel words" usually means *"words that suck the life out of the words next to them, just as a weasel sucks the egg and leaves the shell"* (Oxford English Dictionary; *c.f.* Stewart Chaplin, *Stained Glass Political Platform,* 1900).

[55] BAE memorandum on Phase 2 costings attaching Task Request No 16-3384 acceptance and version of BAE Proposal to Nimrod (ES) IPT (November 2003).

Where suitable data is available the assessment of risk severity and probability levels will be evaluated numerically. Where this is not possible the risk severity and probability levels will be evaluated qualitatively by best engineering judgment combined with in-service experience.

In these cases the severity and probability criteria will be estimated by reference to descriptive equivalents (e.g. Remote, improbable etc.) as defined within ES(AIR)BP1201 Issue 2 and the resultant hazard risk index will be accordingly annotated "qualitative" in the CASSANDRA hazard log. The source of mitigating evidence utilized within this work will be documented against the following check list for each hazard:

(a) *Design configuration e.g. redundancy features in system*

(b) *Test Reports (BAE SYSTEMS, Vendor, QinetiQ etc)*

(c) *Technical analysis reports*

(d) *Maintenance/Operating Procedures & appropriate Training*

(e) *Service history i.e. Incident & Fault Reports, RAF IRDS data (assumed to be provided GFE)*

For hazards able to be mitigated by existing evidence to a level that is ALARP these (subject to acceptance by the NIM(ES)IPT) be classed as "Managed" in the CASSANDRA hazard log. For hazards which mitigating evidence is not readily available then these will be classed as "Open" in the CASSANDRA hazard log and a statement issued to NIM(ES) IPT recommending further action/work to enable the hazard to become "Managed". It is understood that such additional work is outside the scope of this programme and will be completed under separate tasking." (emphasis added)

10A.95 In my view, the terms of BAE Systems' *"Statement of Work"* were tolerably clear: (1) BAE Systems agreed to assess or estimate *"the risk severity and the probability levels"* of each hazard identified in Phase 1. This was to be done either quantitatively (if suitable data was available) or qualitatively (using *"best engineering judgment combined with in-service experience"* and the descriptive equivalents in BP1201, *e.g."Remote", "Improbable" etc.*); (2) In order to carry out this evaluation, BAE Systems would conduct an analysis of each hazard utilising each of the five categories of documents in the checklist; (3) These equated to five areas which would be considered in the analysis of whether each hazard could be mitigated to ALARP, namely Design, Testing, Technical Analysis, Procedures/Training and Service History;[56] and (4) Where it was not possible to mitigate a hazard to ALARP because the mitigating evidence was not *"readily available"*, the hazard would be classed as *"Open"* and further work would be recommended which would be outside the scope of the contract.

10A.96 BAE Systems' Phase 2 Proposal document rated the risk of there being insufficient evidence to mitigate the risks to ALARP as *"Medium-High"*; but went on to reassure that hazards left open would be *"highlighted"* to the Nimrod IPT as soon as possible so that appropriate action could be taken in accordance with the Nimrod SMP. [57] It will be recalled that the Proposal was made against a background where BAE Systems had said that it had a *"high level of confidence"* that it could complete the NSC task in a cost effective manner. Whilst there was said to be a *"Medium-High"* risk of there being insufficient mitigation evidence to manage all the hazards to ALARP, at no stage was there any suggestion that the number of hazards left open would be significant. The risk that the relevant specialist engineer might not be available to support the NSC programme full-time due to modifications etc. was, however, rated as *"High"*. This was due in part to the increased operational demands on the Nimrod as a result of the various conflicts in which the fleet was engaged. The Gantt Chart which was attached indicated a completion date of May 2004.

BAE Systems' man-hours estimate

10A.97 The risk of the man-hours estimate for Phase 2 being incorrect was rated as *"Low-Medium"* on the basis that a 'best' man-hour estimate had been produced against the above statement of work by each specialist department. The man-hours estimate in fact proved to be inadequate by a considerable margin. Richard

[56] As Chris Lowe confirmed to QinetiQ at a meeting on 19 May 2003.

[57] BAE Proposal to Nimrod (ES) IPT (November 2003), paragraph 5.0.

Oldfield was responsible for obtaining the man-hours estimates from the various departments. He said in evidence to the Review that each specialist department had made its own estimate of how long it would take them to investigate their records and to carry out the necessary work to establish relevant mitigation. But the contemporaneous evidence suggests that the specialist departments only quoted for the time it would take to make a document search, and did not include time to carry out any analysis of those documents.

10A.98 The original man-hours estimate allowed a total of 3,960 man-hours for Phase 2.[58] The Work Breakdown Schedule (WBS) included the following estimated hours for each of the main departments: The Mechanical Systems Department (Mech Systems): a total of 650 hours (of which 350 was *"Provide mitigating evidence (where extant)"* and 150 was *"Compile Fire/ Explosion Analysis/ Survey"*); the Avionics Department (Avionics): a total of 575 hours (of which 250 hours was *"Providing mitigating evidence (where extant)"*); the Electrical Systems Department (Electrical Systems): a total of 470 hours (of which 325 hours was *"Provide mitigating evidence (where extant)"*); and the Airworthiness Department (Airworthiness): a total of 1,328 hours. The WBS estimate included the following rider: *"The above estimate is based on the generic nature of mitigating hazards in the hazard log. It is not expected that any additional work is required in providing 'new' qualification/ mitigation against hazards identified".* This indicates, in my view, that BAE Systems expected that the hazards would be mitigated 'generically' using design/qualification/testing material from the archives; and did not expect to have to do any additional work by way of finding 'new' mitigation evidence. This assumption proved to be wrong.

21 November 2003: QinetiQ criticised by IPTL at Fourth PSWG Meeting

10A.99 At the Fourth PSWG Meeting on Friday 21 November 2003 at RAF Wyton, QinetiQ was represented by Martin Mahy, a Systems Safety Engineer from QinetiQ's heavy aircraft technical evaluation service. Martin Mahy, who was the 'Task Manager' at QinetiQ and subsequently appeared for QinetiQ at meetings involving the NSC (save, notably, at the Customer Acceptance Conference on 31 August 2004 when he was unavailable and replaced by Witness O [QinetiQ]). He had taken over from Witness L [QinetiQ]. Martin Mahy played an active role in this and future meetings concerning the NSC. At this meeting, he raised concerns with BAE Systems regarding the need for 'quantifiable targets' for the preparation of the NSC. It appears that he received a somewhat hostile reception from the Nimrod IPTL, George Baber, who complained that QinetiQ had not been consistent in its review of various safety case reports (relating to specific modifications and installations) and said he had warned QinetiQ about this several times. Martyn Mahy recalls George Baber saying *"I don't need to get independent safety advice from QinetiQ, I can go elsewhere"*, referring to *"bloody QinetiQ"* and saying *"QinetiQ is just touting for business".* (George Baber and other members of the IPT denied that any hostility was displayed towards QinetiQ, but QinetiQ's version of events is well supported by the contemporaneous documents). Frank Walsh said that he had had to put Witness L [QinetiQ] *"back in his box"* recently. Another member of the Nimrod IPT referred to the content of some of QinetiQ's reports as *"Tosh!".* George Baber told Martyn Mahy that QinetiQ would be able to comment on the NSC when it was completed in March 2003. After the meeting, Martyn Mahy spoke to Frank Walsh who said he was surprised at the *"viciousness"* of the IPTL's comments about QinetiQ. Frank Walsh said in his evidence to the Review that the relationship with QinetiQ was the subject of some *"tension"* at this time because it was felt by the Nimrod IPT *"that QinetiQ's recommendations were often influenced by a desire to generate more work and income for themselves."*

10A.100 Martyn Mahy was somewhat taken aback by his carpeting at RAF Wyton. When he returned to the office on Monday 24 November 2003, he reported in writing in an e-mail to his Project Managers at QinetiQ, Witness M [QinetiQ] and Witness N [QinetiQ], exactly what had transpired in detail. His e-mail said *"I think we… need some sort of 'rescue plan' to win back the confidence of the IPTL"* and concluded:

> *"Additionally, I am concerned that the Nimrod safety strategy has not been clearly defined and that the safety targets are blurred. As BAE are only producing a qualitative baseline SCR, it will be convenient for them to ignore the quantitative safety targets at this stage, only to resurrect them as a concern later on. I would like to see a copy of the Nimrod Safety Management Plan and to know whether QinetiQ was given the opportunity to comment upon it."*

[58] See the WBS, dated 9 December 2003.

10A.101 It appears, however, that QinetiQ was not furnished with a copy of the Nimrod SMP. The reasons why not are not altogether clear. It is not clear what formal requests were made by QinetiQ for a copy. It appears Martyn Mahy remained unclear whether an SMP had been completed. This is unfortunate because it was difficult to see how QinetiQ could properly perform its task (Task 010) of advising the Nimrod IPT on its Safety Management System (SMS), including the NSC, without a copy of the Nimrod SMP. A copy was not provided by the Nimrod IPT to QinetiQ until November 2007, prompting the following (sarcastic) internal e-mail at QinetiQ: *"It's a miracle!! After years of asking for it, the IPT have just sent us a copy of the Nimrod R1/MR2 Safety Management Plan!!".*

Subsequent meeting to 'clarify and defuse tensions' (9 March 2004)

10A.102 QinetiQ was anxious to remain on good relations with the Nimrod IPT and not to lose business. Accordingly, at QinetiQ's request, a meeting to 'clarify and defuse tensions' subsequently took place with the Nimrod IPT on 9 March 2004. Present for QinetiQ were Martyn Mahy, Witness M [QinetiQ], Witness N [QinetiQ], and Colin Blagrove. Present for the Nimrod IPT were George Baber, Michael Eagles and Frank Walsh. The minutes record George Baber requiring *"an essential change to the QQ reports"* because QinetiQ were *"not currently offering advice that he felt was needed"* or *"value for money".* QinetiQ appear to have acknowledged what may have been seen as over-zealous advice in the past by Witness L [QinetiQ] on a 'tie-wraps' issue but explained that he had left the company. The minutes also record QinetiQ suggesting that it would be better if QinetiQ were brought in early because *"a teamed approach would improve the safety case"*, QinetiQ could assist and advise and provide 'route maps' for safety which *"should be approved quickly".* The meeting seems to have been successful in smoothing things over. Witness L [QinetiQ] said that QinetiQ's Project Managers went to *"extraordinary lengths"* to keep their IPTLs happy and were, on occasions, prepared to modify their position. It is clear that the Nimrod IPT continued to view QinetiQ with some scepticism and QinetiQ were certainly eager to please.

QinetiQ's advice on LBI's rejected as 'gold-plated'

10A.103 Martyn Mahy was subsequently tasked to re-write the Nimrod IPT's Local Business Instructions (LBIs) for the safety cases for modifications to the Nimrod fleet. Martyn Mahy regarded them as deficient and made a number of comments and recommendations. His advice was, in the main, rejected by Frank Walsh and the Nimrod IPT on the basis that QinetiQ was advocating a depth of investigation that was *"out of proportion"* to the task. The final paragraph of Frank Walsh's e-mail response on this topic, dated 28 May 2004, gives an indication of the mind-set of the Nimrod IPT at the time:

> *"In conclusion, the Nimrod fleet has a proven safety record, taking into account the fleet flying hours against the number of accidents, of* 1×10^{-5} *and, as 2 of the accidents were not caused by equipment failure, it can therefore be argued to be even safer in practice. The remit of the IPT is to operate, maintain and modify the aircraft to ALARP principles and that includes the time, cost and effort needed to staff any changes. We appreciate the time and effort that you have put in to reviewing our processes and will take forward many of your recommendations. However, we consider that to follow your full guidance would produce <u>a "gold plated" solution</u> that does not meet the ALARP principle and would not represent value for money."* (emphasis added)

10A.104 Martyn Mahy expressed his concern at Frank Walsh's response in an internal e-mail to his superior, Colin Blagrove, on 3 June 2004. He said that it was the Nimrod IPT's right to reject his recommendations but it must be aware of *"the implications of not providing sufficient identification and risk mitigation of hazards".* As regards the NSC itself, he said that much would depend on his *"examination"* of the BLSC on 17 June 2004: *"The IPT want to ensure that* [there] *will be no surprises when we all come to review and (hopefully) sign-off the Baseline Safety Case in July".* His e-mail concluded, presciently: *"My fear is that we may find the safety case inadequate, with no time left for BAE to correct it within the project timescales. Then again, maybe I should be more optimistic (not easy for an objective Safety Eng!)."* Frank Walsh stated in interview that he regarded QinetiQ's approach to the LBIs as "*over the top*".

10A.105 In the light of the above, there can be little doubt that Martyn Mahy and QinetiQ were expecting to conduct their own *"review"* of the completed NSC in due course, and to check and comment upon the substance and detail of what they found. The fact that there were no formal instructions to do so *qua* ISA was unfortunate; but QinetiQ's status as 'independent advisor' in relation the NSC was clearly regarded as sufficient at the time.

BAE Systems' price for Phase 2

10A.106 The WBS gave rise to a price estimate of £228,859.75 inclusive of profit.[59] There was some complaint from the IPT that this was too high. BAE Systems' Commercial Department assured the IPT that BAE Systems was not *"trying it on"* and that the estimate had been based on the Statement of Work which had been jointly developed by Richard Oldfield and Frank Walsh and that since the NSC was a *"high risk"* project, it attracted the appropriate risk factor. (It is difficult to see, however, that searching archived reports might be said to be "high risk".) On 23 January 2004, the commercial branch of the Nimrod IPT authorised BAE Systems to carry out the Phase 2 work for a price of £212,048.40. A six month period was allowed, with a start date of 4 February 2004 and a finish date of 30 July 2004.

BAE Systems' own evidence

10A.107 The Review has had to piece together the story of Phase 2 of the production of the NSC from the personal archives and notebooks of BAE Systems' personnel that came to light very late in the day. A number of contemporaneous personal notebooks of BAE Systems' personnel were produced, together with dozens of volumes of minutes of internal BAE Systems meetings, correspondence and other contemporaneous documents.

Witness K [BAE Systems]'s Notebooks

10A.108 These contemporaneous documents and records proved illuminating. Of particular importance were the manuscript notebooks of Witness K [BAE Systems], an engineer in Mech Systems, whose line manager was Eric Prince (BAE Systems' Flight Systems and Avionics Manager). These provided a detailed and meticulous record of events as they unfolded, as well as a remarkably candid commentary of his unvarnished views at the time. On the surface, there was no reason to suppose that this project was not progressing relatively smoothly, with no major problems and with all those involved on the BAE Systems side confident in how they were going about it and confident as regards completing it on time and according to budget. The reality, however, was very different. Almost from the outset, the project was beset by delays, doubts and divisions.

Early problems

10A.109 There were a number of problems which manifested themselves right from the outset regarding BAE Systems' handling of Phase 2. First, a lack of clear direction by BAE Systems' management team as to how, in practice, the hazard mitigation process was to be carried out and the precise methodology to be employed. The project management was poor from the start. Second, the man-hour estimates for the mitigation exercise were inadequate. It transpired that the original estimates given by the specialist departments had been for document searches only, and did not include time spent on analysing them. Third, the initial document searches revealed little by way of developmental reports in the archives which could be used for the purposes of hazard mitigating evidence. This was contrary to what had been envisaged and expected. Fourth, there were manpower resources problems, particularly with the Electrical Systems. Fifth, a difference of opinion as to approach, coupled with a clash of personalities, quickly led to significant tensions developing between two key members of the BAE Systems' team (Chris Lowe and Witness K [BAE Systems]). These tensions were allowed to fester and cause an element of paralysis of the project for some months. These problems persisted. I analyse these issues further in **Chapter 11**.

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[59] See Order Pricing dated 9 December 2003.

1 March 2004: BAE Systems strategy meeting

10A.110 Concern at the lack of clarity of approach was voiced by Eric Prince at the first Phase 2 internal Baseline Safety Case (BLSC) Design Review meeting on 1 March 2004, attended by those personnel who were tasked to carry it out. It should be noted that the minutes of that meeting also record a concern as to sensitivities *"after an accident"*.

10A.111 The person in the best position to determine the approach to be employed was Chris Lowe. He was the head of the Airworthiness Department and in overall charge of drawing together the technical aspects of the NSC. At the initial BAE Systems' NSC team meeting on 1 March 2004, however, he gave advice of only a very general nature. He explained that, whilst there were potentially two million fire/explosion risks, there were only eight or nine zones where fire risks were "high", including the cabin cockpit, underfloor, engine bays and the bomb bay. He also seems to have assumed, at least initially, that the majority of relevant mitigation would be found in documents such as the Declaration of Design Performance (DDP).[60] This subsequently proved to be mistaken. Chris Lowe was also noted to have said at the meeting that even where there was a source of ignition such as a transformer next to a fuel pipe, it might be considered acceptably safe in service after 30 years. He said that a cost/benefit exercise needed to be carried out in order to determine whether further analysis was necessary, but it was not clear that this was ever done.

Witness K [BAE Systems]'s ideas

10A.112 Present at this initial meeting was Witness K [BAE Systems], a meticulous, hardworking and able employee. He clearly did not think that a limited trawl for certification, qualification and test documents was enough to amount to a Safety Case. Following the meeting on 1 March 2004, off his own bat, he produced an outline of the process which he thought should be followed, namely, first, searches of: (1) the local archive; (2) the deep archive; (3) the microfilm archive; (4) the IPT databases for in-service failure rates and modes; (5) the fault investigations for relevant design reports; (6) the drawings database; (7) the AP technical publications; and (8) the PDS task reports, the fruits of which would provide the basis for, second, a *"Technical Report"* on each hazard which would comprise argument and methodology identifying and addressing all hazards and showing compliance with all appropriate standards. On 9 March 2004 he sent his ideas in the form of slides to Chris Lowe and Witness C [BAE Systems] in the Airworthiness Department and asked for guidance on whether a technical report format he had received from Witness P [BAE Systems] complied with the Airworthiness Department's requirements. He received by return an e-mail from Chris Lowe stating that Mech Systems' job was confined to *"digging out"* relevant reports and the safety case argument should be left to him, Chris Lowe, to write. These were the first seeds of disagreement between Witness K [BAE Systems] and Chris Lowe which subsequently led to serious tensions in the team.

Man-hours estimate proved inadequate

10A.113 Meanwhile, Witness K [BAE Systems] had set about carrying out his first hazard mitigation exercise in relation to the airbrakes (Hazard H8). His early report to an internal meeting on 10 March 2004 was that the task might take him 40 man-hours, of which two days were dedicated to the archive search. The original estimate by Mech Systems allowed however, for only 650 hours to be spent analysing 120 hazards i.e. about five man-hours per hazard. If the 40 hours was repeated for every hazard this would inevitably *"blow the budget"*.[61]

10A.114 It transpired, therefore, that the man-hours estimates had been calculated on an incorrect basis. Mech Systems had given a man-hours estimate on the basis of a document search only,[62] not a detailed analysis,[63] nor, for instance, producing *"a design configuration statement/complete set of test reports and in depth list of all relevant maintenance and operating procedures or service history."* This was Witness K [BAE Systems] and Eric Prince's view at the time. Eric Prince in interview with the Review sought to deny this; but the

60 See Witness K [BAE Systems]'s manuscript notes of the meeting of 1 March 2004.

61 See Witness Q [BAE Systems]'s subsequent note.

62 Not including a search of the drawings archive (see the statement by Eric Prince at the meeting of 2 April 2004).

63 See internal e-mail dated 11 March 2004 from Witness K [BAE Systems] to Eric Prince.

contemporaneous evidence is clear.[64] Eric Prince is recorded as complaining at the meeting on 10 March 2004 that Mech Systems *"did not have the resource or time to complete the requirements in anything like the timescales required"* and said that *"we were not going to do the report in that manner."* It was agreed that these issues would have to be clarified by the Airworthiness Department or delay in mitigating hazards would seriously affect BAE Systems' ability to meet the payment milestones. Chris Lowe sought to suggest in interview that only Witness K [BAE Systems] had misunderstood the nature of the task which Mech Systems was being asked to undertake. In my view, however, this was clearly not the case.

11 March 2004: optimistic report to Nimrod System Safety Working Group

10A.115 In these circumstances, it is surprising that Chris Lowe reported to a meeting of the Nimrod System Safety Working Group on 11 March 2004 (attended by members of the IPT) that he was confident that Phase 2 of the NSC would be finished *"on time"* and *"on cost".* This indicated an optimism that subsequently proved to be misplaced.

BAE Systems archives – a shambles

10A.116 In early March 2004, Witness K [BAE Systems] suggested that, before they went any further, he should spend two weeks sorting out and indexing the Mech Systems archives in order to save time later. This was agreed. It was recognised that they needed to be become 'slicker' with regard to mitigation. There had been a reminder, however, that the man-hours budget had been 'set' for the task and must be adhered to.

10A.117 It took Witness K [BAE Systems] over two weeks to sort out the Mech Systems archives. The 'local' archive was in filing cupboards located at the north end of the BAE Systems Chadderton office. It comprised various master reports and other documents. These were stored fairly neatly in box files and were described by Witness K [BAE Systems] as *"fairly well managed"*, although he still had to spend 25 hours indexing them.

10A.118 The Mech Systems 'deep' archive was an altogether different matter. It had been moved several times and was in a fairly shambolic state. The apparent lack of care with which it had been treated by the Design Authority is a matter of concern. It had originally been kept in a padlocked area in the Military Repair Centre at Woodford. It was then moved to the south end of the factory, which suffered roof problems and was flooded on one or two occasions. In the mid-1990s, the archive was split and part was moved to Chadderton when the DA for the Nimrod and VC10 moved from Woodford to Chadderton. This part was kept in the auditorium area at Chadderton, a large, dusty room with 'Dexian' shelving. It is not clear whether the remaining part of the archive at Woodford was re-united with it. At some stage, the archive was in storage with Iron Mountain.[65] It was finally placed in racking on the first floor above the BAE Systems Tanker Transport & Reconnaissance Organisation (TTRO) offices.

10A.119 There had been a previous attempt to bring some order to the deep archive when it was stored at the Military Repair Centre at Woodford. The Mech Systems boxes had been identified and labelled with yellow stickers marked *"MSM"* (Mech Systems Manchester) although no sorting out or indexing had been carried out at that stage. Witness K [BAE Systems] found 30 boxes of files labelled *"MSM"* in the racking. These boxes contained miscellaneous lever-arch files and documents stretching back many years, including documents relating to the Comet and the AEW3 project. He spent a total of 70 hours methodically going through each of these boxes looking at each document, deciding whether it might contain potentially useful mitigation material and drawing up an index. He was not aware of the other Systems Departments doing the same exercise.

10A.120 It should be noted that time Witness K [BAE Systems] spent on the archives was charged to the Nimrod IPT NSC account, *i.e.* 25 hours on local archive index compilation and 70 hours on deep archive index compilation. Arguably, it should not have been because the customer was entitled to expect that BAE Systems kept its DA archives in proper order.

[64] See e.g. Witness K [BAE Systems]'s notes: *"We have only budgeted for document search – EP* [Eric Prince] *agreed."*

[65] A document storage company.

Initial 'pro-forma' template too complex

10A.121 On 16 March 2004 the Airworthiness Department produced a draft template for the Functional Hazard Pro-Forma. This was a standard form designed to provide a framework for the various specialist departments to follow when carrying out their hazard analysis for each hazard. It ran to nine pages. It was decided that it was too detailed and impractical and Mech Systems agreed to produce a revised template. Witness K [BAE Systems] drew up a simpler form of Functional Pro-Forma report which he circulated by e-mail on 2 April 2004. This went through two further iterations before it was finalised.

April 2003: Nothing useful found by BAE Systems in archives

10A.122 At an internal NSC meeting on 5 April 2004, Witness K [BAE Systems] warned that in his initial searches of the Mech Systems local and deep archives he had found little by way of mitigating evidence in the form of developmental system testing reports, *i.e.* the key DA reports that would prove that particular system hazards had been identified and mitigated. He queried where such reports were. His notes record his view: *"value for money felt to be poor"*. In his oral evidence to the Review he explained his thoughts at the time: *"We are going on an expensive paperchase. That is the activity, as far as I am concerned."* It is clear that the budget was a serious topic of concern even at this early stage because manuscript notes of the meeting taken by the then BAE Systems Assistant Business Management Officer, Witness Q [BAE Systems], refer to discussions about *"blowing the budget"* and a debate going on about matters which were not within the budget. At an internal BAE Systems' meeting a couple of days previously, on 2 April 2004, there was a call for an *"urgent"* rationalisation and it had already been noted that *"work is exceeding budget"*.

10A.123 At or shortly after the meeting on 5 April 2004, Eric Prince suggested that Mech Systems should simply search the archive and not itself make a statement on whether the hazard was mitigated or not, but leave the question of whether a hazard was to be classified as 'closed', 'managed' or 'open' to Witness C [BAE Systems] of the Airworthiness Department.

10A.124 On 13 April 2004 Witness K [BAE Systems] circulated a summary of where the Mech Systems local, deep and microfiche archives were to be found. The same day, Richard Oldfield reported to a BAE Systems TTRO Engineering Integration Meeting chaired by Witness B [BAE Systems] that 10% of the NSC budget had been spent and that the NSC was *"slightly behind schedule"* but *"good preparatory work"* was being done to speed the job up. This too proved to be overly optimistic.

QinetiQ Task Review Meeting: 20 April 2004

10A.125 At a QinetiQ TRM on 20 April 2004, QinetiQ reported that there were *"generic procedure issues"* with the production of the NSC which would be addressed at the next PSWG meeting.

26 April 2004: office tensions surfacing

10A.126 Less than two weeks later, however, concerns were again expressed at an internal BAE Systems' NSC design review meeting on 26 April 2004 as to *"the time factor and resource problem"*. Following a request by Witness K [BAE Systems] for guidance as to what was required, Chris Lowe outlined the Airworthiness Department's requirements. Witness K [BAE Systems] sought to summarise these requirements in an e-mail to Chris Lowe later the same day. He expressed surprise that the Airworthiness Department only required Mech Systems to give *"a simple objective response to each identified zonal hazard"* and asked for confirmation that he had understood correctly. This elicited a somewhat sarcastic response from Chris Lowe which confirmed he had understood correctly but did not disguise his irritation at Witness K [BAE Systems]: *"...*[your] *continuous string of e-mails reminds me of a song called "…there's a hole in my bucket…""*. This did little to improve relations between them.

10 May 2004: Design Review meeting

10A.127 A further internal BAE Systems NSC Design Review meeting on 10 May 2004 showed further slow progress being made by BAE Systems on Phase 2. The rationalisation of hazards from 1,300 to 105 had been completed. But of the 55 rationalised hazards which were *"on the street"* (*i.e.* had been given to the Specialist Departments) only six had been returned, including only one by Witness K [BAE Systems]. There had been no input yet from Electrical Systems, which had a *"resource problem"*. Witness C [BAE Systems] criticised the *"poor pre-planning"* of the project and Witness K [BAE Systems] said in evidence that he felt *"the cart was before the horse"*, namely an estimate had been made before working out the pro-forma procedure. Good project management would have been to work out the procedure to be adopted first, and then to have made the man-hours estimate.

10A.128 At the meeting, Witness K [BAE Systems]'s draft Functional Mech Systems Pro-Forma was considered. It included a 'Summary and Conclusion' section which required Mech Systems to carry out an analysis of the post-control probability status of each hazard, *i.e.* an assessment of its probability after the Phase 2 work had considered what measures had been taken to reduce any risk. There was a discussion between Eric Prince, on behalf of Mech Systems, and Witness C [BAE Systems], on behalf of the Airworthiness Department, as to whether the Pro-Formas should include any analysis of a post-control probability. As noted above, previously it had been the Airworthiness Department's position, as expressed by Chris Lowe, that the assignment of a post-control probability was not Mech Systems' role but should be done by the Airworthiness Department alone. Chris Lowe was, however, not present at this meeting. In his absence, it was eventually agreed that Mech Systems should do *both* the document search and the analysis assigning the post-control probability, notwithstanding the fact that the Mech Systems' budget estimate had not allowed for this. Witness K [BAE Systems]'s draft Functional Mech Systems Pro-Forma was adopted.

MOD's guidance on Safety Cases

10A.129 At the meeting, Witness K [BAE Systems] circulated a copy of the Safety Case chapter in the MOD's *"An Introduction to System Safety Management & Assurance"*[66] which set out in pithy form, the basic requirements of a safety case. The MOD's guidance also explained that safety cases must be *"tailored"* to reflect the differences of legacy systems, and pointed out some of the difficulties of legacy systems, including finding original design information and justifications for developmental decisions. Following the meeting on 10 May 2004, Witness K [BAE Systems] circulated a message summarising his understanding of the requirements for the mitigation of zonal hazards laid down by the Airworthiness Department, which he believed called for an *"objective response"* and *"best judgment"* or estimate by Mech Systems in the light of the ZHA description, photo and any drawings that could be found.

13 May 2004: Witness K [BAE Systems]'s dissatisfaction with minutes

10A.130 On 13 May 2004, Witness K [BAE Systems] expressed his dissatisfaction and disquiet to Witness Q [BAE Systems] that a number of previous concerns which had been raised by him and others at meetings had not been minuted. These were not insignificant concerns and included the fact that a full Hazard Report was too time consuming; there were 'limitations' on archive search, no Comet data was being found; there was a lack of ideal historical or mechanical systems evidence, the archive search was not *"value for £"*; the initial Mech Systems' estimate had been for an evidence search only not analysis; and the fact that a safety case structure as to what was required should have been produced initially and would still be of use. Witness Q [BAE Systems] responded that the minutes were only meant to be a brief summary and he could attach his own Mech Systems minutes if he so wished.

18 May 2004 – optimistic report to Fifth PSWG Meeting

10A.131 The Fifth PSWG Meeting took place on 18 May 2004, chaired by George Baber. Also present were Michael Eagles and Frank Walsh from the IPT, and Martyn Mahy from QinetiQ. Chris Lowe attended on behalf of BAE Systems and reported on the progress of the NSC. The minutes record: *"Mr Lowe gave a presentation indicating the level of work that had been completed on Phase 2 and stated that the work should be*

[66] See **Chapter 9**.

completed on time." Chris Lowe's PowerPoint presentation, in fact, put the matter even more optimistically: *"Project considered to be progressing well…. BAE Systems highly confident that they will produce the Baseline Reports as programmed (end July 2004)"*. It is difficult to see how this statement could properly have been made (see further below).

10A.132 The minutes also record a decision that Nim(ES)Safety would arrange a meeting between BAE Systems and QinetiQ *"to ensure that the SC is independently assessed without any surprises".* This was followed up by an e-mail from Frank Walsh to Martyn Mahy on 21 May 2004 in which he said: *"I feel that we need a meeting between yourself, BAE Systems and me to look at the Baseline Safety Case as it develops further. That way there should be no surprises when you assess the final version."* He asked Martyn Mahy if he would make himself available for a meeting at BAE Systems' offices at Chadderton on 17 June 2004. A meeting duly took place on that date (see further below). Martyn Mahy suggested in evidence to the Review that the minutes and e-mail somehow had different meanings and it was not contemplated at this stage that QinetiQ would "independently assess" the NSC when completed. I disagree. Martyn Mahy said in interview that he had specifically advised the IPT that: there was *"there was a need for the safety case to be independently assessed or assessed by an independent body"* because *"Frank Walsh didn't seem to be aware that that was a requirement."* I have found no independent evidence to support this assertion; nor is it recorded anywhere in writing, as it should have been since it represented material professional advice. In these circumstances, I do not accept that any such advice was specifically given by Martyn Mahy to Frank Walsh. As I explain in **Chapter 11**, however, both were, or should have been, well aware that the NSC should have been independently assessed by a properly appointed ISA.

21 May 2004: BAE Systems Newsletter

10A.133 In keeping with the optimistic impression he had conveyed at the Fifth PSWG, Chris Lowe submitted the following piece which was published in the internal BAE Systems' TTRO *"Weekly News"* for the week ending 21 May 2004:

> *"Nimrod Platform Safety Working Group – was attended by TTRO Airworthiness at RAF Brampton on 18 May 2004. A major agenda item was a presentation of progress on the Nimrod Aircraft Level Baseline Safety Case. Whilst the group was satisfied with progress so far, there is still a high volume of work to be discharged by TTRO engineering in order to deliver the Baseline reports for approval by the end July this year and official IPT acceptance by September latest. <u>It was pointed out that this is looked upon as a Nimrod IPT showcase project, and a fundamental milestone in Nimrod IPT 2004 activities.</u> In view of this, Group Captain Baber wished that achievement of the Safety Case acceptance and sign-off be formally recognised by a publicity gathering to mark the occasion."* (emphasis added)

10A.134 Witness K [BAE Systems]'s reaction at the time when he read this article was one of incredulity. The following entry that he made in his personal notebook (the first part of which was written in red ink for emphasis) is worth quoting in full:

> *"Q: N.S.W.G. Major agenda item! Presentation of progress on NSC…*
>
> *"Group satisfied with progress so far" – what was presented? 18/05/04*
>
> *"Approval by end July this year" – engineering reports.*
>
> *Show case / milestone proj / Public gathering!*
>
> - *"Knowing" on the 18/5/04 that all hazards had still not yet been delivered to engineering (and should have been supplied to program by end Feb) (final ones 28off delivered 21-5-04)*
> - *"Knowing" we still did not have a practical way ahead on ZHA's*
> - *"Knowing" engineering had a 4 month window post 1-2-1 (now reduced to 1 month)*
> - *How did Gp Capt Baber came to the conclusion that we were on program to finish by July?"*

10A.135 Witness K [BAE Systems] was asked in interview about this entry in his notebook. He explained these were his personal thoughts at the time and said:

> ***"Witness K [BAE Systems]:*** *I think the notes are pretty conclusive, aren't they? They say what I was thinking at the time."*

10A.136 When asked why he wrote this note, he explained that the statement in the Weekly News simply *"didn't compute"*. He said *"I don't see how somebody could make that statement, knowing where we were up to."* The answer to the question posed at the end of his manuscript note, *"How did Gp Capt Baber come to the conclusion that we were on program to finish by July?"* was obvious: George Baber had been reassured by Chris Lowe.

24 May 2004: delays causing further tensions at BAE Systems' Design Review meetings

10A.137 An internal BAE Systems Design Review meeting took place a couple of days later on 24 May 2004. The minutes show just how far behind BAE Systems was in the project. Some 104 hazards were *"on the street"* but only eight had been returned, *i.e.* less than 10%. This was after nearly four months, with only two months remaining. Witness K [BAE Systems] and Mech Systems had completed only four of the 20 functional hazards and none of the 33 zonal hazards. A week had been lost in Mech Systems due to other projects. Witness G [BAE Systems] and Structures had completed four out of 12 mitigations. There had still not been any input from Electrical Systems in relation to its 34 hazards because of resource problems. It was decided that Eric Prince would arrange electrical cover from Woodford and that Mech Systems would be given further resources. The archives were described as containing *"holes in the mitigation audit"*.

10A.138 Witness K [BAE Systems]'s notes of the meeting show the considerable tensions present at this time. Chris Lowe insisted, in uncompromising terms, that the project had to be finished on time and took Mech Systems to task for not getting on with the job. The notes record Chris Lowe saying "[Group Captain Baber] *is ordering the sandwiches for the* [completion] *meeting already",* the project was *"high profile"* and *"cannot afford to fail".* He said Witness K [BAE Systems] *"cannot cope"* and *"needed more resources".* He told Witness K [BAE Systems] that he needed *"to get a move on"* and he should send fewer e-mails and correspondence. Chris Lowe denied in interview that he had said some of these things; but I am satisfied that the contemporaneous manuscript note is an accurate record of what was said at the meeting. Witness K [BAE Systems]'s considerable anger at being carpeted in this way by Chris Lowe is apparent from a colourful disparaging acronym he wrote in his notes. As Witness K [BAE Systems] admitted in interview, he was *"not happy"* at his treatment at the hands of Chris Lowe. This was a considerable understatement. There was clearly a major clash of personalities between him and Chris Lowe. Witness K [BAE Systems] saw himself (with some justification) as going about things in a careful and meticulous way. Chris Lowe, on the other hand, was senior to him and the dominant character in the BAE Systems team, and did not take kindly to what he saw as Witness K [BAE Systems]'s obstructive and finicky approach to the task. But rather than discussing a way forward, in particular on the question of agreeing a model zonal Pro-Forma, Chris Lowe was inclined to *"throw his toys out of the cot"* as one former BAE Systems' employee put it. There was a lack of management grip at the time able to sort out this *impasse*.

25 May 2004: man-hours spend over budget

10A.139 On 25 May 2004, Witness K [BAE Systems] sent Eric Prince a breakdown of his hours spent. These totalled 226 hours to date. He calculated that it would take another 418 hours to complete the remaining 19 Functional Pro-Formas (at an average of 22 hours each). This would use up most of the 650 hours budgeted for Mech Systems (226 + 418 = 644 hours). Accordingly, the vast majority of the time taken to complete the (33) Zonal Pro-Formas would be outside the budget.

June 2004: slow progress on zonals

10A.140 The slow progress on zonal hazards continued throughout June 2004. At a TTRO Engineering Integration Meeting on 10 June 2004, Phase 2 of the NSC was reported as being *"at risk"* and Eric Prince and Richard Oldfield were tasked to increase resources in order to meet the milestones. At some stage, the agreed completion date was pushed back from the end of July to the end of August 2004.

10A.141 One problem was that the methodology to be used for the mitigation of zonal hazards had still not been worked out by early June. It was, once again, Witness K [BAE Systems] who took the main initiative in formulating a procedure. He started work on devising a Zonal Pro-Forma on 8 June 2004. He produced the first Mech Systems Zonal Pro-Forma on 17 June 2004 for Zone 111 (Hazard 44). On 21 June 2004, he circulated templates for Functional and Zonal Pro-Formas and procedures for issuing Pro-Formas. On 22 June 2004, Eric Prince approved and signed the first Mech Systems Zonal Pro-Forma produced by Witness K [BAE Systems] for Hazard 44. Even by 7 July 2004, however, Witness K [BAE Systems] was still inquiring whether Airworthiness accepted his Zonal Pro-Forma.

Certification statement completed

10A.142 Meanwhile, the Type Certification Statement Report which formed part of the NSC documentation was drawn up and signed in June 2004. It confirmed that *"all appropriate standards have been met".*[67] This was a straightforward document.

17 June 2004: Review meeting

10A.143 On 17 June 2004, Frank Walsh and Martyn Mahy of QinetiQ (who was referred to as an *"evaluating officer"*) visited Chadderton. Martyn Mahy had called for the meeting to enable him *"to look at the Baseline Safety Case as it develops further*". The meeting was referred to by BAE Systems as a 'progress review meeting'. Richard Oldfield's notes of the meeting record that Frank Walsh and Martyn Mahy were informed at the meeting that 33 out of 99 hazards were *"Managed"* and the *"slower than planned progress"* was being addressed. In the course of the meeting Martyn Mahy was given access to, and examined, examples of the Zonal Hazard Analysis, the Pro-Formas, and the CASSANDRA database. However, Martyn Mahy did not feel that such limited access was sufficient and said that he *"could not assess the content of these reports in detail in the time given*". Consequently, he asked to take away some of the reports, but his request was refused by Frank Walsh. When asked if the reports could be sent to him, Frank Walsh replied "*I will think about it*". Nonetheless, he and Frank Walsh accepted that BAE Systems had completed sufficient work to justify the first 'milestone' payment. This is, perhaps, a little surprising given that Martyn Mahy was uncomfortable at the limited access he had to the basic information.

Successful completion of NSC regarded by BAE Systems as a "Pools win"

10A.144 Chris Lowe reported the *"good ne*ws" that payment would be forthcoming in an e-mail to the Commercial Department and Witness A [BAE Systems] later on the same day. He said there had been much "*fruitful discussion*" on BAE Systems methodology which had led to a *"good impression all round"* from Wyton and QinetiQ. He also said that George Baber "*looked forward*" to final sign-off, probably late August/early September, which would be recognised in a *"blaze of publicity"* which he had heard would include trade journals such as Janes Defence Weekly and Air Force magazines. Clearly, Chris Lowe was excited at the prospect of publicity for the project. Witness Q [BAE Systems]'s contemporaneous notes of the meeting show that the official handover of the NSC to George Baber was even referred to in terms of being a *"Pools Win".* This reflected the fact that BAE Systems hoped the publicity it would receive for handing over the NSC would make its name as a leader in Safety Cases and open up a great deal of lucrative work in the field. The Commercial Department congratulated Chris Lowe and his team on their good work. Witness Q [BAE Systems]'s attempt to explain away her note on the basis that *"Pools Win"* was a "*place*" in the UK where the handover would take place was, frankly, unedifying. As was Richard Oldfield's attempt to suggest that it

[67] BAE Report MBU-DEF-C-NIM-SC0674, Nimrod MR Mk2 and R Mk1 Safety Case Baseline Report Phase 2 Certification Statement.

referred to some sort of 'handover' ceremony. It was clearly a candid reference as to how BAE Systems viewed the prospect of being able to trumpet the first proper, large aircraft, safety case: it would lead to further work (and cash) rolling in.

18 May 2004: first 'milestone' payment authorised

10A.145 On the next day, 18 June 2004, Frank Walsh formally authorised the milestone payment stating that in some areas BAE Systems had completed *"more of the task than expected as this point"*. This may have been generous given the Fire & Explosion Report had not been completed as required by the original Gantt Chart[68] and, indeed, it had not even been started by 7 July 2004. Chris Lowe e-mailed his team inviting them for celebratory drinks. He pointed out that the project was *"extremely challenging"* but *"very important"* to the Nimrod IPT and one in which George Baber had *"a very keen interest"*.

QinetiQ "quite satisfied" with work so far done

10A.146 Martyn Mahy's impressions of the meeting were recorded in an e-mail dated 24 June 2004 to Frank Walsh and others (which were also repeated to the QinetiQ Task Review Meeting on 16 July 2004):

> *"I visited BAE Chadderton on 17th June to review the <u>nearly completed</u> BSC for Nimrod R1 and MR2 aircraft. Chris Lowe gave me a presentation of the work performed so far, which included a look at some reports, e.g. ZHA and HazMat reports and an examination of the CASSANDRA database. I was quite satisfied with the work done so far and the approach taken. The CASSANDRA database correctly identifies accidents, hazards, controls, hazard probabilities & accident severity. It contains many live hyperlinks to BAE documents, including photographs of the Zones analysed in the ZHA. Due to the plethora of hyperlinks to documents on the BAE Chadderton computer network, the CASSANDRA database will not be protable [sic] and will have to remain on the Chadderton site.*
>
> *<u>Providing all the risk mitigation evidence is included in the final safety case report, I don't foresee any difficulties supporting the DPA in the sign-off of the baseline safety case.</u>"* (emphasis added)

10A.147 Martyn Mahy suggested in evidence to the Review that what he meant by his latter requirement that *"all mitigation evidence is included in the final safety case report"* was merely that there had to be links to the supporting evidence in CASSANDRA and any deficiencies highlighted in the NSC Report itself. I do not accept this. In my view, he meant what he said at the time, namely, that all relevant mitigating evidence had to be included in the final NSC Report and, therefore, available for examination and checking when it came to be reviewed. He had been shown examples of Pro-Formas during this meeting and was indicating that he expected to see the full set included in the final Safety Case Report.

QinetiQ confirm "don't foresee any difficulties" in supporting eventual sign-off

10A.148 Subsequently, at a QinetiQ TRM on 16 July 2004, Martyn Mahy's impressions of the meeting of 17 June 2004 as expressed at the end of his e-mail of 24 June 2004 were formally relayed to the Nimrod IPT. The annex to the minutes records:

> *"QinetiQ satisfied with the work done so far and the approach taken. <u>Providing all the risk mitigation evidence is included in the final safety case report, QQ does foresee any difficulties in supporting the DPA in the sign-off of the baseline safety case</u>."* (emphasis added).

[68] In my view, the reference in the Gantt Chart to *"complete fire/explosion <u>risk analysis</u>/survey"* (emphasis added) by end February 2004 (first milestone) is a reference to the completion of a Fire & Explosion report.

10A.149 Unfortunately, neither QinetiQ nor the Nimrod IPT checked to see whether all the risk mitigation evidence was included in the final safety case reports delivered by BAE Systems. In fact, BAE Systems included none.

Early July 2005: Mech Systems only 20% completed

10A.150 On 5 July 2004, Witness K [BAE Systems] reported to Eric Prince that six out of 20 Functional Pro-Formas and three out of 33 Zonal Pro-Formas had been completed. He estimated that Mech Systems' task was only about 20% complete and that a further nine weeks of manpower would be required to complete the remaining 14 Functional Pro-Formas and a further 17 weeks of manpower would be required to complete the remaining 30 Zonal Pro-Formas. In an attempt to address the resource problem, Eric Prince arranged for a further BAE Systems engineer, Witness R [BAE Systems], to be brought in from Woodford to help Witness K [BAE Systems] with some of the load in Mech Systems. Witness R [BAE Systems] worked on the Mech Systems Pro-Formas. It was Witness R [BAE Systems] who was to complete the Mech Systems Pro-Forma for Hazard H73.

10A.151 On 7 July 2004, a Safety Case Review Meeting took place. Witness K [BAE Systems] gave his status report on behalf of Mech Systems. It was reported that, in total, only 41 out of 104 hazards had been returned and 63 still remained to be done. The 'best' case scenario for completion was the second week of August using 600 hours and the 'worst' case scenario was the end of August using 900 hours. A major problem was summer holidays.

10A.152 On 8 July 2004, a TTRO Engineering Integration Meeting took place. Witness B [BAE Systems] was not present so the meeting was chaired by Richard Oldfield. The NSC does not appear to have featured significantly at this meeting save for a mention that *"Resource reviewed and new estimate to completion issued."*

8 July 2004: MRA4 Generic Data obtained to sentence hazards

10A.153 At an internal BAE Systems NSC meeting on 8 July 2004, Witness R [BAE Systems] inquired whether there were *"standard values"* which could be used to sentence hazards. Witness S [BAE Systems] of the Airworthiness Department and Eric Prince said there were and agreed to try to find them. Later the same day, Witness S [BAE Systems] circulated an e-mail attaching MRA4 generic probability data which he said had been extracted from the Nimrod MRA4 System Safety Working Practices (Annex K) AWN/NIM/897 Issue 7 (Re 7 Ver 2). He explained that the significance of this data was that *"the Customer has extracted the figures"*. The e-mail was copied to Chris Lowe but neither he, nor anyone else, raised any objection to the use of such MRA4 data (notwithstanding his earlier rejection of the use of any MRA4 data).

10A.154 The MRA4 generic data (used to make probability assessments in the MRA4 project) gave a standard failure probability rating for a number of common failure types. A failure of a *"fuel pipe and associated coupling"* was ascribed a failure probability of 1E-6, viz:

Failure Type	**Failure Probability**
…	
Hydraulic pipe and associated coupling	1E-6
Fuel pipe and associated coupling	1 E-6
ECS pipe seal	1.5E-7

10A.155 The use of MRA4 generic data to sentence MR2 hazards was inappropriate for the reasons given by Chris Lowe when the idea was first raised at the Inaugural PSWG Meeting on 18 March 2002, namely because the two aircraft were *"significantly different in roles and systems"*. Furthermore, the generic probability given for a coupling failure was absurdly low: 1E-6 or 10^{-6} = one-in-million flying hours which equated to one fuel coupling failure in approximately 66 Nimrod years. Any Nimrod line engineer would have said this was absurd, if asked. Failures of fuel couplings were not a rare occurrence.

July 2004: Progress continued to be slow

10A.156 Progress in dealing with zonal hazards in Mech Systems continued to be slow. It was hampered at times by confusion over which pictures related to which (subsumed) hazards. When Witness K [BAE Systems] raised this with the Airworthiness Department, he was told: *"Ask the question and we will try and help you, otherwise do as we do and GUESS."* Witness K [BAE Systems]'s habit of sending e-mails raising repeated queries about the photographs and other issues which concerned him caused irritation amongst some of his colleagues. He explained, presciently, *"I think formal communication provides a good historical record for future review. If it's not written down – it never happened."*

10A.157 On 12 July 2004, there was a meeting of the Design Authority Safety Working Group (DASWG), which met before each PSWG. This forum, as Witness C [BAE Systems] reminded those present, had *"primary responsibility for providing a corporate overview of all matters pertaining to the continued safety of our products".* Richard Oldfield reported that Phase 2 of the NSC was due to be completed on 31 August 2004 and was *"on schedule for completion on time".* This was overly optimistic.

10A.158 On 21 July 2004, Witness K [BAE Systems] reported to Eric Prince, prior to going on two weeks holiday, that the Mech Systems had done six of the 19 Functional Pro-Formas and only three of the 33 Zonal Pro-Formas. He estimated the task was only about 40% complete. He also said that they had still did not have a co-ordinated joint approach with Electrical Systems in relation to hazards which required input from both Mech Systems and Electrical Systems.

10A.159 By 22 July 2004, a total of 38 hazards had been completed. Witness C [BAE Systems] returned from holiday on 23 July 2004 to be informed by Witness P [BAE Systems] in an e-mail that: only three hazards had been mitigated since he had been away, the end date had *"slipped to end August"*; Witness K [BAE Systems] was away on holiday for the next two weeks; Witness H [BAE Systems] had been away at RAF Waddington for the past three weeks and was not due back until the end of the following week; and there had been no further inputs received from Electrical or Mech Systems. He ended ironically, *"So nothing has changed really…".*

10A.160 On 22 July 2004, Richard Oldfield and Chris Lowe discussed the planned 'customer acceptance' meeting with Frank Walsh and fixed two days commencing 30 August 2004. It was probably unwise for Richard Oldfield and Chris Lowe to have fixed the acceptance conference for the end of August since the project had fallen significantly behind and there remained a large amount of work still to be done. The effect of fixing the completion date was to place everyone under considerable time pressure. Chris Lowe said in interview that he was *"optimistic"* in getting matters finished in time; but this optimism was to come at the cost of quality.

August 2004: Mech Systems task only 60%

10A.161 Witness K [BAE Systems] returned from holiday on Monday 9 August 2004. He reported to Eric Prince that Mech Systems had now done 13 of the 19 Functional Pro-Formas and 11 of the 33 Zonal Pro-Formas. He estimated the task was only about 60% complete and said that there was still not a co-ordinated approach with Electrical Systems. On 13 August 2004, Witness T [BAE Systems] reported that he had completed the Electrical Systems Pro-Formas for 14 hazards,[69] and that he was working on those remaining.

Hazardous Materials List and Nimrod In-Service Accident History Report completed.

10A.162 On 16 August 2004, the Hazardous Materials List, which formed part of the NSC documentation, was completed.[70] This was a straightforward list of the substances carried on board the Nimrod which might be considered hazardous. It appears also that, at some stage in August, the Nimrod In-Service Accident History Report was also completed.[71] This was also a straightforward report.

[69] Hazards H44, H46, H47, H48, H50, H51, H52, H53, H54, H55, H56, H57, H58, H59.

[70] BAE Report MBU-DEM-R-NIM-NM-0667 Hazardous Materials List.

[71] BAE Report MBU-DEF-R-NIM-SC-0676 Review of Nimrod In-Service Accident History.

Fire & Explosion Report completed

10A.163 The Fire/Explosion Hazard Assessment (Fire & Explosion Report) was completed by Chris Lowe in August 2004.[72] It had originally been envisaged that Mech Systems would produce the Fire & Explosion Report and that this would be based on a ZHA. There was a logic to this because Mech Systems were best placed to carry out such a task. As at 7 April 2004, it was envisaged that Chris Lowe would provide Eric Prince with a skeleton for the Fire & Explosion Report and Eric Prince would allocate resources from Mech Systems. The value of a Fire & Explosion Report had been questioned but defended by Chris Lowe. By 10 May 2004, it was decided that the Fire & Explosion Report should be done by Witness U [BAE Systems] of Mech Systems using Chris Lowe's framework and MSC thesis.[73] However, the task was eventually passed to the Airworthiness Department because Witness U [BAE Systems] did not have sufficient time and Chris Lowe ultimately drew it up himself. He said that he completed it over a period of six weeks by working on it at home. It is unfortunate that he had not been present at either visit to RAF Kinloss or RAF Waddington and therefore had not examined the aircraft.

10A.164 The Fire & Explosion Report purported to highlight the catastrophic risk of a serious on-board fire. In particular, it stated pertinently:

> *"In the case of a deep-seated on-board fire remaining undetected and unsuppressed during flight, irrespective of the location of the fire on the aircraft, it can very quickly contribute to any combination of major structural failure, loss of fundamental control or total loss of thrust; thus resulting in catastrophic loss of aircraft and occupants.*
>
> *In the case of an on-board fire-related explosion (such as a fuel tank explosion), such an event invariably leads to all three consequences simultaneously. …"*[74]

10A.165 Unfortunately, the Fire & Explosion Report was of very poor quality. It contained numerous errors and omissions and failed to identify and highlight the catastrophic risk of an 'uncontrollable' fire risk in the starboard No. 7 Tank Dry Bay. There was also little, or no, attempt to reconcile the apparently contradictory conclusions of the Fire & Explosion Report and the BLSC Reports. These matters are particularised and analysed in more detail in **Chapter 11**.

16 August 2004: task only 68% complete

10A.166 By 16 August 2004, the position had clearly become critical. Only 50 out of 104 hazard Pro-Formas had been done. There remained 33 to be completed by Mech Systems, 29 by Electrical Systems, seven by Avionics and one by Structures. There were, however, only two weeks to go until the Customer Acceptance Conference (see below). At a review meeting that morning, Chris Lowe said there was to be a *"final push"* and the aim was for *"end of the week completion"*. A further week was going to be required to carry out the necessary input into CASSANDRA and finalise the reports (on the basis of inputting at a rate of half an hour per hazard). Mech Systems was told *"to come up with a plan"* to complete the remaining hazards *"by the end of the week"*. This was not realistic. It was also likely to put undue pressure on the engineering staff involved to cut corners simply to finish the job. Witness K [BAE Systems]'s note of the meeting states that Eric Prince *"played along with this deadline"*. He did not come up with a plan. Eric Prince suggested in interview with the Review that Chris Lowe had not meant that all the hazards should be completed by the end of the week, but merely that he (Eric Prince) was required to come up with a *plan* by the end of the week; and further, that this was *"the usual sort of pressure"* which was encountered with projects. In my view, neither explanation was convincing.

[72] BAE Systems Report MBU-DEF-C-NIM-SC0710: "PDS Task 06-3409 Nimrod MR Mk2 & R Mk 1 Safety Case Baseline Report Phase 2 Fire/Explosion Hazard Assessment", dated August 2004.

[73] Lancaster University Engineering Department, September 2003.

[74] BAE Systems Report MBU-DEF-C-NIM-SC0710: "PDS Task 06-3409 Nimrod MR Mk2 & R Mk 1 Safety Case Baseline Report Phase 2 Fire/Explosion Hazard Assessment", dated August 2004, Page 12.

10A.167 Following the meeting, Witness K [BAE Systems] wrote a personal note to himself which showed his frustration:

> *"[Witness K] Note (Personal)*
>
> *Seemed pointless to contest the end of week completion date as all know % complete is stated as 68% and we've been on the job for over 4 months and at best completing end date by end Aug-mid Sept. Also no metrics to size each of remaining tasks has been done. So no-one around the table had an est. of hours to completion, only hours remaining. No accurate estimate; no rate of completion figure; no calculated end date therefore no chance of an accurate forecasted completion date, obvious end of week crap but one guess I suppose is all that's req'd. CL & RO: Sat end of week is sched finish. I suppose that we're 2/3/4 weeks behind approach will be used in the forth-coming weeks. TTRO planning at its best!!!!!"*

10A.168 Witness K [BAE Systems] shared his concerns with his line manager, Eric Prince.

Electrical Systems merely add 'addendum' to completed Mech Systems Pro-Formas

10A.169 In order to speed up the Electrical Systems response, on 16 August 2004, a change of approach was adopted. Rather than producing their own separate 'stand alone' Pro-Formas, it was decided that Electrical Systems would simply add an addendum to Mech Systems' Pro-Formas where Electrical Systems' input was required. This was plainly cutting corners. As will be seen, the quality of analysis by Electrical Systems deteriorated markedly as time ran short. On 17 August 2004 alone, Witness T [BAE Systems] sent by e-mail three Electrical Systems 'addenda' to Mech Systems for incorporation. An increasing number of addenda completed by Witness T [BAE Systems] in the latter half of August simply contained the phrase, *"Further analytical techniques are considered necessary in order to categorise the risk…".* The reason for this was quite simply that Witness T [BAE Systems] ran out of time to conduct the necessary analysis, as various witnesses such as Witness C [BAE Systems] confirmed. The effect of this rider was that hazards which had been classified as 'Improbable' or 'Remote' by Mech Systems became 'Unclassified'. This was also unsatisfactory, as I discuss in more detail in **Chapter 11**.

23 August 2004: Mech Systems Pro-forma for Hazard H73 finalised and approved

10A.170 The next two weeks involved a period of frantic activity, particularly in Mech Systems and Electrical Systems, processing Pro-Formas. It fell to Witness R [BAE Systems], who had been seconded to Mech Systems, to draw up the crucial Mech Systems Zonal Hazard Analysis Pro-Forma for zones 514/614 relating to the No. 7 Tank Dry Bays (port and starboard) and the risks associated with the Cross-Feed/SCP duct. This was known as zonal Hazard H73. Witness R [BAE Systems] finalised and signed the Mech Systems Pro-Forma for Hazard H73 on 23 August 2004. Eric Prince added his signature on the same day against the legend *"Contents Approved".*

10A.171 Zonal Hazard H73 represented the rationalisation and combining of two zonal hazards, Hazard H367 and Hazard H498:

2. Hazards Subsumed & Description *(Taken from: M:\MBU\Design\Airworthiness\Flight Safety\NIMROD\hazard log\MAJOR HAZARDS (SCOTT)\zonal hazard.xls)*

	Hazard No. NM/H**	Hazard Title	Description	A/C type	Cause *(hazard- Section 3)*
A	367 (photo Dcp0221)	Fire/Explosion - Fuel or hydraulic leak onto Hot Engine Bleed Pipe	Potential fuel or hydraulic leaks from fuel pipe joint, Flap hydraulic pipelines or No 7 Tank main feed fuel pipe immediately above the HP, High Temp engine bleed take-off port or associated ducting potentially causing an uncontrolled fire or explosion.	Both	Fluid Leak (C, F)
B	498 (photo Dcp0312)	Multiple systems in very close proximity	In an area closely packed with flight control cables and pulleys, hydraulic services, unprotected electrical cables and hot air ducting there exists a potential for hot air, fuel or hydraulic leaks and possible fire.	Both	Fuel Leak (All)

10A.172 The Hazard H73 Pro-Forma identified the risk of fuel and hydraulic leaks onto hot ECS ducts as 'key potential hazards' at a single point failure level:

3. Key Potential Hazards simplified
(List the potential hazards identified & the simply described potential causes)

	Potential Hazard *(taken, or assumed, from hazard description)*	Potential Cause *(taken from subsumed hazard Description)*	Failure Level
A	Fire/Explosion	Fuel Leak onto electrical circuits/cables	Double
B	Fluid Contamination	Fuel Leak onto electrical circuits/cables	Single
C	Fire/Explosion	Fuel Leak onto Hot ECS Duct	Single
D	Fire/Explosion	Fuel Leak onto Control Cables	Single
E	Fluid Contamination	Fuel Leak onto Control Cables	Single
F	Fire/Explosion	Hydraulic Leak onto Hot ECS Duct	Single
G	Fluid Contamination	Hydraulic Leak onto electrical circuits/cables	Single

10A.173 It specifically recited the requirement of AvP 970 regarding fire zones:

U		AvP970 Chapter 715 Fire Precautions	***Fire Zones:*** *Any region in which a single failure of an installation or any part of it could result in a fire or break out of existing controlled fire (e.g., combustion chamber) into the aeroplane shall be regarded as a fire zone.*
		Leaflet 715/2	*There is, however, the risk that a severe danger of fire may be present in certain other regions due for example to the necessity for the location of pipes carrying inflammable fluids near to a non-flameproof motor with the result that only a single failure could lead to a catastrophic fire.*

10A.174 Regrettably, notwithstanding this, it went on to embody a number of fundamental, obvious and causative errors:

10A.174.1 Section 4 of the Pro-Forma referred to relevant parts of the BCARs and AvP 970 but the serious breaches of those regulations inherent in the design of the No. 7 Tank Dry Bay and the risk posed by an exposed ignition source were not identified, namely both the No. 7 Tank Dry Bays should have been designated *"fire zones"*.

10A.174.2 Section 5 of the Pro-Forma stated that *"the Bleed ducting is insulated and so surface temperatures will be below bleed air temperatures"* but failed to note that: (a) there are gaps between the insulation; (b) some parts of the bleed ducting have no insulation; and (c) the insulation is in poor condition in some areas. This was notwithstanding the fact that the risk of fuel leaking on to the hot ECS duct was given as a *"single"* failure in Section 3. With an ignition source present, a *"single"* failure from a fuel leak could cause a fire.

10A.174.3 Section 6 of the Pro-Forma incorrectly stated that the Cross-Feed duct *"is only pressurised when the cross-feed pipe is open, i.e. during engine start"*, and failed to take into account the lengthy periods the cross-feed duct can be pressurised (at a working temperature of up to 420°C) when feeding the SCP.

10A.174.4 Section 6 of the Pro-Forma stated that *"From in-service data the potential for fuel pipe leakage is given as Improbable",* i.e. 10^{-6}. Any line engineer would have known this was unrealistic.

10A.174.5 The Pro-Forma failed to pick up on the zonal risk presented by the location and proximity of the No. 1 fuel tank blow-off valve immediately forward of the starboard No. 7 Tank Dry Bay, such that fuel expelled from the blow-off valve could track back onto the SCP pipe elbow and ignite.

10A.175 I deal with these errors in more detail in **Chapter 11**. I conclude that the Pro-Forma for Hazard H73 was a sloppy and muddled piece of work, carried out under time pressure without sufficient guidance or management oversight. It should be emphasised that some of the mistakes in the Pro-Forma were very basic indeed. For instance, the mistake in relation to the Cross-Feed duct being pressurised *"only…during engine start"* displayed a startling lack of knowledge by BAE Systems about its own aircraft. Anybody who knew anything about Nimrods would know the cross-feed duct was *bound* to be used in flight (a) to re-start engines which had been routinely shut down and (b) to run the SCP.

Last minute rush: task not completed by 31 August

10A.176 The process of completing Pro-Formas continued right up to the Customer Acceptance Conference on 31 August 2004. On 28 August 2004, Witness K [BAE Systems] reported to Eric Prince that Mech Systems had completed 49 out of 58 Pro-Formas, Electrical Systems had completed 18 out of 35 Pro-Formas and Avionics had completed 10 out of 12. On the afternoon of 30 August 2004, the day before the Customer Acceptance Conference, Witness K [BAE Systems] reported to Eric Prince that Mech Systems had completed 52 of the Pro-Formas with 6 *"on-going"*, and Electrical Systems had completed 27 of the Pro-Formas with several for signature and 4 *"on-going"*. In fact, several Pro-Formas were not completed by Electrics until *after* the Customer Acceptance Conference: Hazards H67, H78, and H79 were completed by Witness T [BAE Systems] on or after 2 September 2004; and Hazard H63 was not completed until 24 September, *i.e.* somewhat curiously *after* the final hard copy of the report had already been circulated to Frank Walsh.

FSD and Serous Fault Signals: word search

10A.177 A further troubling feature is that, as late as 24 August 2004, the results of a word search on the VC10 & Nimrod Flight Safety Database in relation to 'fire', 'smoke', 'fumes', 'burning' and 'smell' was circulated. It is not clear, however, as to what use, if any, this research was put.

16 August: BAE Systems' internal "Independent Review"

10A.178 At the 16 August 2004 meeting, it had been decided that Chris Lowe should request Witness V [BAE Systems] or Witness A [BAE Systems] to carry out an 'independent' review of the NSC work prior to the Customer Acceptance Conference. Witness A [BAE Systems] was ultimately contacted on 24 August 2004 by Chris Lowe, who e-mailed him with copies of what were referred to as *"the major reports in support of the safety case you may wish to peruse".* But only copies of three out of the six 'deliverable' reports were in fact attached, namely, the Fire & Explosion Report, Review of Accident History, and Certification Statement, the latter two of which comprised essentially factual summaries as opposed to analytical analysis. Witness A [BAE Systems] was not shown the BLSC Reports for the MR2 and R1. Nor was he asked to conduct a proper *"independent review"* of the Nimrod BLSC. Rather, he explained in evidence that he was only asked to *"cast an eye"* over the three reports. It appears that an internal BAE Systems meeting may have taken place on Wednesday 26 August 2004, attended by Witness A [BAE Systems] and Chris Lowe, at which only these three reports were reviewed.

10A.179 The minutes of the Customer Acceptance Conference suggest that a rather gilded picture was conveyed to those present at the Conference of the internal *"independent review"* which had been conducted :

> *"Mr Lowe stated that an independent review of the Nimrod baseline safety case had recently been carried out by BAE Systems airworthiness function. This review ratified the approach taken by the design authority and the production of this baseline safety case, and confirmed the robustness of the safety case argument for a mature platform such as the Nimrod." (Minutes of Customer Acceptance Conference, paragraph10.3)* (emphasis added)

10A.180 Witness A [BAE Systems] agreed in interview that the use of the term 'independent review' was *"putting it quite high"* for what was merely *"casting an eye"* over a few reports. He was unable to recollect a specific meeting that would justify the use of that term. He said that if he had conducted such a formal or semi-formal *"independent review"*, he would have documented it. He agreed with Counsel to the Review that he had never been in a position to confirm the *"robustness"* of the NSC argument.

'Rehearsal' Meeting

10A.181 BAE Systems management also decided to hold an internal 'rehearsal' meeting before the Customer Acceptance Conference, in order to run through what questions might be raised by the Nimrod IPT at the Customer Acceptance Conference. Evidence as to what took place during this 'rehearsal' meeting was scant.

Customer Acceptance Conference – 31 August and 1 September 2004

10A.182 The 'Customer Acceptance Conference' itself took place at BAE Systems' offices at Chadderton on 31 August and 1 September 2004. It was a crucial meeting. Its aim was to obtain the IPT's agreement that BAE Systems had completed its Phase 2 task.

Who was present at the meeting?

10A.183 The meeting was attended by five people from the Nimrod IPT, Michael Eagles, Frank Walsh, Witness W [MOD] (NIM(ES)AV(Av)), Witness X [MOD] and Witness Y [MOD] (RPO at Chadderton). Witness X [MOD] had been asked to attend in place of Witness Z [MOD] who was unavailable. Michael Eagles had to leave at the end of the first day to attend another meeting with BAE Systems at RAF Woodford, leaving Frank Walsh in charge. There were 12 people present from BAE Systems, including: Richard Oldfield, Chris Lowe, Witness AA [BAE Systems], Eric Prince, Witness C [BAE Systems], and Witness K [BAE Systems].

10A.184 QinetiQ was represented by Witness O [QinetiQ] who had stepped in at the last moment for Martyn Mahy. On or about Friday 27 August 2004, Martyn Mahy had contacted Witness O [QinetiQ] and asked him if he could attend the two day Nimrod BLSC meeting at Chadderton on 31 August and 1 September 2004 in his stead because he was suddenly unable to attend for unavoidable family reasons. Witness O [QinetiQ] agreed to stand in for Martyn Mahy. In a subsequent telephone call, Witness O [QinetiQ] received a short briefing from Martyn Mahy who told him that 66% of the risk mitigation was outstanding and requested him specifically to ask at the meeting what proportion of the mitigation was complete. Witness O [QinetiQ] received no other briefing, nor any preparatory documentation before attending the meeting the following week. Martyn Mahy said in interview with the Review that it would have been better if Witness N [QinetiQ], the Technical Manager, had gone to the meeting, but he was otherwise engaged. Witness N [QinetiQ] said he was aware that the meeting was for *"the contractual sign off of the Safety Case-work so far done by BAE Systems"*, but that he was content for Witness O [QientiQ] to attend and assumed he would be briefed by Martyn Mahy.

10A.185 Given the importance of the meeting, it was unfortunate that the three relevant senior figures from the three organisations, Witness B [BAE Systems] of BAE Systems, Martyn Mahy of QinetiQ and Michael Eagles of the Nimrod IPT were not present or (in the latter case) only present for part of the meeting.

What had been planned for the meeting?

10A.186 It is necessary to examine what was originally planned for the 'Customer Acceptance Conference' and how this changed at the last minute. It was envisaged from the outset that BAE Systems would hold a detailed two-day conference with the IPT at the end of the Phase 2 project *"to go through all the hazards with IPT".* The original Phase 2 Proposal provided that a final *"Customer Review"* meeting would be held following the completion of Phase 2 during which BAE Systems would formally present its findings to the Nimrod IPT *"for acceptance".* Subsequently, on 29 April 2004, it was expressly agreed with Frank Walsh that there would be a two-day meeting to *"review"* the hazards with the IPT, including two Section Heads, in order to classify them further, e.g. as 'Managed'. This final meeting was referred to in the minutes of an internal BAE Systems meeting on 24 May 2004 as an *"'Ending Conference' where each Hazard will be reviewed".* It appears, therefore, to have been axiomatic at this stage that the final meeting would comprise a detailed review of every hazard in the Acceptance Conference with the client.

10A.187 On 22 July 2004, Richard Oldfield and Chris Lowe had discussed the planned 'customer acceptance' meeting with Frank Walsh. It is noteworthy that the draft agenda envisaged the entire first day being spent on *"Functions & Zonal Hazard Log".* It is perhaps indicative of Michael Eagles' peripheral role that Frank Walsh's list of probable IPT attendees at the '*Customer Acceptance Conference*' did not initially feature Michael Eagles, although the later Agenda did.

10A.188 On 27 July 2004, Chris Lowe circulated a 'Meeting Call Notice' to the 10 BAE Systems' staff involved in the NSC Phase 2 informing them that a two day *"Final Hazard and Documentation Review Conference"* was to take place on Tuesday 31 August and Wednesday 1 September 2004 with the Nimrod IPT. He explained that the purpose of the conference was *"to review in detail"* the hazard log contents, together with the other reports and final baseline reports *"in the presence of Nimrod IPT representatives".* He emphasised that BAE Systems' aim or strategy was to get the task signed off by the customer:

> *"The <u>exit criteria</u> from the conference will be BAE SYSTEMS engineering disciplines and <u>customer buy-in and sign-off</u> of both baseline reports, the specific reports tasked, and completeness of the hazard log, together with accepting the validity of the recommendations (irrespective of whether the MOD wish to take up those recommendations)..."* (emphasis added)

10A.189 The proposed agenda included on the first day a *"review"* of the final BLSC Reports and on the second day a *"full review"* of the Hazard Log contents. A Provisional Agenda was subsequently circulated on 19 August 2004 which simply included a *"Review of Hazards Log and Mitigation of Identified Hazards"* on the first afternoon; to which was then added *"...and Summary of Recommendations".*

10A.190 Chris Lowe volunteered in interview that, although by mid-August there was a possibility of over-run and the task not being completed, *"….it perhaps wasn't inappropriate to run the* [customer acceptance] *conference because it would have been difficult to shift it".* This was an incautious, but telling, remark. The truth is that, by 16 August 2004, over-running was certain since only 68% of the work was complete;[75] but it would have been very difficult to delay the Customer Acceptance Conference without seriously disappointing the customer. What he and BAE Systems should have done, however, was to come clean with the Nimrod IPT at this stage and seek further time in which to complete the project properly. Regrettably, they did not do so. Instead, Chris Lowe insisted the Mech Systems and other Departments made a *"final push".*[76] It is not surprising that, as a result, work on the remaining hazards (including Hazard H73) was rushed, and many hazards were left *"Open"* and *"Unclassified"* using the expedient that Electrical Systems needed to carry out *"further analytical techniques".* Regrettably, BAE Systems felt unable or unwilling to 'come clean' at the Customer Acceptance Conference as to just how much work had in fact been completed (see further below).

[75] As recorded in Witness K [BAE Systems]'s notes.

[76] Ibid.

Switch in strategy for meeting

10A.191 At some stage shortly before the Customer Acceptance Conference, there was an important and subtle switch in strategy by BAE Systems as regards the format of the meeting: a decision was made no longer to include a detailed review of the baseline reports or the hazard log contents, but only to present the IPT with a summary. In my view, BAE Systems' motive for this switch in presentation is not difficult to fathom: BAE Systems was naturally concerned that the IPT would refuse to sign off the Phase 2 contract if it became alert to the fact that: (a) so much work remained to be done (as explained further below, BAE Systems were shaping to leave over 40% of the hazards *"Open"*, some 30% *"Unclassified"*, and a large proportion with vague recommendations of 'further work' being required); and (b) the BLSC Reports themselves had not even been finalised.

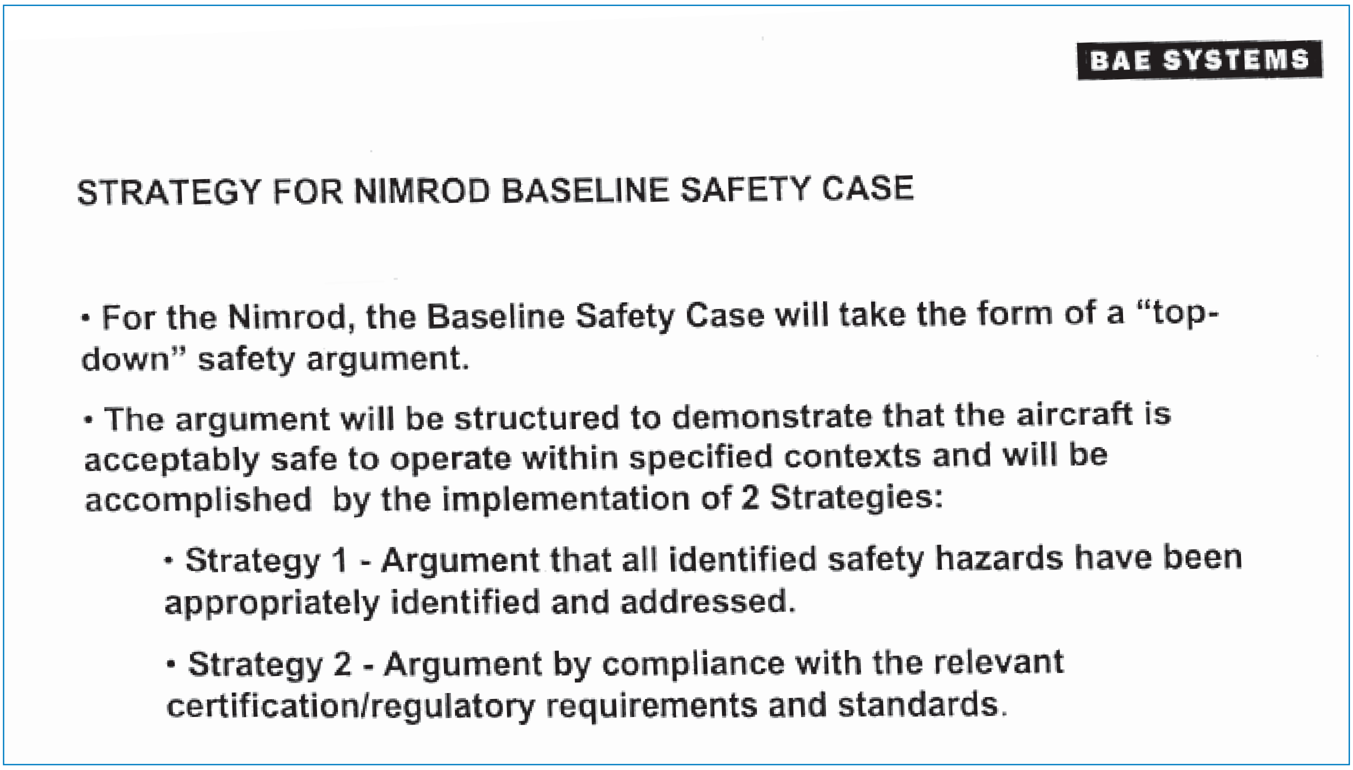
What happened at the meeting?

10A.192 The minutes of the meeting, prepared by the Secretary to the meeting, Richard Oldfield, and sent to the IPT some three weeks later, on or about 21 September 2004, are only a partial record of what took place. Once again, it is Witness K [BAE Systems]'s contemporaneous manuscript notes which give the full picture.

10A.193 The meeting was opened by Richard Oldfield. He welcomed the Nimrod IPT representatives on behalf of BAE Systems and explained that the purpose of the meeting was for BAE Systems to present the results of the work carried out in *"completing"* Phase 2 of the NSC and to demonstrate to the satisfaction of the Nimrod IPT 'customer' that *"the contractual requirements of PDS Task 06-3409"* had been satisfied. Chris Lowe said in evidence that *"It was as much a commercial meeting as a technical meeting"*. The minutes only record three presentations being given by BAE Systems to the IPT representatives on the first day.

Richard Oldfield's presentation

10A.194 The first was a PowerPoint presentation by Richard Oldfield entitled "NIMROD BASELINE SAFETY CASE – AIMS, REQUIREMENTS AND STATUS". It was clearly aimed at giving the impression that the task had, indeed, been completed. The key slides are reproduced below:



BAE SYSTEMS

Programme Status 31st August 2004

- Review and rationalisation of hazards produced in Phase 1 (WBS 1.1.2 &1.2.1)
  - Complete - 1300 hazards reduced to 105.

- Provision of mitigation (where extant) of each rationalised hazard identified from Phase 1 (WBS 1.3).
  - Complete - Extant mitigating evidence sourced for 105 hazards and entered into Cassandra.

- Complete Fire/Explosion Risk Analysis survey for Nimrod (WBS 1.4).
  - Complete - Report Ref: MBU-DEF-C-NIM-SC-0710

BAE SYSTEMS

Programme Status 31st August 2004 (cont.d)

- Identification of all safety critical equipment containing embedded software (WBS 1.8)
  - Complete - Statement included in final Baseline Safety Case Reports (WBS 1.10)

- Review of service accident history of Nimrod type (WBS 1.9)
  - Complete - Report Ref: MBU-DEF-R-NIM-SC-0676

- Produce final Baseline Safety Case Report for both marks (WBS 1.10)
  - Complete - Report Refs: MBU-DEF-C-NIM-SC-0713 (MR2)
  - Complete - Report Ref: MBU-DEF-C-NIM-SC-0714 (R1)

10A.195 Richard Oldfield's PowerPoint presentation thus gave the clear indication that the task had been 'completed' by BAE Systems. This, however, was manifestly not the case. As Witness A [BAE Systems] readily accepted in interview, with a large percentage of hazards left *"Unclassified"* by BAE Systems, the top-level goal could not be said to have been achieved and the impression given by Richard Oldfield's presentation was wrong. Richard Oldfield's presentation was, however, received without demur or comment by the unsuspecting Nimrod IPT and QinetiQ representatives present. As the minutes record: *"There were no comments or actions arising from this presentation"*. Richard Oldfield was unable to give a satisfactory explanation as to why his presentation had said that the baseline reports were *"complete"* when, in fact, they were not complete, either in substance or even form. He was also unable to give a satisfactory explanation of what he knew at the time. He initially suggested in interview with the Review that it was his *"understanding"* at the time that the task was complete; but he was unable to say when he became aware that 40% of the hazards had been left open. The fact is that he was intimately involved managing all stages of the project and must have been fully aware of the true position. He admitted in interview that *"we were obviously under pressure to actually meet the timescales."*

Richard Oldfield's Notes

10A.196 Subsequent to Richard Oldfield's first interview with the Review, some manuscript notes came to light which he had made shortly before the Customer Acceptance Conference on his copy of the draft of Annex B which formed part of Witness C [BAE Systems]'s PowerPoint presentation (see below) which showed he had calculated the precise numbers and percentages of hazards which remained *"Unclassified"*, namely 12 out of 66 functional hazards (18%) and 22 out of 39 zonal hazards (56%), respectively. He therefore had a perfect grasp of the figures at the time and knew that a large proportion of the NSC work remained to be done.

Chris Lowe's presentation

10A.197 The second presentation was a short PowerPoint presentation by Chris Lowe entitled "THE SAFETY CASE. WHAT IS IT?". This was similar to previous presentations on the topic and explained the nature of a safety case and the advantages of the 'top down' approach to safety cases for legacy aircraft.

Witness C [BAE Systems]'s presentation

10A.198 The third presentation was a presentation by Witness C [BAE Systems]. This comprised a presentation on screen to the Nimrod IPT and QinetiQ of the CASSANDRA Hazard log 'architecture' and contents, and a demonstration of how CASSANDRA worked. The demonstration required those at the meeting to crowd round the single CASSANDRA computer terminal in another room. The screen presentation included screen shots of an 'interacting systems hazard' (Hazard H54), together with pdfs of the associated Pro-Formas. In the course of his presentation, Witness C [BAE Systems] also put up on the screen a table showing the 'Post Mitigation Probability' of Hazards H1 to H105. This was a draft of what was to become Annex B to the BLSC Reports. The table comprised four columns as follows:

Hazard Ref	Title	Post Mitigation Probability	Status
H1	Environmental Hazard due to Adverse Weather Climate or Conditions	Improbable	Approved
H2	Environmental Hazard due to Contaminated Runway	Unclassified	Approved
H3	Environmental Hazard due to lightening strike	Improbable	Approved
etc.			

10A.199 It is clear from Witness K [BAE Systems] and Richard Oldfield's notes that the table was shown at the meeting. It is also tolerably clear that most or all of the five pages of the table were put up on the screen including the later pages showing the zonal hazards (Hazard H44 onwards) because the minutes record a request being made by the Nimrod IPT representatives for a description of the zones to be included after each zone in CASSANDRA.[77] It would have been apparent from a careful look at the third and fourth pages of the table

[77] This was done in the final version of Annex B to the BLSC Reports.

that there were a large number of *"Unclassified"* hazards, including Hazard H54. It is not clear, however, how long these pages were posted on the screen for or whether those watching could or would have appreciated or been able to count the number of *"Unclassified"* hazards. Witness K [BAE Systems]'s notes record an explanation being given that *"Unclassified"* meant insufficient evidence to make a probability assessment. *"Approved"* meant that the hazard was formally recognised as a hazard and properly included in the Hazard Log. At some stage, Chris Lowe assisted Witness C [BAE Systems] by posting up on the screen the draft of the 'Recommendation Table' which was to become Annex C to the BLSC Report. Witness K [BAE Systems] said in evidence: *"I think that I would have remembered if we had gone through hazards line-by-line. I would have made a note."*

10A.200 Witness C [BAE Systems] said in interview that he recalled sending out a copy of the 'Post Mitigation Probability' table to Frank Walsh before the Customer Acceptance Conference meeting. His recollection is mistaken. A search of the e-mail records shows no such e-mail was sent. Nor does it appear that hard copies were handed out at the meeting itself, unlike Richard Oldfield and Chris Lowe's PowerPoint presentations which did form hand-outs at the meeting.

Chris Lowe's "review" of the Draft BLSC Report

10A.201 Witness K [BAE Systems]'s notes show that Chris Lowe also gave a further lengthy presentation after his PowerPoint presentation on safety cases on the first morning. Curiously, the formal minutes make no reference to this. His presentation comprised a *"review"* of the draft BLSC Report. It seems probable that he used slides. His review was, however, limited to the text of the *general* parts of the BLSC Report, *i.e.* the text of Chapters 1 to 12. These chapters merely contained general information about the objectives, scope, definition, methodology of the NSC etc. but no detail as to the actual findings. In his presentation, Chris Lowe highlighted certain aspects of the text, including the structure of the safety case argument, and explained how the 'Top Level Goal' was *"demonstrated as being met"*. The text of paragraph 9.2.5 of the BLSC stated in terms:

> *"All identified hazards were assessed for initial (pre-mitigation) risk imposed, and appropriate mitigation of those risks identified by the relevant DA engineering disciplines. Wherever possible, hazards have been shown as having been eliminated by design. Where this was not possible, towards mitigation of those hazards to a level that is considered ...ALARP, the following evidence was primarily considered..."*

10A.202 Then listed were the five categories of evidence set out in the Phase 2 Proposal.[78] The text then went on:

> *"Where this approach was not considered appropriate or complete, the following additional mitigating evidence has, where available and applicable, been presented...".*

10A.203 Then listed were a further nine categories of evidence, including *e.g.* ground, flight and EMC/EMI reports, which (it is presumed) were to be found in the archives. It is far from clear, however, as to how much use was in fact made of this material for mitigation purposes. Paragraph 9.2.6 of the text then explained that each identified hazard had been *"assessed after mitigation"* to determine its *"hazard severity"* and *"qualitative probability"* by reference to the HRI in order to determine the *"Acceptability of Risk towards decision having achieved ALARP"*; and added that where existing mitigation was *"inadequate or unavailable"*, the BLSC Report contained *"appropriate recommendations for further corrective/ mitigation evidence".* Paragraph 9.2.8 contained a comprehensive table listing all 105 functional and zonal hazards. He commented that probabilities had been determined by looking at service records and using *"best engineering judgment".* His presentation stopped at paragraph 12.0.

10A.204 Significantly, his presentation did not cover or touch upon the contents of the Executive Summary, Conclusion, or Appendices (which apparently had not been finalised). It appears that, at no stage did he tell his audience what was likely to be contained in the Executive Summary and Conclusion of the final version of the BLSC Reports. He did not mention that 43 out of 99 hazards were to be left *"Open"* and a significant proportion *"Unclassified"*.

[78] (1) Design configuration and established design best practices; (2) historic service reliability/ experience of system; (3) periodic test/inspection/ maintenance procedures; (4) crew training and flight operational procedures; and (5) maintenance/service personnel training.

10A.205 Although the BLSC Reports had not been finalised by this stage since a number of hazards still remained to be sentenced, its broad conclusions and recommendations were, or must have been, well known to the senior BAE Systems' personnel present. The vast majority of hazards had been assessed by the Specialist Departments and the relevant Pro-Formas already finalised and/or signed off. Accordingly, most of the BAE Systems' personnel present (in particular those in management positions such as Richard Oldfield, Chris Lowe and Eric Prince) were undoubtedly fully aware that a substantial proportion of hazards had been left *"Open"* and/or *"Unclassified"*, and further, to a fair degree of accuracy, the percentage involved, as Richard Oldfield's notes show.

10A.206 In these circumstances, it is highly surprising that at no stage during the meeting, in particular during Richard Oldfield or Chris Lowe's presentations, was the Customer, the Nimrod IPT, or the Customer's independent advisor, QinetiQ, informed as to precisely how many hazards had been *"Closed"*, how many remained *"Open"* or *"Unclassified"* and how much work remained to be done even in broad percentage terms. As Witness B [BAE Systems] accepted in interview, this was *the* key information which any customer would have wanted to be told at a 'Customer Acceptance Conference'. As Witness K [BAE Systems] put it, in simple terms what the customer would want was a '*traffic light*' system, *i.e.* to be told which hazards were closed (green), which required perusal (amber) and which required further work (red). The customer was not given this information.

Why was the Customer not told? Was it inadvertent or deliberate?

10A.207 Why was the Customer not told this crucial information at the meeting? Was it mere oversight, or inadvertence, or worse?

10A.208 After careful consideration of all the oral and written evidence, I have been driven to the regrettable conclusion that it was, in fact, a deliberate and conscious decision by the senior BAE Systems representatives present (namely Chris Lowe, Richard Oldfield and Eric Prince) not to mention or otherwise draw the Customer's attention to the large percentage of hazards which it had left *"Open"* and *"Unclassified"*. The motive was simple: it was embarrassing to reveal the actual figures and it might lead to an unseemly argument with the Nimrod IPT representatives as to whether the task had been properly completed by BAE Systems and whether final payment could be made. All the evidence points inexorably to this conclusion, in particular: the unexplained late switch in format of the meeting to a broad 'high level' overview; the carefully crafted PowerPoint presentations which gave the impression of a 'complete and thorough' job but skated over the detail; the silent witness of Richard Oldfield's manuscript notes as to the starkness of the figures (56% of the Zonal Hazards remained Open); and the fact that the more junior BAE Systems' personnel present felt '*uncomfortable bystanders*' and were keeping '*schtum*' (as one put it) in the hope that the Customer would not ask any awkward questions (see further below).

10A.209 I analyse this regrettable conduct and responsibility for what took place at the Customer Acceptance Conference in further detail in **Chapter 11**.

Review of 'deliverable' reports

10A.210 On the close of the first day and the morning of the second day of the 'Customer Acceptance Conference', there were what the minutes refer to as *"reviews"* of four of the *"deliverables"*, *i.e.* reports, which BAE Systems were contracted to deliver, namely: (i) the Type Certification Statement Report; (ii) the Fire & Explosion Report; (iii) the Hazardous Materials Report; and (iv) the Nimrod In-Service Accident History Report. Each of these Reports had been completed. Copies of the Fire & Explosion Report and the Nimrod Service Accident History Report had previously been sent to the IPT during August 2004. It is also likely that the IPT had previously been sent drafts of the Type Certification Statement Report and the Hazardous Materials Report, although the Review found no direct evidence of this. In any event, the review of the four completed reports at the Customer Acceptance Conference would have reinforced the impression that the overall Task had been completed and that the Nimrod types were acceptably safe to operate within the meaning of BP1201:

10A.209.1 The Type Certification Statement Report stated: *"**In summary, therefore, it may be considered that this statement provides the appropriate evidence in support of the declaration that "all appropriate standards have been met" towards the Safety Case argument that both types would be acceptably safe to operate and maintain within given contexts.**"*

10A.209.2 The Fire & Explosion Report stated: *"In view of the above summary, and on the assumption that the recommendations are reviewed, it may thus be concluded that the design and operational assessment of both types, together with the in-service record of both types, indicate that both types are acceptably safe to operate and maintain within given contexts and in peacetime from a fire/explosion safety hazard point of view.*

***It is thus recommended that the overall fire/explosion risk imposed by both types is considered tolerably low to the extent of being considered to be As Low As Reasonably Practicable (ALARP).**"*

10A.211 The substantive question for the meeting was *"whether the Safety Case aims have been met"*. The minutes record the following decision being made:

> *"9.1 The meeting revisited the requirements for the Phase 2 of the Nimrod Baseline Safety Case as defined within the Proposal issue to the Nimrod IPT (Reference: NIM/HX/P1.3/002 dated 2003) <u>and reached a consensus that the aims and objectives of the project had successfully been achieved by the Company</u>.*
>
> *NIM(ES)AV(Safety) thanked BAE SYSTEMS for the professional manner in which the Nimrod Baseline Safety Case had been completed and stated that PDS Task 06-3409 could be considered closed <u>by the issue of the minutes from this Conference</u>."* (emphasis added)

10A.212 This was, on the face of it, a somewhat surprising *"consensus"* for the IPT and QinetiQ representatives to have been party to. It was also a somewhat odd formulation to have agreed to, namely, that the task could be considered closed *"by the issue of the minutes"*. At this stage, neither the IPT nor QinetiQ had actually *seen* all of the six NSC reports or 'deliverables'. Certainly, the IPT had not seen the all-important BLSC Reports. These were not sent out by BAE Systems in advance of the meeting. They were not handed out at the meeting. Parts of them were merely trailed on PowerPoint. The completed versions of the six reports were not, in fact, delivered by BAE Systems to the IPT until three weeks after the meeting, attached to the minutes.

10A.213 I analyse in **Chapter 11** how and why, in such circumstances, the IPT and QinetiQ representatives present[79] managed to find themselves agreeing at the meeting that *"the aims and objectives of the project had successfully been achieved"* by BAE Systems. The answer lies in a combination of cynicism and lassitude: on the one hand, not being given the full picture by BAE Systems and, on the other hand, not themselves asking any intelligent questions.

'Uncomfortable bystanders'

10A.214 It is clear that not all of the BAE Systems NSC team were happy with the assurances being given to the Customer at the meeting. Indeed, there were a number of 'uncomfortable bystanders' amongst the more junior BAE Systems staff present.

10A.215 Once again, Witness K [BAE Systems] notebook is particularly illuminating. It contains a carefully written (starred) note to himself. He accepted in interview that he had written the note during the meeting to read out in case he was called upon to give an acceptance statement. It was a heavily qualified and defensive speaking note, designed to protect himself and Mech Systems in the event of later criticism. The note read:

> *"* "Acceptance statement if req'd (Witness K[BAE Systems]-mech sys)*
>
> *Given the 'limited detail' and generalised hazard information received, and considering the time allotted to complete this task.*
>
> *I'm satisfied that the mech systems responses are adequate, assurance of this came from the initial approval by Airworthiness of the mech systems Pro-Forma format."*

[79] I deal in **Chapter 11** with an issue as to whether Witness O [QinetiQ] was party to this consensus.

10A.216 Witness K [BAE Systems] was clearly uncomfortable about the quality of the work done on the NSC and the fact that so many hazards had been left *"Open"* and *"Unclassified"*. As it happens, he was not called upon to speak at the meeting and therefore remained silent. He was questioned about this in interview and explained that there were more senior BAE Systems people present who were conducting the meeting:

> *"**MR HADDON-CAVE QC:** Why didn't you tell the customer that 40 per cent of the hazards remained open?*
>
> ***WITNESS K [BAE Systems]:** Mr Haddon-Cave, I don't know. I didn't know. I didn't do an account of how many of the hazards were open. At the customer meeting, why didn't the airworthiness lead, or the project engineering team lead at the meeting, say how many hazards were open? I don't know. It was their meeting and I was there, should anybody ask about the mechanical or the zonal pro formas. And I would be able to answer them if there was any detail in there that they wanted to go to. But with respect to the important people in that room, the higher level people in that room, and their -- basically their meeting with the customer, of which I was in attendance, you know, I wasn't asked to stand up and give my opinion on the entire safety case."*

10A.217 Witness K [BAE Systems] was not alone in his feelings. Witness T [BAE Systems] in interview also referred to himself as a *"bystander"* and said that there was *"unrest"* at what might be asked by the customer about the hazard mitigation. Likewise, Witness P [BAE Systems]'s recollection was that he may have had a *"private thought"* and *"conferred with* Witness C [BAE Systems] *across the table... and looked at each other and thought, 'We hadn't quite done 105'"*. He went on to explain in interview:

> ***"MR PARSONS QC:** So do you remember looking at each other and then raising an eyebrow?*
>
> ***WITNESS P [BAE Systems]:** We may have glanced at each other, yes.*
>
> ***MR PARSONS QC:** Were you rather hoping the client didn't ask you if it was actually all finished?*
>
> ***WITNESS P [BAE Systems]:** I think we both just sat there, schtum.*
>
> ***MR PARSONS QC:** Do you remember other people sitting there, a little bit uncomfortable about what was being said?*
>
> ***WITNESS P [BAE Systems]:** I would imagine that if Witness K [BAE Systems] had been present, then he would have sat there and probably thought "that's not true either", but a joint front was being taken in front of the customer."*

10A.218 As to the latter answer, Witness K [BAE Systems] was, in fact, present throughout the meeting but as he explained, he did not feel it was his role to speak out.

QinetiQ's representative 'booed'

10A.219 I turn now to consider the role of QinetiQ's representative, Witness O [QinetiQ], during the Customer Acceptance Conference. At the beginning of the meeting, Witness O [QinetiQ] introduced himself and explained that was standing in for Martyn Mahy at short notice. He was seated beside Frank Walsh. He had not previously been involved in the NSC and was not familiar with the project or the detail. Accordingly, he was for the most part a passive observer during the meeting. He said that everyone else seemed to know each other and that he felt like *"a fish out of water"*. He did, however, raise the question of the level of risk mitigation controls in place during the demonstration of CASSANDRA. He was told that the risk mitigation was only 85-90% completed but would be before the Phase 2 was completed.

10A.220 When, at the end of the second day, all present were asked to state in turn whether they supported the completion of Phase 2 of the NSC by BAE Systems, Witness O [QinetiQ] said that, because he was only standing in for Martyn Mahy and had not seen any of the key deliverable documents, he felt that he could not validate BAE Systems' claim that these documents satisfied the contractual requirements. His account in his statement to the Review of what then happened is striking:

"I have a strong memory that upon stating this, various meeting attendees booed me and muttered things along the lines 'bloody safety engineers always have to caveat their statements'. I can remember this clearly because I have never been booed in a meeting before (and have not been at any time since)."

10A.221 He said that, although the booing was not intentionally aggressive, he found it intimidating and was surprised and embarrassed at being heckled in this manner. BAE Systems' representatives were questioned about this matter in interview, but said they had had no recollection of such an incident. I have no reason, however, to doubt Witness O [QinetiQ]'s recollection of being subject to this sort of treatment at the meeting. It has the ring of truth about it.

10A.222 I analyse in **Chapter 11** whether Witness O [QinetiQ] stood his ground at the end of the meeting or whether he bowed to the majority 'consensus' and became party to it. I also discuss the pressures he might have been under and what might realistically have been expected from someone who found himself in that position.

'Bands and goats'

10A.223 Following the meeting, Chris Lowe reported to Witness A [BAE Systems] in glowing terms as to the process and outcome of the meeting. In an e-mail to Witness A [BAE Systems] on the afternoon of 1 September 2004, Chris Lowe reported they had just spent the last two days *"locked away with no less than 4 MOD guys, one RPO*[80] *and one QinetiQ guy, going through the complete safety case"*, and that, save for a few minor matters and completing the BLSC conclusions, the MOD had accepted the task as being completed. He added *"All visiting parties (including QinetiQ for once!!) were highly praiseworthy as to the amount of effort and quality of what they are getting..."*. He went on to explain that the next stage was a formal review of the documentation at RAF Wyton and the final and formal sign-off by George Baber before the end of September *"to the accompaniment of bands and goats, of course"*.

Third Phase of NSC in Chapter 10B

10A.224 This brings to an end the First and Second Phases of the NSC and BAE Systems' main involvement. I turn in **Chapter 10B** to consider the Third Phase of the NSC, which starts at the point at which BAE Systems formally handed over the NSC to the Nimrod IPT, namely, the six 'deliverable' reports including the BLSC, on 21 September 2004. From this point, it was the Nimrod IPT's job to complete any remaining aspects of the NSC.

[80] The IPT's Resident Project Officer.

CHAPTER 10B – NIMROD SAFETY CASE: THE FACTS (THIRD PHASE)

Contents

Chapter 10B deals with the Third Phase of the Nimrod Safety Case.

Summary

1. **Chapter 10B** continues the chronological story and deals with the Third Phase of the preparation of the Nimrod Safety Case by the Nimrod IPT (September 2004 to March 2005). (**Chapter 10A** deals with Phases 1 and 2 of the Nimrod Safety Case carried out by BAE Systems.)

2. **Chapter 10B** explains events after the Customer Acceptance Conference (see **Chapter 10A**) and the handover of the six Nimrod Safety Case 'deliverable' reports by BAE System to the Nimrod IPT on 21 September 2004.

3. BAE Systems' work on the Nimrod Safety Case was formally signed-off by the Nimrod IPT in November/December 2004. This 'sign-off' was supported by QinetiQ.

4. Following the Nimrod IPT's appreciation that 43 out of 105 hazards had been left *"Open"* by BAE Systems, it subsequently proceeded to sentence the remaining hazards itself.

5. Ironically, the fact that Hazard H73 was one of the 43 hazards left *"Open"* by BAE Systems, meant that the Nimrod IPT had a second chance to capture the serious fire risks inherent in the Cross-Feed/Supplementary Conditioning Pack duct.

6. Unfortunately, the Nimrod IPT did not grasp this opportunity: it proceeded to sentence the remaining hazards (including Hazard H73) on a manifestly inadequate, incorrect and unsatisfactory basis.

7. The Nimrod IPT declared the Nimrod Safety Case completed in March 2005.[1]

[1] See Frank Walsh's e-mail to BAE Systems of 16 March 2005.

Third Phase of Nimrod Safety Case (September 2004 to March 2005)

Delivery of the Baseline Safety Case Reports to the Nimrod IPT

10B.1 Following the Customer Acceptance Conference, Richard Oldfield circulated the minutes to Frank Walsh *via* email on or about 21 September 2004, together with 'pdf' copies of the six deliverable reports and a 'snapshot' of the CASSANDRA database. This was followed by a CD ROM version of the CASSANDRA Hazard Log and copies of the six deliverable reports on disc.

QinetiQ

10B.2 It does not appear, however, that QinetiQ was sent a copy of the minutes or the attached reports or the CD Rom at this stage. Although QinetiQ was included in the list of *"attendees"* on the distribution list at the end of the minutes, neither Martyn Mahy nor QinetiQ were copied in on the e-mail containing the minutes sent out by Richard Oldfield on 21 September 2004. It is clear, however, that at some stage QinetiQ did obtain a copy of the minutes, because Martyn Mahy found a paper copy of the Minutes in a file at QinetiQ's offices when preparing his statement for the Review.

CD Rom of CASSANDRA Hazard Log

10B.3 The CASSANDRA Hazard Log itself could only be interrogated at BAE Systems' computer terminal at Chadderton. It could not be accessed remotely by the Nimrod IPT from RAF Wyton. This was a major drawback. It severely limited the utility of the CASSANDRA Hazard Log as a 'living' database and as a useful tool for the operators of the aircraft.

10B.4 The CD Rom version of the CASSANDRA Hazard Log sent to Frank Walsh by BAE Systems contained a summary of each of the 105 hazards, the current classification of each hazard in terms of severity and probability, and the post-control classification of each hazard, *i.e.* the classification history of each hazard including the 'initial' probability ascribed. It did not, however, contain the embedded 'pdf' files (*i.e.* the completed Pro-Formas for each hazard) that were held on the CASSANDRA Hazard Log at Chadderton and only accessible from that BAE Systems terminal. This puts paid to the (unreal) suggestion by Chris Lowe in interview that he would have expected Frank Walsh to have read every single Pro-Forma and either have endorsed or amended it as necessary. Not only would this have been a Herculean, if not impossible, task for any one individual (still less one who was neither qualified nor familiar with Nimrods) but, in any event, there was no access to the embedded 'pdf' Pro-Formas without specially travelling to Chadderton to use the BAE Systems' CASSANDRA terminal there.

10B.5 The CD Rom version of the Hazard Log must nonetheless have seemed impressive to Frank Walsh. It would have also served to cement what he had been told by BAE Systems at the Customer Acceptance Conference, namely, that the NSC had been *"completed"*.

Six 'deliverable' NSC reports

10B.6 As listed in the minutes to the Customer Acceptance Conference, the six reports comprising the NSC 'deliverables' from BAE Systems were the following:

(1) NIMROD MR MK2 EQUIPMENT BASELINE SAFETY CASE REPORT: Reference: MBU-DEF-C-NIM-SC-0713 dated September 2004.

(2) NIMROD RMK1 EQUIPMENT BASELINE SAFETY CASE REPORT: Reference: MBU-DEF-C-NIM-SC-0714 dated September 2004.

(3) NIMROD MR MK2 and RMK 1 EQUIPMENT BASELINE SAFETY CASE REPORT PHASE 2 CERTIFICATION STATEMENT: Reference: MBU-DEF-C-NIM-SC-674 dated June 2004.

(4) NIMROD MR MK2 and RMK 1 EQUIPMENT BASELINE SAFETY CASE REPORT FIRE/ EXPLOSION HAZARD ASSESSMENT: Reference: MBU-DEF-C-NIM-SC-710 dated August 2004.

(5) NIMROD MR MK2 and RMK 1 HAZARDOUS MATERIALS LIST: Reference: MBU-DEF-C-NIM-SC-0667 dated August 2004.

(6) REVIEW OF NIMROD IN SERVICE ACCIDENT HISTORY: Reference: MBU-DEF-C-NIM-SC-0713 dated August 2004.

10B.7 As explained in **Chapter 10A**, however, in fact, only four of the six 'deliverable' reports had been completed by the time of the Customer Acceptance Conference, namely, the Type Certification Statement Report, the Fire & Explosion Report, the Hazardous Materials Report, and the Nimrod In-Service Accident History Report. The two key Baseline Safety Case (BLSC) Reports were not completed until afterwards. They both bear the date *"September 2004"*. An examination of BAE Systems' computer records revealed that Annexes B and C to the BLSC Report for the MR2 were last amended on 9 September 2004, with the last amendment to the Report itself being made on 13 September 2004.[2]

'Thud' factor

10B.8 The delivery of the six reports together to the Nimrod IPT must have had a considerable 'thud' factor. The sheer weight of paper, which ran to several inches, would have given the recipient IPT a sense of comfort that a substantial, and indeed thorough, job had been done by BAE Systems. The BLSC Phase 2 Reports for the MR2 and R1 were, in particular, substantial and impressive-looking documents. This all would have re-enforced the assurance and consensus, given and reached, at the Customer Acceptance Conference, that all elements of the task had been *"completed"* by BAE Systems. The Nimrod IPT would, therefore, understandably have been desensitised and expecting to receive reports which comprised the complete NSC.

10B.9 The impression of 'completeness' would have been reinforced by an initial glance at the Executive Summary of the BLSC Phase 2 Reports for the MR2 and R1, the second page of which contained the following declaration by BAE Systems:

> *"From the above, <u>it is thus declared all potential safety hazards have been identified, assessed and addressed</u>, and that all appropriate standards have been met. Accepting this, <u>the top level goal of the Nimrod MR Mk2 Type Equipment Safety Case that</u>*
>
> ***"The aircraft type is deemed acceptably safe to operate and maintain within specified contexts"***
>
> *<u>has been demonstrated as having been achieved</u>.*
>
> *In relation to underpinning the claims of the Safety Case with the in-service history of the Nimrod types, it has been determined from Section 12.0 of this report that the actual occurrence of a CATASTROPHIC Accident in service is 5.0 E-6, which when error margins relating to small population of flying hours of this claim are taken into account, compares favourably with the MOD requirement to achieve 1.0E-6 probability of occurrence in service."* (emphasis added)

10B.10 A careful reading of the first page of the Executive Summary, however, should have raised alarm bells. The Executive Summary of the BLSC Phase 2 Report for the MR2 said **in red** in its heading: *"This abstract should be read in conjunction with ANNEX B and ANNEX C to this report."* The text of the Executive Summary included the following:

[2] Curiously, this is some 11 days *before* the final Pro-Forma (Hazard H63) was completed by Witness T [BAE Systems] in the Electrics Department.

> *"In regard to identification mitigation of those hazards and subsequent entry of the mitigation into the CASSANDRA Hazard Log, it is considered that all extant mitigation for which BAE SYSTEMS has control has been identified and recorded accordingly against the respective hazard in such a fashion as to provide an adequate documentation audit trail of such mitigation.*
>
> *99 hazards were identified against the Nimrod MR Mk2 type, all of which impose a potential CATASTROPHIC outcome as a worst case scenario. The contents of ANNEX B are derived from the CASSANDRA Hazard Log status as per the date of this report, and quotes the Hazard Risk index for each identified Hazard. For the Status of these hazards, refer to Annex B to this report. In relation to the DA recommendations made against all identified hazards remaining open (qty 43), refer to ANNEX C of this report.*
>
> *For the above, it can thus be concluded that, subject to IPT consideration of the above-mentioned recommendations, all potential safety hazards relating to operation and maintenance of the Nimrod MR Mk2 type (as an equipment asset) have been appropriately addressed...."* (emphasis added)

10B.11 It should have been apparent to anyone reading the BLSC Reports reasonably carefully that, far from the NSC being completed, BAE Systems had left 43 hazards out of the 105 hazards 'open', *i.e.* some 40% of the total, all of which were classed as having *"a potential CATASTROPHIC outcome as worst case scenario".*

10B.12 BAE Systems accepted in interview that the Executive Summary involved *"awkward writing"* but maintained that the BLSC Reports as a whole were not misleading. This is to miss the point. It is true that a reasonably careful reading of the BLSC Reports should have picked up the fact that 43 of the hazards remained *"Open"* and a large number *"Unclassified"* and many had only the vaguest recommendations along the lines of *"further analytical techniques are required".* However, anyone quickly glancing at the Executive Summary of the BLSC Reports (particularly someone who had already been told that the task had been *"completed"*) would find their eye naturally alighting on the unqualified concluding words in bold italics at the end: *"… the top level goal* ***"The aircraft type is deemed acceptably safe to operate and maintain within specified contexts"*** *has been demonstrated as having been achieved"* (emphasis added), and could easily have been misled. This appears to have been recognised later by Witness B [BAE Systems] in his notes of a meeting with the Nimrod IPT on 3 January 2008, where he recorded *"Summary of safety case report is too positive. Should reflect 32* [sic] *open hazards."*

10B.13 If a query had been raised by anyone at the Nimrod IPT on reading the Executive Summary of the BSLC Phase 2 Report about the number of *"Open"* hazards, BAE Systems could have pointed to the 'consensus' reached at the Customer Acceptance Conference and said that the completion of the task had already been agreed. To this extent the Nimrod IPT and QinetiQ had already somewhat been been 'sold the pass'.

10B.14 It an unfortunate fact of life that, in busy offices, where numerous lengthy and apparently impenetrable technical reports pass over people's desks, many people tend often to do no more than glance at the Executive Summary and then too often put the report on the shelf. Few venture to read all of such reports. If, however, the reader had ventured to the Conclusion to the BLSC Phase 2 Report for the MR2, at page 45, he or she would have found the following:

> *"– 50 Hazards have been assessed as HRI 'C'. It is recommended that IPT accept these hazards as closed at a probability of IMPROBABLE, by being adequately managed ALARP without further recommendation being proffered.*
>
> *– 11 Hazards have been assessed as HRI 'B' and are considered as still being 'OPEN' with a current probability of REMOTE. Towards closure, it is recommended that IPT consider the ANNEX C Section C2 Table 1 recommendations proffered against these respective Open Hazards.*

– 6 Hazards have been assessed as HRI 'B'. It is recommended that IPT accept these hazards as closed at a probability of REMOTE, by being adequately managed ALARP without further recommendation being proffered.

– 32 Hazards of which the majority are of the Zonal Hazard type, remain OPEN as probability of UNCLASSIFIED due to DA being unable to identify sufficient evidence for a robust and meaningful probability. Towards closure, it is recommended that IPT consider the ANNEX C Section C2 table 1 recommendations against these respective Open Hazards." (emphasis added)

10B.15 The Conclusion also had the following subtly different formulation of the statement which appeared in the Executive Summary:[3]

"From the above, it is thus declared that all potential hazards have been identified, assessed and addressed to ALARP (subject to consideration of the proferred recommendations) and that all appropriate standards had been met. Accepting this the top level goal of the Nimrod MR Mk2 type Equipment Safety Case that

"The aircraft type is deemed acceptably safe to operate and maintain within specified contexts"

is considered as having been demonstrated as having been achieved." (emphasis added)

10B.16 There was also no mitigation evidence of any sort included in either of the BLSC Reports. There was, therefore, no basis upon which the Nimrod IPT or QinetiQ could check and satisfy themselves that BAE Systems had used appropriate mitigation evidence to sentence the hazards.

Annexes to BLSC

10B.17 The BLSC Phase 2 Report for the MR2 ran to 46 pages, and had attached several lengthy Annexes including: Annex A, *"Fault Tree Analysis Accident Model"* (42 pages); Annex B, *"Summary of Hazard Risk Indices against Nimrod MR Mk2 Identified Hazards"* (9 pages) and Annex C, *"Summary of Nimrod MR Mk2 Recommendations made within this Safety Case Baseline Project"* (26 pages).

10B.18 Annex B stated in relation to Hazard H73 (one of the 32 open hazards left *"Unclassified"*):

HAZARD I/D	ZONE DESCRIPTION	*SEVERITY*	PROBABILITY	HRI	RECOMMENDED HAZARD STATUS
H73	**Zone 513/613 Interacting System** Hazards – No. 7 Fuel Tank	CATASTROPHIC	UNCLASSIFIED	–	OPEN

[3] Page 46 of the BLSC Report on the MR2.

10B.19 Annex C stated in relation to Hazard H73:

Hazard Ref (H...)	Control Ref (C...)	Recommendation: (See Individual Safety Cases Baseline Hazard Log Entry for full recommendation)
73	100	• From the photographic evidence obtained during the zonal hazard review at RAF Kinloss & Waddington, it appears that there are potentials for fire hazards on the R Mk 1 and the MR Mk 2 aircraft. Further investigation is required to confirm that the potential loss due to the contamination of the various services in the zone (514/614) would not be a hazard to the aircraft. • Further analytical techniques are considered necessary in order to categorise the risk of the specific fire/explosion hazard identified.

"Further analytical techniques..."

10B.20 The same or similar recommendation: *"Further analytical techniques are considered necessary in order to categorise the risk of the specific fire/explosion hazard",* was repeated in relation to a further eight hazards and, in respect of at least a further 12 hazards, it was stated that *"further work"*, *"further analysis"*, *"further investigation"* or *"further analytical techniques"* were required. Such 'recommendations' were, in large part, meaningless. They were merely a thinly-veiled way of saying that further work needed to be done in order simply to *categorise* the risk. There was no attempt to advise the customer what that further work might entail or cost or how long it might take. There was also no attempt to indicate to the customer how many of the 43 *"Open"* hazards or 32 *"Unclassified"* hazards might require serious attention.

Sentencing of Hazards by the Nimrod IPT

Nimrod IPT office at RAF Wyton

10B.21 The Nimrod IPT office at RAF Wyton was 'L'-shaped and largely open plan. It comprised sets of desks and several offices. The desks were conventionally configured, three on one side and three on the other, with low partitions which people could see and talk across. The sets of desks were in close proximity to each other, so communication between them was easy. The 'A' Desk sat together at one desk. The Nim(ES)AV(Safety) (C1 Frank Walsh) sat close by at a desk next door but one. The 'A' desk was near to the corner office of the IPTL (Group Captain (now Air Commodore) George Baber) and opposite the office of Hd AV (Wing Commander Michael Eagles).

The Airframe Desk

10B.22 The Airframe Desk (colloquially known as the 'A' desk) comprised six people: a Squadron Leader (NIM(ES) AV(A)); a Flight Lieutenant (NIM(ES)AV(A)1); a Grade C2 Civil Servant (NIM(ES)AV(A)3); a Warrant Officer (WO) (NIM(ES)AV(A)2); and two Chief Technicians (CT) (NIM(ES)AV(A)2a and b). The 'A' desk was responsible for processing all engineering and technical aspects of the Nimrod relating to the airframe, including structure, systems and ground support equipment (including the fuel and air systems).[4] The 'A' desk was nominally sub-divided into three desks: desk A(1) (comprising NIM(ES)AV(A)1) dealt with structural integrity issues; desk A(3) (comprising NIM(ES)AVA(3)) deal with systems issues; and desk A(2) (comprising NIM(ES)AV(A)2a and b) dealt with both structural and systems issues and provided technical support to both other desks and to the Head of the Section, as well as advising on maintenance issues. The A(2) desk had specific responsibility for managing Nimrod engineering instructions, including Urgent Technical Instructions (UTIs), Routine Technical Instructions (RTIs), Special Technical Instructions (STIs) and Servicing Instructions (SIs). The wider role of desk A(2) was due to the fact that those on the A(2) desk (Witness AB [MOD], Witness X [MOD] and Witness AC

[4] There was a suggestion that responsibility for the fuel system was shared between the Airframe Desk and the Engine Desk (headed by NIM(ES) AV(Spey)) or, at least, a 'grey' area ; but it is clear that the Engine Desk were only responsible for the fuel system within the engine compartment zones.

[MOD]) had considerable experience of working on Nimrods, which was not the case with the A(1) and A(3) desks. There were similar desks responsible for the Spey engines and Avionics.

BLSC Reports not read carefully by Nimrod IPT when first received

10B.23 Frank Walsh said in interview with the Review that, following receipt from BAE Systems on 21 September 2004, he recalled circulating the Minutes of the Customer Acceptance Conference and the six deliverable Reports within the Nimrod IPT, including to the specialist desk officers, most likely by email. He also said in interview that, upon receipt of the six Reports, he would have printed them off and started *"wading through"* them himself, with a view to putting together a list of issues for consideration by the other IPT desk officers. There is, however, no evidence of the six Reports ever being circulated by Frank Walsh within the Nimrod IPT or to the relevant IPT desk officers. I have concluded that he did not do so. I have also concluded that he did not read all of the BLSC Reports carefully at this stage. Nor did Michael Eagles at any stage. Nor did George Baber. I discuss in **Chapter 11** the reasons why not and the consequences of the same.

10B.24 It would appear that, in so far as Frank Walsh gave any consideration at all to the six deliverable Reports, he focused primarily on the Certification Statement and the Fire & Explosion Report and paid little or no attention to the (key) BLSC Reports. He had been shown the content of the Fire & Explosion Report by Chris Lowe at the Customer Acceptance Conference and no doubt regarded it as the over-arching report dealing with the major risk of fire and explosion. It made a limited number of recommendations (nine) and concluded that the fire/explosion risk was 'ALARP'. The extent to which Frank Walsh properly read, digested and understood the Executive Summary of the BLSC Reports is unclear. Frank Walsh admitted in interview with the Review that his primary focus was on the CASSANDRA Hazard Log which he had been sent in CD Rom form. He said that he had probably worked from the CASSANDRA hazard log rather than the annexes. He also said that at some stage he rang Witness C [BAE Systems] or Chris Lowe regarding the 'unclassifieds' and was told to focus on CASSANDRA since things had 'moved on'. He said: *"I believe I queried the fact that there was* [sic] *differences between the safety case report and what was actually now in the hazard log. And I was told that the hazard log had been updated with the latest information."* The extent to which this may be *ex post facto* rationalisation for using CASSANDRA rather than Schedules B and C of the BLSC Reports is unclear. At all events, as I explain below, it appears he did not understand the nature of the 'initial probabilities' in CASSANDRA.

Preparations for the Sixth PSWG

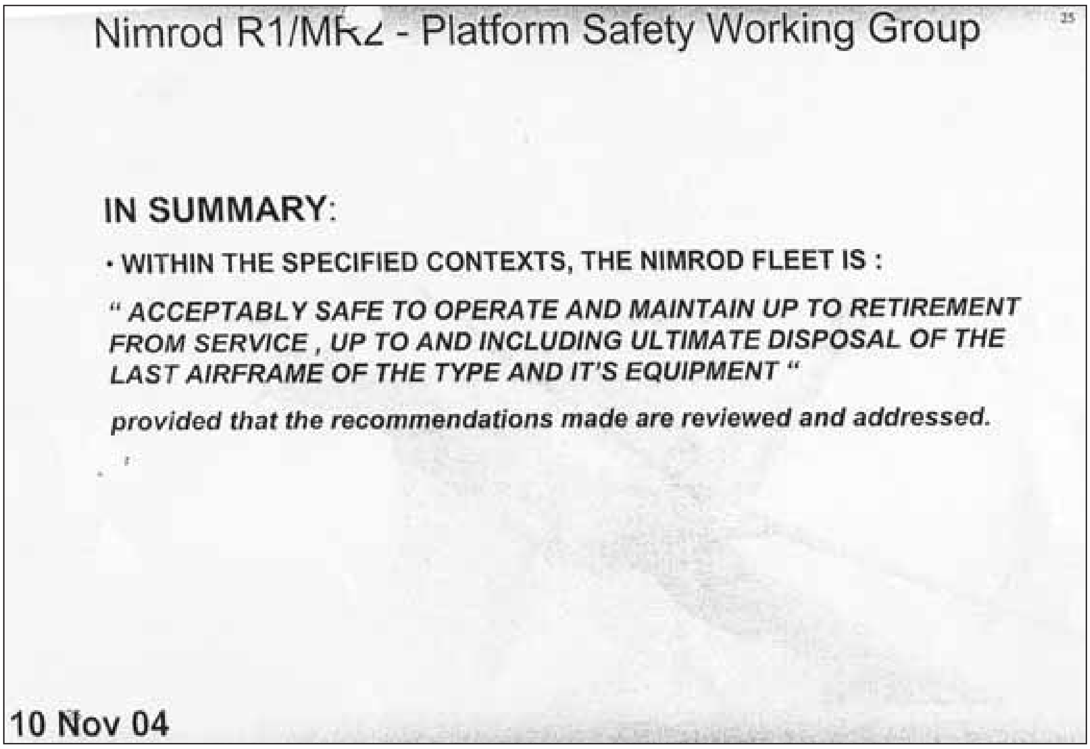
10B.25 Following the delivery of the six Reports, it was intended that the completion of the 'BLSC' by BAE Systems would be formally acknowledged and 'signed-off' by the Nimrod IPTL at the next PSWG. The Sixth PSWG was scheduled for 10 November 2004. Frank Walsh was tasked to prepare briefing documents for this meeting. He drew up two annexes dealing with 'outstanding recommendations' under the NSC. Annex A identified 13 outstanding recommendations, all emanating from recommendations in the Certification Statement, Fire & Explosion Report, the Hazardous Materials List, and the Review of Service Accidents. Annex B identified outstanding recommendations relating to Hazards H2, H15, H23, H26 and H27; these appear to have been taken randomly from CASSANDRA; only two overlap with Annex C of the BLSC Reports. Neither Annex made any reference at all to the BLSC Reports. Neither touched on, or even mentioned, the large number of recommendations in relation to the 43 *"Open"* hazards contained in Annex C thereto.

10B.26 It appears, therefore, that despite having received copies of the BLSC Reports, Frank Walsh still remained ignorant of the full picture. As indicated above, he had either simply failed to read the BLSC Reports at all by this stage, or had merely glanced at the Executive Summary thereof and assumed the top-level goal had been achieved from the words: *"The aircraft type is deemed acceptably safe to operate and maintain within specified contexts"*. I reiterate: a careful reading of the Executive Summary and Annexes B and C to the BLSC Reports, however, would and should have alerted him to the fact that 43 of the hazards remained *"Open"*, some 33 hazards remained completely *"Unclassified"* and a large catalogue of recommendations had been made which required further action. It is unfortunate that Frank Walsh appears not to have studied the BLSC Reports more carefully or at all at this stage because if he had appreciated that over 40% of the hazards remained *"Open"*, it is likely, although not certain, that he would have raised this with George Baber or, possibly, Michael Eagles; and the Annexes that he prepared for the Sixth PSWG may have been markedly different, *i.e.* he might have listed all the recommendations contained in Annex C to the BLSC Reports.

10B.27 It remains the fact that, at this stage, nobody at the Nimrod IPT spotted the fact that BAE Systems' BLSC Reports had large gaps: over 40% of the hazards were *"Open"* with a large number of open-ended recommendations for further action. Thus it was that the Nimrod IPTL, George Baber, and the other representatives of the Nimrod IPT walked into the Sixth PSWG meeting ignorant of the true position.

10 November 2004: Sixth PSWG Meeting and 'sign off' of BLSC

10B.28 On 10 November 2004, the Sixth PSWG was held at RAF Wyton. It was chaired by George Baber. 19 people were present, including Michael Eagles, Witness AB [MOD] and Frank Walsh from the Nimrod IPT; Chris Lowe, Richard Oldfield and Witness C [BAE Systems] from BAE Systems; and Martyn Mahy from QinetiQ. The NSC was the major item at the meeting. Chris Lowe gave a PowerPoint presentation which essentially reinforced the impression that BAE Systems had completed the NSC task**,** stating as it did that the CASSANDRA Hazard Log was *"fully populated"*; and that all foreseeable hazards had been *"identified and assessed, and addressed"*. The presentation went on to conclude:



10B.29 There were two further presentations at the meeting by BAE Systems. Richard Oldfield gave a PowerPoint presentation re-capping the basic NSC methodology**.** Witness C [BAE Systems] then gave a demonstration of CASSANDRA. Frank Walsh then presented the procedure that would be used to populate CASSANDRA with future hazards.

10B.30 It appears that, again, the BAE Systems representatives: (i) did not review in detail how each of the 105 hazards had, in fact, been classified, mitigated and sentenced; (ii) did not state how much or little 'extant' mitigation had in fact been found; (iii) did not state how many of the 105 hazards BAE Systems, in fact, had left *"Open"* and/or *"Unclassified"*; (iv) did not give any indication as to how serious the remaining hazards might be; and (v) did not give any idea as to how much further work was required, or the likely time and cost involved, in order to complete the NSC. Equally, at no stage did any of the Nimrod IPT representatives present raise any queries in relation to the above, or ask BAE Systems any of the intelligent questions which arguably should have been asked. It is clear that everyone present was content simply to regard the NSC as essentially completed. The minutes then record that George Baber formally thanked BAE Systems for producing the Safety Case and Hazard Log and the meeting decided: *"Nim(ES)Safety would produce a document and a suitable date for the IPTL to sign off the Safety Case Report for both the air vehicle and the mission system".*

10B.31 It is fair to say that the other Nimrod IPT representatives present were probably relying on Frank Walsh to tell them if there were any problems with the NSC Reports produced by BAE Systems. His Annexes A and B to the Agenda, however, merely referred to a handful of hazards needing to be dealt with.

Bronze Award

10B.32 Following the meeting of the Sixth PSWG, BAE Systems congratulated itself on a 'job well done.'[5] In due course, the NSC project was nominated for the BAE Systems' Chairman's Award and the Airworthiness Department ultimately received a Bronze Award. In the Award nomination form and Chris Lowe's presentation in support of the Award, he (Chris Lowe) expressly relied (amongst other things) on the fact that: (1) BAE Systems had used *"highly experienced teams"* of personnel; (2) that there had been a *"timely performance of tasks"*; (3) the project had been completed in partnership with the IPT and had therefore *"engendered trust to allow* [the] *IPT to contract us for continued safety management activities"*; and that there had been (4)*"no surprises or showstoppers at the final acceptance conference"*. On the back of the apparent success of the NSC, in December 2004, Chris Lowe made a sales pitch to the Nimrod IPT to prepare 'Operational' Safety Cases.

19 November 2004: QinetiQ support 'sign off' of BLSC

10B.33 As regards the other attendees at the Sixth PSWG, there is no evidence that QinetiQ had either seen or read any of the six Reports in the meantime, let alone checked the BLSC Reports. Nonetheless, at the Task Review Meeting on 19 November 2004, attended by representatives of the Nimrod IPT, including Frank Walsh, Martyn Mahy presented the Situation Report that he had previously prepared. The minutes record in terms: *"QQ (Mr Mahy) reported that QQ were now ready to sign off the BLSC..."*. In the Task Review Summary on the Safety Management System the following entry is recorded:

> *"1. CASSANDRA.*
> *QinetiQ attended the Nimrod BLSC Review at BAE Systems Aug 04 and are happy with CASSANDRA and support the sign-off of the Baseline Safety Case.*
> *NIM(ES)Safety confirms remaining 10-15% of safety mitigation has been entered into the CASSANDRA…"*

10B.34 It is not clear where Frank Walsh got the 10-15% figure from. It tallies, however, with Witness O [QinetiQ]'s evidence that he was told at the conference that 85-90% of the mitigation had been completed.

10B.35 Martyn Mahy admitted in evidence to the Review that there was some disquiet (*"mutterings"*) at the meeting by other QinetiQ representatives present as to whether QinetiQ was in a position to support the sign off the NSC. He recalls the QinetiQ Project Manager, Witness M [QinetiQ], saying: *"Have we seen the reports yet?"*; to which the answer was: *"No, we still haven't received the reports".* It appears, however, that the QinetiQ representatives present, who numbered more than a dozen, including the QinetiQ Technical Assurance Manager and also the Design Approved Organisations Scheme (DAOS) signatory, Colin Blagrove, were content to assent to the statement of Martyn Mahy that *"QQ were now ready to sign off the BLSC..."*, or at least did not raise an objection or demur. The minutes record the next item as being Colin Blagrove simply going on to referring to QinetiQ having introduced a new policy of *"Independent Safety Case Review"* which he said *"should ensure that their reports met the IPT's requirements, without detailing unnecessary requirements."*

[5] See, for example, the minutes of the TTRO Nimrod MR2 & R Engineering Integration Meeting held on 11 November 2004, section 3.2: *"Baseline Safety Case – Now complete and delivered – the closure meeting successfully resulted in recommendation for payment and the results were then presented to a further audience with the Group Captain for Nimrod commenting on an excellent piece of work."*

10B.36 I deal in **Chapter 11** with the appropriateness of QinetiQ's conduct in supporting the sign-off of the BLSC. I conclude that it was manifestly inappropriate, not least because QinetiQ had neither read the Reports, nor checked them, nor seen any ISA review. Furthermore, the BLSC contained large holes: 40% of the hazards remained *"Open"* and 30% *"Unclassified"* with a series of open-ended recommendations.

Sentencing of remaining hazards by the Nimrod IPT

10B.37 I now turn to how the remaining *"Open"* and *"Unclassified"* hazards came to be sentenced by the Nimrod IPT such that, by March 2005, the NSC was considered completed and proof that both Nimrod types were ALARP.

Irony

10B.38 There is an irony about these events. BAE Systems had failed to complete the BLSC by a substantial margin, having left a large proportion of hazards *"Open"* and *"Unclassified"* (including Hazard H73 which it had failed to analyse properly in the first place). BAE Systems sought, effectively, to pass a substantial proportion of the NSC task back to the Nimrod IPT undone. This meant that, in theory at least, the Nimrod IPT had a fresh opportunity to capture the risks which BAE Systems had not previously spotted, including the risk inherent in Hazard H73. Unfortunately, the Nimrod IPT failed to grasp this opportunity. This was for a variety of reasons, but not least that the Nimrod IPT's guard was down because of what they had understood from the Customer Acceptance Conference. This was, however, no excuse for their failure to analyse and sentence these remaining risks properly.

15 December 2004: Formal 'sign-off' letter of the BLSC by George Baber

10B.39 Frank Walsh had been tasked by the Sixth PSWG meeting to produce a document for the IPTL to 'sign off' the NSC. On 15 December 2004, he presented a memo to George Baber for signature with wide distribution (including to DG Log(Strike), D Log 2/3 Gp and AD Eng Pol) announcing the IPTL's intention to sign-off the Nimrod BLSC. The memo said that the production of the NSC for the MR2 and the R1 had been completed by BAE Systems, and that their reports concluded that the platforms were *"ACCEPTABLY SAFE TO OPERATE AND MAINTAIN UP TO RETIREMENT FROM SERVICE…"* but the Reports were too large to distribute and would be kept on file. The memo concluded:

> *"Therefore, following acceptance of the Reports at the 6th Nimrod Platform Safety Working Group held on 10 Nov 04, I am pleased to advise of my intention to sign-off the Nimrod Baseline SC. I would like to thank and congratulate both BAE Systems and EWAD on the depth of detail and standard of production that they have employed in meeting the requirements of a Baseline SC."*

10B.40 On 22 December 2004, Frank Walsh faxed a copy of this memo to Witness C [BAE Systems] referring to it as the 'baseline' letter.

20 January 2005: E-mail from Frank Walsh to George Baber

10B.41 On 20 January 2005, Frank Walsh e-mailed George Baber as follows:

> *"George,*
> *All the hazards in CASSANDRA, with the exception of H2 .... have controls and references in place to show that they are at ALARP. I am awaiting a copy of the Unit snow and ice plan to include as mitigation for H2.*
> *I believe that the hazards, except H2, should be set to MANAGED on CASSANDRA now and H2 when the last piece of mitigation is in place.*
> *If you agree I will instruct BAE Systems to amend CASSANDRA.*
> *Frank"*

10B.42 Frank Walsh's e-mail does not appear to have contained any detail or supporting material or referenced any input from the Nimrod IPT Specialist Desks or Heads of Branch or Michael Eagles. Nevertheless, it appears that George Baber was prepared to approve his request, because subsequently, on 1 February 2005, Frank Walsh wrote to BAE Systems authorising them to set the post control status of the hazards in CASSANDRA in accordance with an attached annex (Annex A) which he had prepared (see further below). I discuss in **Chapter 11** the significance of this and other steps taken in relation to the sentencing of the remaining risks. The above e-mail shows an informality of approach to the sentencing of risks by both George Baber as IPTL and Frank Walsh as Safety Manager. George Baber's explanation in interview was *"I trusted him and I took what he said at face value"*. It remained, however, George Baber's personal responsibility as IPTL, Project Engineer and Letter of Delegation holder, to ensure that the risks were properly sentenced.

1 February 2005: Frank Walsh's memo to BAE Systems

10B.43 On 1 February 2005, Frank Walsh drafted a memo to BAE Systems which he signed and sent out under his own name. It stated that the Nimrod IPT had reviewed the BLSC produced by BAE Systems, agreed with the status of the hazards set by BAE Systems, and had considered the evidence to set the rest. Attached to the memo was an annex (Annex A) entitled *"Evidence for Mitigation of Hazards" (Annex A) which he had prepared,* and which was described as *"the evidence that should be entered into the hazard log as controls and the post control status as decided by the IPT"*. Frank Walsh said that his Annex A was based on a template which he had been sent by Witness C [BAE Systems]. It was not clear when, but probably shortly before.

Annex A

10B.44 Frank Walsh's Annex A purported to show the mitigating Controls and Post Control Status of 33 hazards. 32 of these hazards were those which BAE Systems had left *"Open"* and *"Unclassified"* in Annex B to the BLSC.[6] A total of 21 of these were referred to as *"Interacting Systems"* hazards and contained identical entries.

10B.45 It is clear, therefore, that by 1 February 2005, Frank Walsh had had a look at Annexes B and C of the BLSC Reports and discovered that there were, in fact, a large number of *"Open"* and *"Unclassified"* hazards which remained to be sentenced. This contrasted starkly with the picture which he had presented to the Sixth PSWG when he had highlighted only a handful of hazards as requiring action.

Frank Walsh's realisation

10B.46 It is not clear precisely when, and how, Frank Walsh, came by this realisation or revelation. He was unable or unwilling to give a clear or satisfactory explanation to the Review in interview. It is likely that, sometime after the Sixth PSWG meeting had tasked him to produce a document to 'sign-off' the NSC, he turned to the BLSC Reports and discovered that there were in fact a large number of hazards which had been left *"Open"* and *"Unclassified"*. Upon making this discovery, it appears that he did not (as one might expect) immediately draw it to the attention of Michael Eagles or George Baber. The question arises, why not? The likelihood is that it was a combination of the fact that he was simply too embarrassed at this point in time because he should have spotted it earlier, and a sense that it did not really matter because the task had been formally signed-off and the Nimrod was safe anyway, and a belief that he could quietly find mitigating evidence to sentence all the remaining hazards without difficulty. This is, in any event, what he proceeded to do. Unfortunately, Frank Walsh's attempt to sentence these hazards (including Hazard H73) was woefully inadequate. There exists no documentary trail, however, of precisely how he went about it.

Annex A: Control and Post Control Status for 19 "Interacting Systems" hazards

10B.47 Annex A contained identical entries in the Control and Post Control Status for 25 of the 30 Unclassified *"Interacting Systems"* hazards (Hazards H44 to H82). The entry for Hazard H73 relating to the No. 7 Tank Dry Bay is illustrative and reads as follows:

[6] There was an extra hazard (Hazard H106) added to Annex A *"Failure of Post Baseline Modifications"* .

Evidence for Mitigation of hazards

Hazard No	Hazard	Control	Post Control Status
H73	Z514/614 Interacting Systems Hazards	1. Systems maintained iaw Nimrod maintenance procedures AP101B-0503-1. 2. Aircraft fire detection and suppression system.	Remote

10B.48 Of the 25 instances where this is repeated, only six of those zones possess a fire detection and suppression system; the other 19 do not. Therefore, the above entry was seriously flawed in three respects. First, the reference to *"Aircraft fire detection and suppression system"* as a hazard control was in many cases, including Hazard H73, a glaring factual error. Second, the inclusion of *"Systems maintained iaw Nimrod maintenance procedures AP101B-0503-1"* was inappropriate as a hazard control. Third, the setting of *"Remote"* as a Post Control Status was inappropriate and illogical since in many cases this was merely the 'initial probability' set on CASSANDRA (see further below).

10B.49 I turn to consider these flaws in more detail below. The explanations given by Frank Walsh as to how they came about were far from satisfactory.

First Error: "Aircraft fire detection and suppression system"

10B.50 Annex A contained a repeated and fundamental factual error in the entries for 19 of the 30 Unclassified *"Interacting Systems"* hazards (Hazards H44 to H82): namely, the statement that an *"Aircraft fire detection and suppression system"* in the third column was a mitigating control. This was erroneous. Of the 25 where *"Aircraft fire detection and suppression system"* is noted, only six zones were fitted with fire detection and suppression systems on either Mk of Nimrod. Three of these zones were on the MR2 and these related to Hazards H45, H47, and H66 , namely, Zone 113 (Aileron Bay), Zone 116 (Elevator Bay), and Zone 413/443 (Nos. 1 and 4 Engines). Of the 19 without detection and suppression systems, some do have overheat detectors which are intended to detect hot air leaks but are not considered to provide 'area' fire detection. In one area, the bomb bay, there is a fire detection and suppression system on the R1 but only a fire detection system on the MR2; this distinction is not made clear in the table.

10B.51 There are no documents shedding light on how such a serious error came to be made and repeated so many times by Frank Walsh when he was drawing up Annex A. The lack of a proper paper trail is unsatisfactory and troubling. It suggests, at least, either that the express requirements of the Nimrod Safety Management Plan (SMP) as to document retention were ignored, or that Annex A was drawn up as a result of an entirely informal process with no peer review and/or supervision (see **Chapter 11**).

10B.52 Frank Walsh had varying explanations as to how he came to make this mistake, all of which were unsatisfactory. He initially suggested in interview that he would not have entered the references to 'Aircraft fire detection and suppression system' in Annex A *"without someone providing me with the information"*. But he was unable to say who the source of the information was. He said he had no clear or independent recollection of events. He said he thought it was likely that he would have drawn up a list of hazards requiring further consideration, circulated this by e-mail within the IPT to relevant Desk Officers and then collated the answers, but he had not retained the e-mails. He said that he could have had a conversation with one of the Desk Officers. He said he believed that the Airframe Desk would have been the most likely source of the information. He said in a later statement that there might have been *"another source"*. I have concluded that his evidence is not to be relied upon on this aspect.

10B.53 In my view, it is unlikely in the extreme that anyone on the Airframe Desk could or would have made such a fundamental mistake. The notion that there was an *"Aircraft fire detection and suppression system"* in so many zones on the aircraft was not just wrong, but absurd to anyone with a cursory knowledge of the Nimrod aircraft, not least because the wings (Zones 522-538 port and 622-638 starboard) beyond the engines would have no need for such fire detection systems, let alone room for so many fire bottles. As Michael Bell[7] powerfully put it in his cross-examination at the Inquest, it was an *"absolutely idiotic error"* to suggest that so many zones in the wings would have fire detection and suppression systems.

[7] Brother of XV230 crew member, Gerard M. Bell, Deceased.

10B.54 The two Nimrod specialists on the A(2) desk, Witness AB [MOD] and Witness X [MOD], had nearly four decades of experience on the Nimrod between them, and a comprehensive knowledge of the aircraft and its systems. Witness AB [MOD] had worked on Nimrods since 1974 for 28 out of his 38 years in the RAF, and spent nine years teaching airframe systems at the Nimrod Maintenance School. Witness X [MOD] was an airframe engineer by training and had spent 11 years at RAF Kinloss (1986 to 1997). In 1986, he completed the Nimrod 'Q' annotation course which covered all aspects of Nimrod airframe related systems and then spent six years in the Nimrod Major Servicing Unit. In 1992, he moved to the Nimrod Undercarriage Bay. In August 1994, he was promoted to Chief Technician and became a team leader in Nimrod Major Maintenance. When deep maintenance was transferred to industry (FRA) in 1995, he moved to Engineering Plans and Records at RAF Kinloss. During all this time he gained a very detailed knowledge of the Nimrod airframe and systems, including the fuel and air systems. I am satisfied that neither individual could, or would, ever have made such a fundamental mistake. I have no doubt if either of them had been specifically asked for information as to what, if any, fire mitigation controls existed in each of the 21 zones in question, they would not only instinctively have known the answer for many of the zones, but also double-checked in the Master Maintenance Schedule (MMS) and Aircraft Publications (AP) held on bookshelves behind them. Equally, if anyone else on the Airframe Desk had been asked the same question, they would have referred the request to the Nimrod specialists on the A(2) desk, or themselves had reference to the MMS and AP.

Zonal system

10B.55 In any event, it is a difficult mistake to make in relation to one or two zones, let alone 17 in total. As I have said, Nimrod specialists would be familiar with the location of many of the zones. The zone numbers can be easily checked in the MMS. The 'zonal' system of identifying parts of the aircraft was introduced for the Nimrod in the late 1980s with Reliability Centered Maintenance (RCM). It is taught at the Nimrod Maintenance School. All zone numbers are three digits long and follow a logical pattern: the '100' numbers cover the upper fuselage; the '200' numbers cover the lower fuselage; the '300' numbers cover the tail unit; the '400' numbers cover the engines; the '500' numbers cover the port wing; the '600' numbers cover the starboard wing; the '700' numbers cover the undercarriage; and the '800' numbers cover the doors, including the bomb bay doors.[8] The following standard MMS diagrams (Figures 10B.1 and 10B.2) illustrating the zones were also to be found reproduced in *e.g.* BAE Systems' BLSC (Phase 1) Zonal Hazard Analysis Report.[9]

[8] The zone numbers refer to the MR2; there are differences between MR2 and R1.

[9] Report No: MBU-DEF-R-NIM-F5-0538

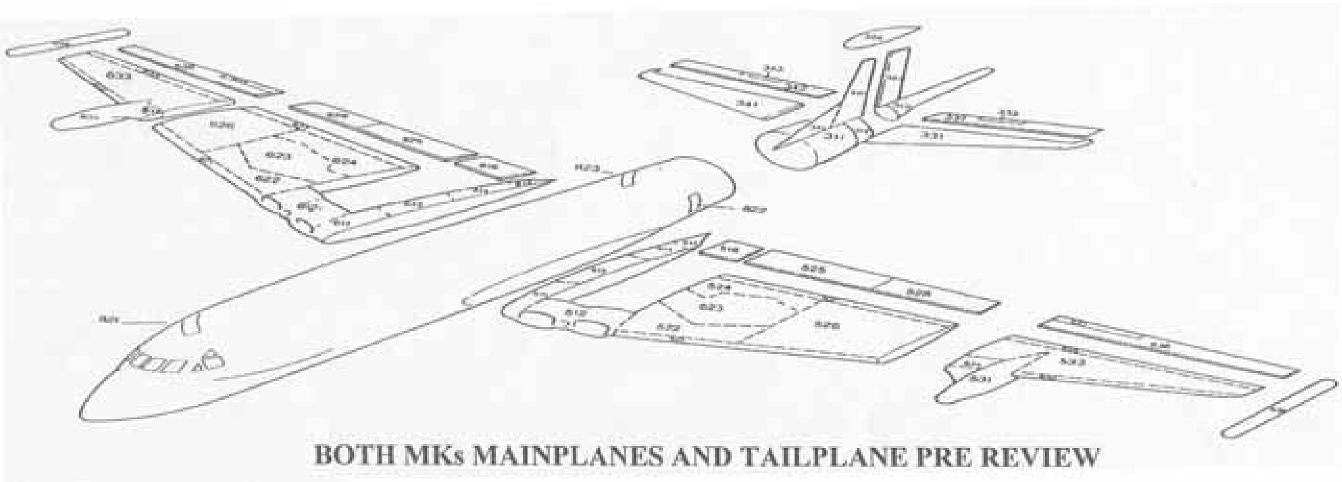


Figure 10B.1: Master Maintenance Schedule diagram showing location of Zone 614

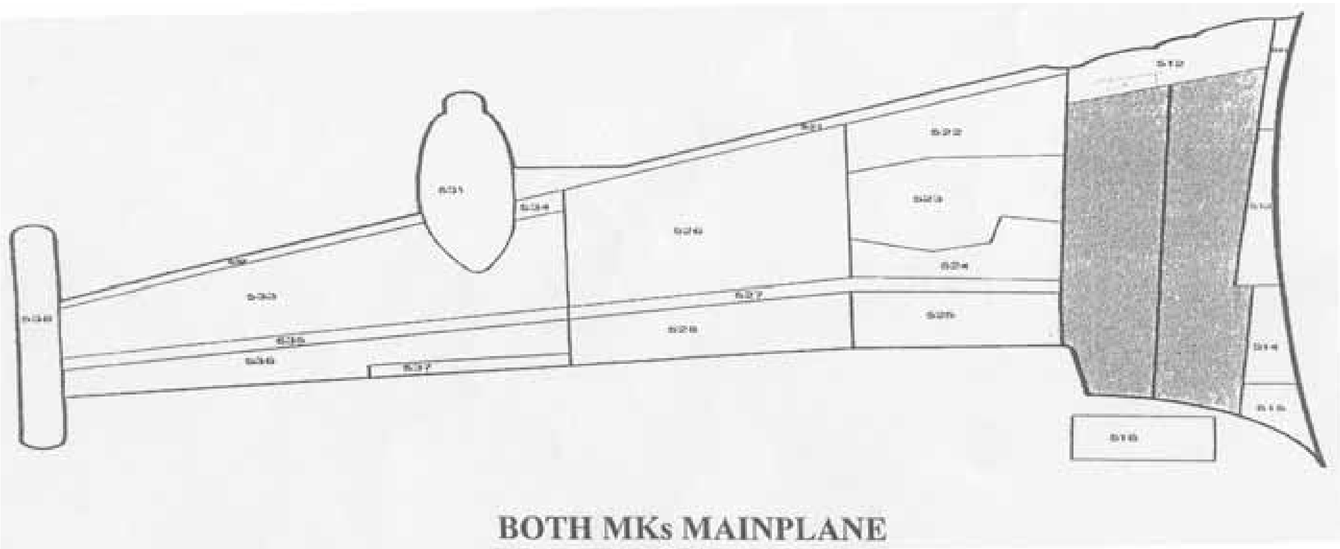


Figure 10B.2: Master Maintenance Schedule diagram showing location of Zone 514

How did the mistake come about?

10B.56 It is unlikely that Frank Walsh would have written in the references to *"Aircraft fire detection and suppression system"* against the hazards in Annex A entirely off his own bat, *i.e.* without the benefit of some information from somewhere. He had never worked on Nimrods himself and had no relevant knowledge of the aircraft's systems.

10B.57 For the reasons set out above, I do not accept that he circulated an e-mail round the office with the list of hazards and zones requesting the various relevant Desk Offices for information as to relevant mitigations. Further, if he had done so, it is likely that, first, the Airframe Desk would have responded accurately given their extensive knowledge of the aircraft; and second, the task would have been recorded on the Nimrod IPT Engineering Management Data Base (EMDB). The fact that the EMDB contains not a single reference to the Safety Case, or to the list of hazards, suggests that no formal request for information was ever made to the Airframe Desk at any stage.

10B.58 The precise reasons how and why Frank Walsh came to make this mistake are not recorded or recalled. I have no doubt, however, that the mistake was essentially of Frank Walsh's own making. It probably came about either because he carried out his own inadequate research in the AP manual, or because he issued a casual request for information of a generalised nature to someone in his office, or even BAE Systems, and misunderstood the answer. In all likelihood, Frank Walsh was probably reluctant to make known the fact that he was now looking to sentence a total of 33 separate hazards because questions might have been raised as to why these had not been raised at the Sixth PSWG, where he had identified only a handful. One plausible scenario is that Frank Walsh, acting on his own initiative, looked up Zone 113 (Aileron Bay) in the AP manual (which *does* have a fire detection and suppression system) and, assuming that the same must be the case for the rest, then simply cut and pasted the same wording it into all 21 of the *"Interacting Systems"* hazards. (It is noteworthy that the Zone 113 entry (Hazard H45) appears at the top of page 2 of Annex A and is the first of the 21 identical *"Interacting Systems"* Hazards H45-H80). Another possible scenario is that Frank Walsh did, at some stage, speak to someone on the Airframe Desk, or even to someone at BAE Systems on the phone, and asked a general question along the lines of: *"What sort of measures does the Nimrod have for preventing fires on board?"*, to which he got a general answer: *"Proper maintenance and fire detection and suppression systems"* and he then simply applied this across the board. In any event, he clearly did not frame a series of detailed questions about the fire controls available in each of the 21 zones relating to the 21 *"Interacting Systems"* Hazards H45 to H80 either orally or in writing. If he had done so, it is likely that he would have elicited the right answer for all (or at least most) of the zones, at least from the notable experts on the Airframe Desk.

Second Error: 'Systems maintained iaw Nimrod maintenance procedures AP101B-0503-1.'

10B.59 The other purported mitigation measure entered in the Control column was *"Systems maintained iaw* [in accordance with] *Nimrod maintenance procedures AP101B-0503-1".* This should not have been relied upon as a hazard control measure. It was not a control measure in any relevant sense since proper maintenance of equipment in accordance with the aircraft Maintenance Manual procedures was assumed, as the Feasibility Study had made clear from the outset.[10] This assumption was further reiterated in the first line of the Summary of the Mechanical Systems (Mech Systems) Pro-Forma for Hazard H73: *"It is assumed that the aircraft is maintained in accordance with ADA approved procedures …"*. There was, therefore, no sense in which the maintenance of the aircraft had any part to play as a hazard control measure.

'Remote'

10B.60 In Annex A, Frank Walsh purported to ascribe a 'Post Control Status' (PCS) to the 33 hazards which BAE Systems had originally marked open and *"Unclassified* in Annex B to the BLSC Phase 2 Report, as follows: *"Occasional"* to two hazards, *"Remote"* to 22 hazards (including Hazard H73), and *"Improbable"* to eight hazards. All 21 *"Interacting Systems Hazards"* were given a PCS of *"Remote"*, *i.e.* a probability of 10^{-5}. The basis for this has not been easy to divine. The fact that 24 hazards remained at a classification of *"Remote"* or above meant that they could not be 'closed' but had to be further 'managed'.

10B.61 Frank Walsh said in interview that even though in the BLSC Phase 2 Report itself BAE Systems had marked 32 of the 43 *"Open"* hazards as *"Unclassified"* (the other 11 *"Open"* hazards being classed as *"Remote"*), he noticed when he went on CASSANDRA that each of the 32 ostensibly *"Unclassified"* hazards had in fact been ascribed 'initial probabilities' on the database. He said that he decided to use these to populate the PCS column of the 32 hazards dealt with in Annex A. The pattern is, however, not consistent. The use of the 'initial probabilities' appears to have repeated for only 24 out of the 33 hazards in Annex A. If one looks at the following three of the 21 *"Interacting Systems"* hazards marked *"Remote"* in Annex A:

- *Hazard H45:* The historical data on CASSANDRA shows Hazard H45 was first ascribed an initial probability of *"Occasional"* on 6 April 2004, with a post probability of *"Unclassified"*. On 25 August 2004, the post probability was revised to *"Probable"*, then *"Improbable"* on 6 September 2004, before being revised back to *"Unclassified"* on 8 September 2004. It was then*,* changed to *"Remote"* on 3 February 2005 following the receipt of Frank Walsh's 1 February 2005 letter.
- *Hazard H62*: The historical data on CASSANDRA shows that on, 15 April 2004, Hazard H62 was ascribed an *"Initial Probability"* of *"Occasional"* with a post control probability of *"Unclassified"*. It was not given a *"Post Probability"* on CASSANDRA of *"Remote"* until 3 February 2005, after BAE Systems received Annex A from Frank Walsh.

[10] Feasibility Study, paragraph 6.2.

- *Hazard H75*: Similarly, the historical data on CASSANDRA shows that, on 19 April 2004, Hazard H62 was ascribed an *"Initial Probability"* of *"Frequent"* with a post probability of *"Unclassified"*. It was not given a *"Post Probability"* on CASSANDRA of *"Remote"* until 3 February 2005, after BAE Systems received Annex A from Frank Walsh.

10B.62 In any event, the approach Frank Walsh took was inappropriate and illogical. It was inappropriate because he chose to ignore BAE Systems' recommendations in Annex C of the BLSC Phase 2 Report that the vast majority of the 32 *Unclassified"* hazards needed *"Further analytical techniques"* or *"further work"* or *"further investigation"* etc. simply in order to classify the hazards. He explained in interview with the Review that he felt there was an element of BAE Systems simply asking for *"more work and money"*. But this may have contained an element of *ex post facto* rationalisation. There is no evidence that he questioned BAE Systems on this aspect, or discussed the approach he was proposing to take with them, or his superiors. He should, at the very least, have done so. From this point onwards, it is unclear precisely: (a) how and why Frank Walsh determined the presence of (non-existent) fire detection and suppression systems in many parts of the aircraft; and (b) how and why he used that information to determine a probability assessment of *"Remote"*. Again, these matters are not the subject of record or recollection. Attempts to divine any real logic to his approach to sentencing these remaining hazards have not proved fruitful.

10B.63 It is, moreover, clear that Annex A was a cut-and-paste job done in a hurry with little real thought given to it. Frank Walsh did not, for instance, include the full zone description from Annex B to the BLSC Phase 2 of the zone in question, i.e. in relation to Hazard H73, Annex B to the BLSC Phase 2 read: *"Zone 514/614 Interacting Systems Hazards – No. 7 Fuel Tank"*. It is worth pointing out at this juncture that it is difficult to see how BAE Systems could have expected the Nimrod IPT properly to sentence these hazards without seeing BAE Systems' Pro-Formas.

Annex A data input to CASSANDRA without being checked by BAE Systems

10B.64 The information contained in Annex A was input to CASSANDRA following its receipt by BAE Systems, i.e. the *"Post Probability"* control status for the relevant hazards was amended in accordance with Frank Walsh's column in Annex A. Witness C [BAE Systems] confirmed in interview that he mechanically typed into CASSANDRA the information provided by Frank Walsh in Annex A without checking or considering whether it was correct or not. He said there was no contractual requirement, as he saw it, for BAE Systems to *"second guess basically the operators of the aircraft and the owners of the aircraft."* On the basis of the strict terms of the Proposal, this is correct. When questioned as to whether or not he queried the number of zones apparently containing a fire detection and suppression system, his response was that, as a non-Nimrod systems expert, it never occurred to him that this was odd and that *"I did not consider it my job to double check what the Air Force were telling me, with regard to their platform."* It is unfortunate that BAE Systems did not see itself as having a wider remit, both as DA and manager of CASSANDRA, not to input nonsense.

10B.65 It is clear that there were some subsequent exchanges between Witness C [BAE Systems] and Frank Walsh. For instance, a copy of Frank Walsh's letter of 1 February 2005 retained in Chris Lowe's working papers, had marked on it in manuscript by Witness C [BAE Systems] a number of amendments to Annex A, including the correct reference for the Nimrod maintenance procedures and further details of the controls for Hazard H42 (Human Factors). These amendments were noted following a telephone discussion conference with Frank Walsh on 3 February 2005. The overall impression gained, from this and other similar documents, is that Witness C [BAE Systems] was generally content merely to amend CASSANDRA in accordance with Frank Walsh's instructions.

22 February 2004: George Baber gives final approval for setting of CASSANRA hazards

10B.66 There is no record of any further discussion between either Frank Walsh and BAE Systems, or Frank Walsh and George Baber until 22 February 2005, when a letter was sent from George Baber to BAE Systems, HQSTC, RAF Waddington, RSAFW4 and Eng Pol AW3, giving final approval for the BLSC. The letter, which was drafted by Frank Walsh and signed by George Baber, stated that the Nimrod IPT had *"reviewed the*

CASSANDRA Hazard Log following receipt of the baseline safety case from BAE Systems" and agreed with the status of the hazards set by BAE Systems and enclosed the evidence to set the rest in the form of Annex A attached to Frank Walsh's letter of 1 February 2005, save for three hazards (Hazards H86, H87 and A6) which required further work (see below). There seems little doubt that a copy of Annex A (expressly referenced in the letter) was in fact attached to the letter. The letter concluded: *"BAE Systems are to accept this letter as the approval to set the CASSANDRA hazards in accordance with Reference A and the status of all hazards and accidents with the exception of H86, H87 and A6 to managed".*

10B.67 It is, on the face of it, puzzling that this letter came to be written and signed at all at this stage. The letter was, on any view, inappropriate and premature because the risks listed could not properly be considered as *"Managed"* at this stage. All 33 hazards listed in Annex A were potentially *"Catastrophic"* risks. The 21 *"Interacting systems hazards"*, together with three others listed in Annex A, were given a PCS of *"Remote"*. These 24 hazards were, therefore, to be classified as category 'B' or *"Undesirable"* risks in the HRI, *i.e.* they required management action to introduce control measures and *"shall only be acceptable once reduced to ALARP"***.** There were seven hazards in Annex A which had been given a PCS of *"Improbable"* and were, therefore, properly to be classified as category 'C' or *"Tolerable"* risks, i.e. tolerable only if further risk reduction was *"impracticable or……grossly disproportionate".* Furthermore, there were two hazards in Annex A (H86 and H87) which had been given a PCS of *"Occasional"* and were, therefore, properly classified as category 'A' or *"Unacceptable"* risks on the HRI, *i.e.* requiring *"Urgent management action since such risk cannot be justified save in extraordinary circumstances".* The Nimrod SMP provided that, in relation to category 'A' or 'B' hazards, it was (only) when control and mitigation actions had been approved by the PE/IPTL and where the PE/IPTL *"…is satisfied that the actions are progressing to plan",* that he/she could change a hazard from *"Approved"* to *"Managed".* The two category 'A' risks (Hazards H86 and H87) were expressly left at the *"Approved"* stage. However, the 24 category 'B' risks were described in the letter as *"Managed".* There is no evidence, however, of any approved management 'actions' being in progress to introduce further mitigating control measures for any of these 24 hazards. Accordingly, these 24 hazards should not properly have been referred to as *"Managed"* in any relevant sense. (The same is true for the 16 other hazards which BAE Systems had also classified as *"Remote"* in Annex B to the BLSC Phase 2, properly classified as 'B' or *"Undesirable"*). There is, however, an air of finality about the letter of 22 February 2005 which suggests that Frank Walsh and George Baber considered the management of all but two of the hazards in Annex A as finished. They were wrong about this.

10B.68 In these circumstances, two questions arise. First, why did Frank Walsh draft the letter in this way and attach Annex A? The most likely explanation is that he did not know what he was doing. He was simply out of his depth. He had never done this sort of exercise before, having never come across a Safety Case or Hazard Log of this type. He had had little or no training or guidance as to how to go about it or the level of rigour that was required. Second, why did George Baber sign the letter? The answer is almost certainly simply because it was put in front of him by a junior officer whom he assumed did know what he was doing, and he did not check that it was correct. I discuss these issues of responsibility in more detail in **Chapter 11**.

16 March 2005: Frank Walsh 'manages' remaining hazards down to 'Improbable'

10B.69 At some stage, Frank Walsh realised that, notwithstanding the letter of 22 February 2005 purporting to give BAE Systems approval to set the status of the vast majority of the hazards listed in Annex A as *"Managed"* in CASSANDRA, it remained necessary to manage a large proportion of hazards in Annex A to acceptable levels, *i.e.* an HRI of 'C'. There were a total of 24 Class A and B hazards in Annex A: 22 hazards (including Hazard H73) had been ascribed a PCS of *"Remote",* and 2 hazards had been ascribed a PCS of *"Occasional"*. The eight hazards which had been ascribed a PCS of *"Improbable"* fell into Class C category and were, therefore, the only ones which could properly be set as *"Managed".* Frank Walsh clearly recognised that the remainder could not remain as class 'A' or 'B' risks.

10B.70 Precisely how and when Frank Walsh came to this realisation again is not clear. It may be that he picked this up during a conversation with someone at BAE Systems. In any event, at some stage on or before 16 March 2005, he drew up a revised version of Annex A. He admitted in interview that he prepared this document entirely on his own. He said that he interrogated the EMDB for details of relevant past incidents. He then added a further column headed *"Further Review"* and entered the following statement for many of the hazards: *"A review of past incidences indicates no major occurrences of these hazards."* The entry for Hazard H73 in this revised version of Annex A read:

No	Hazard	Control	*Further Review*	*Post Control Status*
H73	Z514/614 Interacting Systems	1. Systems maintained iaw Nimrod maintenance procedures AP101B-0503-1. 2. Aircraft fire detection and suppression system.	*"A review of past incidences indicates no major occurrences of these hazards."*	*Remote Improbable*

10B.71 Frank Walsh's intention with this document appears to have been further to manage the classification of 43 hazards which had been classed as 'B' and/or *"Open"* risks in Annex B to the BLSC Reports to a level of *"Improbable"* or below in order that they could be classified as 'C' risks. Thus, in this revised table, all the hazards which had previously been classed as *"Remote"* or *"Occasional"* were re-classified as *"Improbable"* (or in one case, Hazard H83, as *"Incredible"*). A total of 33 remaining hazards were downgraded to *"Improbable"* on the basis of what purported to be a *"Further Review"* entered in the further mitigation column which read: *"A review of past incidences indicates no major occurrences of these hazards"* (see the above schedule extract). This figure of 33 comprised: (a) all the 11 hazards which had originally been classified as open and *"Remote"* by BAE Systems in Annex B to the BLSC; plus (b) the 21 *"Interacting Systems Hazards"* which had previously been given a PCS of *"Remote"* by the IPT in 'Annex A' (including Hazard H73 relating to the No. 7 Tank Dry Bay starboard). Frank Walsh's final sentencing of these hazards (including Hazard H73) on this latter basis was flawed and inappropriate. As was pointed out in the NSC documents themselves, the limited flying hours of the Nimrod made reliance on past occurrences an unsafe basis for mitigation. I reject Frank Walsh's belated suggestion that he would have discussed this work with George Baber. There is no evidence of this.

10B.72 Frank Walsh appears to have sent the revised Annex to Witness C [BAE Systems] under a covering e-mail dated 16 March 2005. I do not accept Frank Walsh's evidence that he conducted his own "*review of past incidences*" by interrogating any databases himself before managing the risks down to "*improbable*". His suggestion that he would have circulated the revised Annex amongst his colleagues in the IPT was thoroughly unconvincing. There is no evidence that he showed it to anyone else in the Nimrod IPT. He did not even see fit to prepare a formal covering letter for the IPTL to sign. The question arises, why would he go about this important task in this manner? The answer again probably lies in the fact that he realised that the previous letter he had asked George Baber to sign did not properly complete the task. It appears, therefore, that he was quietly prepared to sentence 43 hazards on his own. This is despite the fact that, under the Nimrod SMP, only Letter of Delegation (LOD) holders were entitled to sentence risks and that he, Frank Walsh, was not an LOD holder.

10B.73 A possible source of information might have been telephone conversations with BAE Systems during which he was told about the MRA4 generic data and BAE Systems own (blanket) finding, *e.g.* that *"from in-service data the potential for fuel leakage was improbable".*[11]

Revised Annex A data inputted into CASSANDRA without being checked by BAE Systems

10B.74 On receipt of Frank Walsh's e-mail of 16 March 2005, Witness C [BAE Systems] again simply mechanically amended the CASSANDRA Hazard Log to reflect the contents of Frank Walsh's e-mail. His view again was that, at this final stage, BAE Systems was merely acting as a 'stenographer' and was under no obligation to check the accuracy of the information supplied by the IPT. CASSANDRA accordingly records receipt of the revised Annex A as: *"IPT statement issued 16-3-2005 by NIM(ES)Safety".* The CASSANDRA entry for Hazard H73 was amended to downgrade the risk to *"Improbable"*:

[11] See, for example, the Mechanical Systems Pro-Forma for Hazard H73.

"Change	*Approving Officer*		*Status*	*Initial Probability*	*Post Probability*
17 Mar 2005	***[Witness C]***	***Current:***	*Managed*	*Remote*	*Improbable*
		Previous:	*Managed*	*Remote*	*Remote*

Rationale: IPT statement issued 16-3-2005 by NIM(ES)Safety:
A further review of past incidences indicates no major occurrences of these hazards."

10B.75 Thus, by the end of March 2005, all 105 hazards identified in the Phase 1 ZHA had been 'sentenced' down to a probability of *"Improbable"* (10^{-6}), *i.e.* Class C 'tolerable', or less and these classifications entered into CASSANDRA.

10B.76 In this way, therefore, the final sentencing of hazards under the NSC was completed and an apparent 'baseline' established which assumed that the Nimrod was, indeed, safe to operate as required by BP1201. This proved, tragically, to be false.

CHAPTER 11 – NIMROD SAFETY CASE: ANALYSIS AND CRITICISMS

Contents

Chapter 11 sets out my analysis and criticisms of relevant bodies and individuals in respect of the preparation of the Nimrod Safety Case (NSC). It answers the following questions:

- Which organisations bear responsibility for the failures of the Nimrod Safety Case and why?
- Which individuals bear responsibility for the failures of the Nimrod Safety Case and why?
- What criticisms of those organisations and individuals can properly be made and why?

Summary

1. The Nimrod Safety Case represented the best opportunity to capture the design flaws which had lain dormant in the Nimrod MR2 fleet in the decades before the accident to XV230. The *raison d'etre* of a Safety Case is to identify, assess and mitigate serious risks.
2. If the Nimrod Safety Case had been prepared with proper skill, care and attention, the catastrophic fire risk to the Nimrod MR2 fleet represented by the Cross-Feed/Supplementary Conditioning Pack duct and Air-to-Air refuelling would have been spotted and XV230 would not have been lost.
3. Unfortunately, the Nimrod Safety Case was a lamentable job from start to finish. It was riddled with errors. It missed the key dangers. It was essentially a 'paperwork' exercise. It was virtually worthless as a safety tool. The defining features of the four years it took to produce the Nimrod Safety Case are high levels of incompetence, complacency and cynicism by the organisations and key individuals involved.
4. Three organisations are responsible and open to significant criticism:
   - BAE Systems, which is the Design Authority for the Nimrod MR2 and R1 aircraft, and which was formally contracted to produce the Nimrod Safety Case;
   - The Nimrod Integrated Project Team (IPT), which had overall responsibility for the Nimrod MR2 and R1 fleets;
   - QinetiQ, which acted as 'independent advisor' to the IPT in relation to the Nimrod Safety Case.

General malaise

5. As explained in **Chapter 10A**, there was a widespread flawed assumption that the Nimrod was 'safe anyway' and this fatally undermined the Safety Case process.

BAE Systems

6. BAE Systems bears substantial responsibility for the failure of the Nimrod Safety Case.

General failures

7. The failures of BAE Systems in relation to the Nimrod Safety Case are legion: the project planning was poor; the personnel involved were insufficiently trained and inexperienced; the general approach was flawed from the outset, the task was wrongly regarded as essentially a documentary exercise; there was no sensible priority given to the high risks; there was no continuity of personnel; there was little operator input; the project management was inadequate; there was insufficient guidance for staff; the man-hours estimate was inadequate; the task was inadequately resourced; there was disagreement, confusion, and dissent between those involved as to how to proceed; the Phase 1 zonal inspections were unsound, superficial and carried out by personnel with little practical knowledge of the aircraft. The inadequacy of the Phase 1 zonal inspections was key to what followed: thereafter everyone was playing catch up. The basics had not been done in the first place.

Rushed work

8. When progress on Phase 2 fell behind, BAE Systems did not react appropriately: the IPT was not told and a suitable extension of the deadline was not sought; work became increasingly rushed and the quality of work suffered; corners were cut; inappropriate data was used to assess and sentence hazards; all the contractually required data was not used; pressure was put on staff to finish by the deadline (end August 2004); there was no proper 'internal review' of the work (although the IPT was subsequently told otherwise); there was strong commercial motivation to finish the Nimrod Safety Case by the deadline at all costs (payment and prestige which BAE Systems hoped would lead to further similar work).

Misleading

9. When handing over the task at the Customer Acceptance Conference on 31 August 2004 to 1 September 2004 (and at a subsequent meeting on 10 November 2004), BAE Systems contrived to create the misleading impression that it had fully and properly completed the Nimrod Safety Case and that it could be safety signed off by the IPT and QinetiQ. As explained in **Chapter 10A**, however, BAE Systems did not give a full or accurate picture: BAE Systems deliberately did not disclose to its customer at the meeting the known figures for the large proportion of hazards which it had left "*Open*" and "*Unclassified*" (many with only vague recommendations that 'further work' was required) or otherwise draw attention to the large gap remaining in its analysis. The IPT and QinetiQ representatives were lulled into a false sense of security (but were to some extent also the authors of their own misfortune (see further below)).

Standard of work lamentable

10. The general standard of BAE Systems' work on the Nimrod Safety Case was lamentable. It was riddled with errors and of generally poor quality throughout. In particular: there was a general lack of consistency; there were significant errors of fact; there was erroneous or poor identification of proper hazard mitigation; there were generally low levels of analysis; and there was evidence of the increasingly deleterious effect of time constraints on the quality of the analysis, and the use of much 'cut-and-paste' and 'get out' phrases such as "*...further analytical techniques are required...*".

Miscategorisation of H73

11. BAE Systems mis-categorised Hazard H73 (the catastrophic fire risk represented by the Cross-Feed/Supplementary Conditioning Pack duct in the No. 7 Tank Dry Bay starboard) as 'Tolerable' when it plainly was not, and then marked it as "*Open*" and "*Unclassified*" because further work was required which it did not have time to do. Its analysis was sloppy, flawed, unrealistic and incomplete.

Breach of contract

12. BAE Systems was in breach of its contractual obligations to the IPT in respect of Phases 1 and 2 of the Nimrod Safety Case in failing to complete the task and failing to use reasonable skill and care.

Causation

13. I am satisfied that if the Nimrod Safety Case had been properly planned, managed and carried out by BAE Systems, the risk of a catastrophic fire in the No. 7 Tank Dry Bay starboard would have been correctly assessed and mitigated to As Low As Reasonably Practicable (ALARP), such that the accident which subsequently befell XV230 would have been avoided.

Criticism of individuals

14. The following key BAE Systems management personnel involved in the Nimrod Safety Case in 2001-2005 bear primary responsibility for the above matters:

- Chris Lowe (Chief Airworthiness Engineer).
- Richard Oldfield (Task Leader).
- Eric Prince (Flight Systems and Avionics Manager).

Lack of true co-operation with the Review

15. BAE Systems says it has recorded more than 20,000 man hours ‘assisting’ the Nimrod Review and providing evidence. It appears to the Review, however, to have spent a significant amount of that time building a wall of denial and obfuscation which the Review has had to dismantle, brick by brick. This has inevitably lengthened the Nimrod Review considerably.

Culture

16. The regrettable conduct of some of BAE Systems’ managers suggests that BAE Systems has failed to implement an adequate or effective culture, committed to safety and ethical conduct. The responsibility for this must lie with the leadership of the Company.

17. BAE Systems formalised its UK ethics policy in 2002, setting out five key principles of ethical business conduct: “*accountability, integrity, honesty, openness and respect*”. In my judgment, all five principles were breached in the present case.

Nimrod IPT

18. The IPT at the time bears substantial responsibility for the failure of the Nimrod Safety Case.

General failures in situ

19. The IPT inappropriately delegated project management of the Nimrod Safety Case task to a relatively junior person without adequate oversight or supervision; failed to ensure adequate operator involvement in BAE Systems’ work on Phases 1 and 2 of the Nimrod Safety Case; failed properly to project manage the Nimrod Safety Case, or to act as an ‘intelligent customer’ at any stage; failed to read the Nimrod Safety Case Reports carefully or otherwise check BAE Systems’ work; failed to follow its own Safety Management Plan; failed properly to appoint an Independent Safety Advisor to audit the Nimrod Safety Case; and subsequently signed-off BAE Systems’ work in circumstances where it was manifestly inappropriate to do so.

Sentence of risks on manifestly inadequate basis

20. The IPT sentenced risks on a manifestly inadequate, flawed and unrealistic basis, and in doing so mis-categorised the catastrophic fire risk represented by the Cross-Feed/Supplementary Conditioning Pack duct (Hazard H73) as ‘Tolerable’ when it plainly was not.

Fundamental failure to ensure safety

21. The IPT failed to ensure that resources within the IPT were properly utilised to ensure the airworthiness of the Nimrod fleet and to ensure that safety and airworthiness was the first priority.

22. The IPT was sloppy and complacent and outsourced its thinking.

23. The IPT fundamentally failed to do its essential job of ensuring the safety of the Nimrod aircraft.

Causation

24. If the IPT had done its job properly, there was a good prospect that Hazard H73 would have been properly assessed and addressed, and XV230 would not have been lost.

Criticism of individuals

25. The following three key personnel within the IPT bear substantial responsibility for the failure of the NSC to capture the risk which led to the loss of XV230 and are open to significant criticism:

- Group Captain (now Air Commodore) George Baber (IPT Leader).
- Wing Commander Michael Eagles (Head of Air Vehicle).
- Frank Walsh (Safety Manager).

QinetiQ

26. QinetiQ also bears some share of responsibility for the failure of the Nimrod Safety Case.

General failures as 'independent advisor'

27. QinetiQ failed properly to carry out its role as 'independent advisor', in particular, QinetiQ: failed to formalise QinetiQ's appointment as 'Independent Safety Auditor' or otherwise to clarify its role at any stage; failed to check that BAE Systems sentenced risks in an appropriate manner, i.e. using appropriate data; failed to check that BAE Systems included risk mitigation evidence in its Reports; sent someone ill-prepared to the critical Customer Acceptance Conference; failed to read the NSC reports or otherwise check BAE Systems' work; failed to advise the IPT properly at the Sixth Platform Safety Working Group meeting or ask any intelligent questions; subsequently 'signed-off' or supported the 'sign-off' of BAE Systems' Nimrod Safety Case reports in circumstances where it was manifestly inappropriate to do so: (a) without even having read any of them; and (b) in the absence of an Independent Safety Auditor audit report, contrary to Joint Service Publication (JSP) 553 and Defence Standard 00-56.

Lax and compliant

28. QinetiQ's approach was fundamentally lax and compliant. QinetiQ failed at any stage to act as the independent 'conscience' of the IPT. As a result, the 'third stool' in the safety process, namely independent assurance, was effectively missing from the Nimrod Safety Case process.

Causation

29. The outcome could have been different if QinetiQ had performed its role properly.

Criticism of individuals

30. The following personnel bear primary responsibility for QinetiQ's failures:

- Martyn Mahy (Task Manager).
- Colin Blagrove (Technical Assurance Manager).

Introduction

Background - Chapters 9 and 10A & B

11.1 This Chapter is to be read together with **Chapters 9** and **10A & B**. As explained in those Chapters:-

> 11.1 Safety cases were mandated for military platforms by Joint Service Publication (JSP) 318B (Edition 4). The *raison d'être* of a safety case is to identify, assess and mitigate serious safety risks. In April 2001, the Nimrod Integrated Project Team (IPT) tasked BAE Systems to produce a Safety Case for the Nimrod MR2 and R1.[1] BAE Systems was the natural choice for this task as the Design Authority (DA). QinetiQ acted as 'independent advisor' in relation to the Nimrod Safety Case (NSC).
>
> 11.2 The NSC was drawn up in three phases: Phase 1 conducted by BAE Systems (April 2001 and to April 2003) comprising 'hazard identification'; Phase 2 conducted by BAE Systems (August 2003 to September) comprising 'hazard assessment' and 'hazard mitigation'; and, following hand over of the 'completed' task by BAE Systems to the Nimrod IPT in September 2004, a Third Phase conducted by the Nimrod IPT (September 2004 to March 2005) comprising sentencing of the remaining hazards left "*Open*" by BAE Systems.
>
> 11.3 The Board of Inquiry (BOI) found inaccuracies in the NSC in relation to the hazard which caused the loss of XV230 (the Cross-Feed/Supplementary Conditioning Pack duct, Hazard H73).[2] The Review conducted a detailed analysis of the entire NSC and found systemic errors, inaccuracies and poor analysis. The Review conducted a detailed investigation into the preparation of the NSC (2001 to 2005) and found major failings in all three Phases of its preparation by all three organisations involved, namely the Nimrod IPT, BAE Systems and QinetiQ.

Criticism of organisations and naming of individuals

11.2 In this Chapter, I set out and explain my detailed criticisms of the three organisations involved and the responsibilities which each bear for the poor state of the NSC and the catalogue of major failures which the NSC embodies, including, in particular, the fundamental failure to capture the risk that caused the loss of XV230. I also specifically name, and criticise, the key individuals within these organisations whose conduct, in my view, fell well below the standards which might reasonably have been expected of them at the time. As explained in **Chapter 1**, I have only named and criticised organisations and individuals where I consider it necessary, fair, and proportionate and in the public interest to do so.

11.3 Given the chronological way in which the NSC was developed, it is convenient to consider the responsibilities and criticisms of the organisations and individuals involved in the following order:

- **BAE Systems;**
- **Nimrod IPT;**
- **QinetiQ.**

General malaise – flawed assumption Nimrod 'safe anyway' and NSC 'paper' exercise

11.4 I turn, first, however, to explain a general malaise which in my view affected the attitude of all those involved in the NSC, to a greater or lesser extent.

11.5 First and foremost, as highlighted in **Chapter 10A**, the NSC process was fatally undermined by a flawed assumption that the Nimrod was 'safe anyway' and that, therefore, the NSC exercise did not really matter. The exercise was seen as merely one of proving something which everyone already knew as a fact, *i.e.* that the Nimrod was safe. This attitude was corrosive and served to undermine the integrity of the whole NSC process.

[1] PDS Task 16 3151.

[2] BOI Report, page 2.32.

11.6 Second, the NSC became a documentary exercise and an end in itself. As explained in **Chapter 9**, the *raison d'etre* of a 'Safety Case' is to 'identify, assess and mitigate' all potential significant hazards to pieces of equipment, platforms or installations, including hidden, or previously unidentified, hazards. Lord Cullen regarded the drawing up of a 'Safety Case' as merely a means to achieving this end, *i.e.* it was intended to provide a structure for critical analysis and thinking, or a framework to facilitate a thorough assessment and addressing of serious risks. Unfortunately, in the case of the NSC, the production of a 'Report' became an end in itself. Critical analysis descended into a paperwork exercise. Compliance with regulations was the aim. This was partly because thinking on all sides was fatally undermined that by the assumption that the Nimrod *was* safe anyway.

11.7 Third, the seeds of these problems were partly sown by BP1201 which espoused an "*implicit Safety Case"* for legacy aircraft based on a "*basic assumption that the aircraft is already operating to acceptable levels of safety.*"[3] The notion of an "*implicit*" Safety Case is, however, something of an oxymoron. A Safety Case is intended to be an exercise in critical thinking and actual assessment of risk. An "*implicit*" Safety Case, based on the assumption there are no actual risks, is the antithesis of this. First, contrary to the philosophy expounded by Lord Cullen,[4] an "*implicit*" Safety Case sanctions reliance on past success as a guarantee of future safety *in lieu* of a proper risk *analysis* based on sound engineering practice. Second, it encourages 'documenting' the past rather than carrying out a fresh assessment of the potential risks in the future, and thus is an invitation to those inclined to paperwork exercises.

11.8 Fourth, as Professor John McDermid[5] pointed out to the Review, there is also a danger in merely contracting for a Safety Case 'report', as opposed to a proper 'risk analysis'. If one contracts for the former, then this is precisely what one is likely to get. The Nimrod IPT contracted for a "*Safety Case report*" to comply with its obligations under BP1201. The Nimrod IPT's own Safety Management Plan (SMP) highlighted that there was already a "*high level of corporate confidence in the safety of the Nimrod aircraft*", but a lack of "*structured evidence*" to support that confidence. This was the context in which the Nimrod IPT instructed BAE Systems to develop a baseline safety case report.[6]

[3] **Chapter 9**, paragraph 9.58.

[4] Subsequently recognised in the *White Booklet* in 2002, which stated that the non-occurrence of an accident was no guarantee of a safe system.

[5] Professor of Software Engineering and leader of the High Integrity Systems Engineering Group within the Department of Computer Science at the University of York.

[6] *Cf.* to similar effect the comments of the (then) IPTL at the Inaugural PSWG meeting on 18 March 2002, see paragraph 10.45 of **Chapter 10A.**

CRITICISMS OF BAE SYSTEMS in relation to the Nimrod Safety Case

Introduction

11.9 In my judgment, BAE Systems bears considerable responsibility for the lamentable quality of the NSC and its singular failure to capture the risk that caused the loss of XV230.

11.10 BAE Systems played a major role in the construction of the NSC. It was tasked by the Nimrod IPT as DA to develop an 'explicit' Safety Case for both Nimrod types. It agreed to do so in two phases: Phase 1 comprising inspections of the aircraft and 'hazard identification'; and Phase 2 comprising 'hazard assessment' and 'hazard mitigation' based on 'readily available' evidence. Both Phases were deeply flawed and unsatisfactory from beginning to end.

11.11 As set out in **Chapter 10A**, there were significant flaws in the NSC which was produced in the period 2001 to 2005. The NSC failed to identify the serious fire risk in the No. 7 Tank Dry Bay starboard which the Cross-Feed/SCP duct posed to the Nimrod fleet (Hazard H73) and which subsequently caused the loss of XV230 in September 2006.

Errors in relation to H73

11.12 The Review initially identified five errors in the NSC in relation to Hazard H73:

(1) The NSC incorrectly stated, as mitigation for the Zone 614 hazards, that there was an aircraft fire detection and suppression system, but neither exist within Zone 614. (This error is repeated for numerous other Zones, *e.g.* 512, 522, 523, 527, 534, 531, 535 and 538.)

(2) The NSC incorrectly stated that the Cross-Feed duct "*is only pressurised when the cross-feed pipe is open, i.e. during engine start*", but did not take into account the lengthy periods it could be pressurised (at a working temperature of up to 420°C) when feeding the SCP.

(3) The NSC stated that "*the Bleed ducting is insulated and so surface temperatures will be below bleed air temperatures*" but failed to note that: (a) there were gaps between the insulation; (b) some parts of the Bleed ducting had no insulation; and (c) the insulation was in poor condition in some areas.

(4) The NSC stated that "*From in-service data the potential for fuel pipe leakage is given as Improbable*".

(5) The NSC failed to pick up on the zonal risk presented by the location and proximity of the starboard blow-off valve immediately forward of the No. 7 Tank Dry Bay, such that fuel expelled from the blow-off valve could track back into the No. 7 Tank Dry Bay and ignite.

11.13 The Review went on to conduct a detailed investigation into the NSC. The Review found: First, the errors identified by the BOI and the Review in relation to Hazard H73 were not one-off, but appear to have been symptomatic of a generally poor standard of accuracy and analysis in the NSC. Second, the NSC Baseline Safety Case Reports (BLSC Reports) produced by BAE Systems left over 30% of the hazards "*Unclassified*" and 40% of the hazards remained "*Open*", many with no recommendation beyond simply that "*Further analytical techniques are required*" before they could be categorised, sentenced and closed. Third, the Fire & Explosion Report did not accord with the BLSC Reports produced by BAE Systems. Fourth, the NSC had not reduced the risks to the Nimrod fleet to ALARP.[7]

Summary of criticisms of BAE Systems in relation to NSC

11.14 In my judgment there were significant failings by BAE Systems at virtually every stage of the planning, management, and execution of Phases 1 and 2 of the NSC. After carefully considering all the witness and documentary evidence, I have come to the conclusion that the following criticisms of BAE Systems are borne out:

[7] *i.e.* Risks were not reduced to As Low As Reasonably Practicable (ALARP). See **Chapter 9**.

(1) BAE Systems' attitude to the NSC was flawed from the outset: it assumed that the Nimrod was 'safe anyway' because of its long record and approached the NSC as essentially a documentary, rather than an analytical, exercise.

(2) BAE Systems failed to carry out a proper 'feasibility study'.

(3) BAE Systems failed to ensure its personnel were properly trained, experienced and competent for the task.

(4) BAE Systems failed to ensure vital operator (*i.e.* RAF) involvement.

(5) BAE Systems failed to ensure continuity of personnel.

(6) BAE Systems' project planning was poor.

(7) BAE Systems' Phase 1 work was superficial and inadequate.

(8) BAE Systems under-estimated the resources required for Phase 2.

(9) BAE Systems' personnel and task management of Phase 2 was poor and there were personality clashes which led to further delays.

(10) BAE Systems' promises as to completion were unreasonably optimistic.

(11) BAE Systems' management exerted unreasonable pressure on its personnel to meet the deadline and the final Phase 2 work was increasingly rushed and corners were cut.

(12) BAE Systems used inappropriate data to sentence risks (including Hazard H73).

(13) When presenting the results of its work at the 'Customer Acceptance Conference', BAE Systems misrepresented that it had completed the task and deliberately did not disclose to the Nimrod IPT or QinetiQ the actual percentage figures for the large proportion of hazards which it had left "*Open*" and "*Unclassified*" or otherwise draw attention to the large gap remaining in its analysis.

(14) BAE Systems' representation that it had carried out an "*independent review*" of its NSC work was an exaggeration.

(15) BAE Systems' BLSC Reports gave the impression to the cursory reader that the aircraft could be "*deemed acceptably safe to operate*" without substantial further work.

(16) When presenting its work to the Platform Safety Working Group, BAE Systems again deliberately kept quiet about the large percentage of hazards it had left "*Open*" and "*Unclassified*".

(17) BAE Systems' analysis, assessment and categorisation of Hazard H73 was seriously erroneous.

(18) The general standard of BAE Systems' analysis, assessment and categorisation of the hazards was lamentable: the Pro-Formas (1) lacked consistency; (2) contained numerous significant factual errors; (3) contained numerous examples of poor or inefficacious mitigation; (4) demonstrated generally low levels of analysis; and (5) showed the increasing effects of time constraints.

(19) BAE Systems' Fire & Explosion Report was superficial and slapdash and failed properly to address the risk of a catastrophic fire in the No. 7 Tank Dry Bay (*i.e.* Hazard H73).

(20) BAE Systems was in breach of contract for: (1) failing to exercise reasonable skill and care; (2) failing to use appropriate data when sentencing risks; and (3) leaving the NSC task incomplete.

(21) If BAE Systems had properly planned, managed and carried out the NSC, the risk of a catastrophic fire in the No. 7 Tank Dry Bay would have been identified, assessed and mitigated to ALARP, such that the accident which subsequently befell XV230 would have been avoided.

(22) BAE Systems is a company in denial – and its defensive attitude has delayed the Review by many months.

(23) BAE Systems has failed to live up to its expressed UK ethics 2002 policy of "*accountability, integrity, honesty, openness and respect*".

Detailed analysis and criticisms of BAE Systems

11.15 I analyse and explain each of these criticisms in turn in detail below.

(1) BAE Systems' attitude to the NSC was flawed from the outset: it assumed that the Nimrod was 'safe anyway' because of its long record and approached the NSC as essentially a documentary, rather than an analytical, exercise.

Prevailing malaise: flawed assumption that the Nimrod was 'safe anyway'

11.16 In my judgment, BAE Systems' attitude to the NSC was fundamentally affected by the prevailing malaise (outlined above) that, because the Nimrod had operated safely for over 30 years, it could be assumed that the Nimrod was 'safe anyway' and that, therefore, the NSC exercise did not really matter. Thus it was that BAE Systems' approach to the NSC was flawed and undermined from the outset: it approached the task assuming 'safety' and viewed the NSC task as essentially a documentary or paperwork exercise aimed at proving something that it already knew, *i.e.* that the Nimrod was safe.

Merely making 'explicit' what was 'implicit'

11.17 BAE Systems' approach involved essentially making 'explicit' that which was 'implicit',[8] namely. to construct an 'explicit' Safety Case by documenting the 'implicit' Safety Case. In other words, it viewed its task as being that of finding the documents to evidence the safety of the aircraft, which could be assumed on the basis of its 30 years' service record.[9] BAE Systems argued in its written submissions to the Review that *"[t]here is nothing wrong with describing the creation of a Safety Case for a legacy aircraft with a good safety record as an exercise in making explicit what has previously been implicit".* I disagree. A Safety Case is pointless if it is simply an exercise in making explicit what is (assumed to be) implicit, *i.e.* documenting the past. As the Zonal Hazard Analysis course which the BAE Systems employees attended highlighted, *"system safety emphasises <u>analysis</u> rather than past experience and standards"* (emphasis added).

'Archaeological exercise'

11.18 BAE Systems initially embarked upon what is best described as an 'archaeological' exercise with regard to the original certification of the aircraft, *i.e.* demonstrating that, at the time the aircraft was designed and built, it complied with relevant safety and certification requirements.[10] A number of witnesses from BAE Systems (as well as the IPT and QinetiQ) sought to justify the validity of such a documentary exercise to the Review. I remain wholly unconvinced as to its utility. Whilst a failure to comply with relevant regulations and standards may, of

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[8] **Chapter 10A**, paragraphs 10A.16 and 10A.17.

[9] Note the Nimrod Safety Management Plan (SMP) envisaged that the existing available evidence would be 'supplemented' by further analysis and a structured assessment of the risks.

[10] As exemplified by the second sub-goal identified in the Feasibility Study (*"all relevant safety and certification requirements and standards are demonstrated as having been met"*).

course, be indicative of a potential hazard, I fail to see that merely demonstrating that the aircraft was designed and manufactured in compliance with certification standards 30 years ago allows any conclusion to be drawn as to the current safety of the aircraft, or potential existing hazards. In my view, even though a trawl through the records may have the attraction of being superficially comforting, as well as relatively undemanding work, it is likely to prove time-consuming and un-rewarding; or, as Witness K [BAE Systems] warned early on in the NSC process, it would end up being *"an expensive paperchase"* and *"poor value for money"*. It is troubling that, as Witness L [QinetiQ] informed the Review, a high percentage of safety cases tend to comprise simply a process of *post hoc* documentation of what engineers originally did to design the system in question.

11.19 BAE Systems spent an inordinate amount of time conducting documentary archaeology, *i.e.* trawling through historical design data, but later skimped on the crucial hazard analysis (see further below). The former was easier to do than the latter but was of substantially less value. In any event, the effectiveness of BAE Systems' trawl of its own records remains questionable. It does not appear to have unearthed any of the 1980s reports concerning the fatigue life of the hot air ducts (see **Chapter 7**) which would have contradicted the conclusion reached by BAE Systems in the NSC that *"From in-service data the potential for bleed air duct leakage is given as Improbable"*[11] (see further below).

'Target' was to find evidence of safety not unsafety

11.20 BAE Systems' stated aim in constructing the NSC was '*wherever possible*' to '*mitigate*' catastrophic hazards down to *"Improbable"* (*i.e.* a 'tolerable' level) using existing documentary evidence.[12] As Witness R [BAE Systems] explained, the task or aim he was given was to look for evidence that would demonstrate the risk was *"Improbable"*. The target was thus *"improbable"*. Herein lay the seeds of the problem: the task was not to find out what the real risks were so much as to document that risks were *"Improbable"*, *i.e.* safe. In other words, the task was to demonstrate that the aircraft *was* safe rather than officiously to look for gaps in safety.

'Wood-for-the-trees'

11.21 In my view, BAE Systems' approach to the NSC was also flawed for a further reason: BAE Systems sought to identify, assess and mitigate *every* conceivable hazard to the same degree. This lacked common sense, particularly given the age of the Nimrod fleet and the limited time and budget available, and was not sound practice. It would have been better to have focused effort on 'identifying, assessing and mitigating' potential high risk areas.[13] This was not a novel idea.[14] Further, BAE Systems' own guidelines for fire zonal hazard analysis (ZHA) for the MRA4[15], recommended the identification of *"High Risk"* fire zones and concentration on 'mitigating' the fire hazards in such zones. BAE Systems nevertheless failed to follow this approach in the NSC. The result was that BAE Systems spread its efforts too thinly and failed to see the 'wood-for-the-trees'.[16] The initial identification of 1,300 'hazards' by the BAE Systems Phase 1 team further demonstrated a lack of competence and basic understanding as to what they were doing (see further below).

11.22 It should be noted that BAE Systems regularly used the term '*mitigating risks*' to describe the task of finding existing mitigation. This should be distinguished from the true meaning of 'mitigating risks' which should properly refer only to the task of putting into effect new control measures to bring identified hazards down to acceptable ALARP levels.

[11] Section 6 of the Mechanical Systems Pro-Forma for Hazard H73.

[12] As admitted in BAE Systems' written submissions to the Review.

[13] As QinetiQ was later to do in its Nimrod Fuel System Zonal Hazard Assessment QINETIQ/EMEA/IX/SA0701788, Issue 1, appended to its Nimrod Fuel System Safety Review QINETIQ/EMEA/IX/SCR0702915, Issue 1, dated October 2007.

[14] See *e.g.* the Jaguar Safety Case analysis.

[15] Contained in, *(e.g.)* Annex G of the Nimrod MRA4 System Safety Working Practices AWN/NIM/897, Draft Issue 7 (Revision 7, Version 1).

[16] *e.g.* The same process was used to assess the (non-existent) fire risk posed by a fuel sampling flask kept in the Nimrod toilet as to assess Hazard H73.

(2) BAE Systems failed to carry out a proper 'feasibility study'.

Assertion rather than research

11.23 In my judgment, BAE Systems is at fault for failing to carry out a proper 'feasibility study' prior to pitching to the Nimrod IPT. The BAE Systems document entitled *"Safety Case and Baseline Report Feasibility Study",* dated March 2002, drafted by Chris Lowe was based on assertion rather than research. In my view, there was little proper justification for BAE Systems' bold assertion therein that it had *"a high level of confidence"* that it could undertake the preparation of the NSC itself and the Baseline Safety Case Reports (BLSC Reports) for the MR2 and R1 *"in an effective, competent, expedient and cost-effective manner"*. None of the BAE Systems personnel involved in the production of the NSC had ever done a Safety Case before. Very few, if any, had any experience of Zonal Hazard Analysis (ZHA). No proper 'feasibility' study had been carried out. BAE Systems had not even undertaken any initial assessment of the current availability of appropriate Hazard Data and Fault Tree Analysis data*,* as required under PDS Task AV(PDS)814. (It was not until March 2004 that Witness K [BAE Systems], acting on his own initiative, even began his search of the archives held by BAE Systems.)

Commercial 'puff'

11.24 BAE Systems explained to the Review that it had drawn on a number of previous in-service safety assessments (on the Jaguar, Harrier and Tornado aircraft and Failure Mode Effect Analyses (FMEAs) on the Nimrod's flight safety critical systems), BP1201 and the *White Booklet*, plus other advisory material available from aerospace industry steering bodies, such as the Society of British Aerospace Companies (SBAC).[17] The SBAC Guidance contained little more than a re-statement of the MOD policies and requirements promulgated in JSP318B, Def-Stan 00-56 and BP1201. There was little underlying basis or justification for BAE Systems' statement of confidence. No proper investigation or 'feasiblity' work had, in fact, been carried out. Attempts by BAE Systems to suggest that success was 'not assured' and little reliance could be placed on the *"Feasibility Study"* because detailed costs and timing had still to be worked out, miss the point: the clue is in the name, *"Feasibility Study"*. As BAE Systems' Chief Airworthiness Process Engineer and Deputy Head of Airworthiness, Witness A [BAE Systems], accepted during interview with the Review, the title *"Feasibility Study"* was something of a misnomer. In my view, it was no more than a commercial 'puff' to secure the business.

(3) BAE Systems failed to ensure its personnel were properly trained, experienced and competent for the task.

11.25 In my judgment, the majority of the BAE Systems personnel involved in the NSC were incompetent to carry out the task. They were insufficiently trained and experienced in Safety Cases and the techniques they were required to employ, in particular, as to how to carry out a Zonal Hazard Analysis (ZHA) or how to carry out the analysis and risk classification required to produce a Safety Case.

Lack of training and experience

11.26 Apart from Chris Lowe, it appears that few, if any, of the BAE Systems personnel had received any significant training on how to produce a Safety Case, beyond attending the short internal BAE Systems course on ZHA,[18] or a general two week system safety course run by York University for BAE Systems. Richard Oldfield, who led the Phase 1 inspection team, had never done a ZHA before, and was not aware that any of his team had done one before, save possibly Witness C [BAE Systems]. Chris Lowe had written an MSc thesis on Fire Safety Cases (entitled *"The Everlasting Fire Threat – A Review of the Overall Fire/Explosion Risk in Commercial Transport Airframe Design and Operation"*[19]) but does not appear extensively to have consulted other departments in BAE Systems who may have carried out similar projects. Further, it is not clear that any of the BAE Systems personnel involved even had any significant training or qualifications in 'safety engineering' itself.

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[17] SBAC guidance entitled *"Issues to be addressed by industry in the provision of an air systems safety case"*.

[18] **Chapter 10A**, paragraph 10A.56.

[19] Lancaster University Engineering Department, September 2003.

Identification of 1,300 'hazards' suggests incompetence

11.27 The initial identification of 1,300 'hazards' by the BAE Systems Phase 1 team demonstrated a lack competence and basic understanding as to what they were doing. They confused 'hazards' with 'events' and 'conditions' leading to hazards. This was described by Witness L [QinetiQ] (see below) as a rudimentary *"schoolboy error"*, which showed a lack of competence in safety engineering.

(4) BAE Systems failed to ensure vital operator (i.e. RAF*) involvement.*

Operator involvement axiomatic

11.28 In my judgment, BAE Systems is at fault for failing to ensure any real involvement of the 'operators' of the Nimrod aircraft (*i.e.* RAF maintenance and flight crew) at any stage during Phases 1 and 2 in the production of the NSC.[20] Lord Cullen in the *Piper Alpha* report had emphasised the need for operator involvement in a Safety Case. This was reiterated by the MOD in the *White Booklet*.[21] It is clear that operator involvement in the process of developing a safety case for a 'legacy' platform such as the Nimrod was axiomatic to its success, not least because those charged with maintaining and flying the aircraft over the years had detailed, practical knowledge of the aircraft and the working of its systems, which the designers would not have.

'Joint' working group initially envisaged

11.29 BAE Systems' failure to involve the operators at any stage is surprising and unfortunate. BAE Systems itself appears to have appreciated the importance of operator involvement and to have embraced the notion, at least initially. BAE Systems recommended that a joint Safety Case BAE Systems/Nimrod IPT working group be set up *"to partake in the identification determine causes and effects and mitigation of all hazards, and contribute toward the consequent population of the hazard log"*.[22] At the Inaugural Project Safety Working Group (PSWG) meeting on 18 March 2002, Chris Lowe stated that the identification and addressing of all safety hazards should be carried out by a joint safety working group, small in size, with input from ADA and MOD and "*be made up of players with genuine expert knowledge*".[23]

BAE Systems never set up joint working group or consulted operators

11.30 BAE Systems failed to ensure that a joint working group was set up and met regularly. BAE Systems did not consult personnel at RAF Kinloss or RAF Waddington responsible for flying or maintaining the aircraft during Phase 1 or 2. It is fair to point out that the Nimrod IPT is equally open to criticism for not insisting on a joint working group, and for not officiously seeking to be involved in Phase 1 or 2 of the process at any stage. The Nimrod IPT was very much hands-off, and eyes-off (see above). There was no satisfactory explanation for BAE Systems' failure to set up a joint working group. It just did not happen. It may have been regarded as giving rise to unnecessary customer interference. This was unfortunate. None of the BAE Systems personnel had suitable practical operating experience of the Nimrod aircraft or its systems. BAE Systems used personnel it called Nimrod 'specialists' but who had never, or rarely, seen or inspected a Nimrod aircraft, and who had little practical knowledge or experience thereof, albeit some had considerable 'design' experience.

Practical experience vital

11.31 In seeking to justify its choice of personnel to the Review, BAE Systems sought to emphasise the number of years that members of the Phase 1 ZHA team had spent working with Nimrods on design issues. In my view, however, such theoretical, design, office-based experience is a far cry from the invaluable practical, hands-on experience that those flying or maintaining the aircraft on a daily basis would have had. Both types of knowledge are required for a proper hazard analysis. Further, whilst broad experience of other aircraft is valuable, it is no

[20] Save for the Fault Tree Analysis.

[21] **Chapter 9,** paragraph 9.66 and 9.67.

[22] See paragraph 10.2 of the Feasibility Study.

[23] **Chapter 10A,** paragraph 10A.35.

substitute for hands-on experience of the legacy aircraft in question. BAE Systems sought to argue that *"past hands-on Nimrod experience (whilst potentially an advantage) was not an essential requirement for the task"* of hazard assessment and mitigation.[24] I profoundly disagree. In my view, those flying and maintaining legacy aircraft are equal, if not greater, repositories of vital knowledge regarding the aircraft than the designers for a hazard analysis exercise. If BAE Systems had ensured proper operator input in Phase 1 and Phase 2 (or had the Nimrod IPT insisted thereon) the outcome might well have been different. BAE Systems' continued denial, in its submissions to the Review, of the absence of any 'necessary' operator or maintenance personnel in Phase 1 or Phase 2, was disappointing.

(5) BAE Systems failed to ensure continuity of personnel.

Importance of continuity of personnel obvious

11.32 In my judgment, BAE Systems is at fault for failing to ensure continuity of the personnel involved in Phase 1 and Phase 2 of the NSC. The need to ensure continuity was obvious: those involved in carrying out the initial Phase 1 inspections also needed to be involved in the later Phase 2 analysis.

Little continuity

11.33 With the exception, however, of Witness G [BAE Systems[and Witness H [BAE Systems], none of the BAE Systems personnel who carried out the Phase 1 physical inspection hazard 'identification' exercise were involved in the Phase 2 hazard 'assessment' and 'mitigation' exercises. Richard Oldfield and Witness C [BAE Systems] did not draw up the Phase 2 Pro-Formas. Thus, the drawing up of the Pro-Formas and the sentencing of hazards was largely done by personnel who had not been involved in the original inspections. They were, therefore, at a considerable disadvantage even though the Phase 1 personnel may have been available in the office. I have highlighted in **Chapter 10A** the difficulties that the BAE Systems personnel involved in the Phase 2 (office) exercise faced in interpreting the sketchy quality of the initial zonal hazard reports and photographs produced by those involved in Phase 1.[25] BAE Systems accepted this criticism but said that it was difficult to 'ring fence' Phase 1 participants from other commitments until such time as the IPT authorised Phase 2 to commence. In my view, having committed itself at the beginning to carrying out the NSC, and having expressed a "*high level of confidence*" in its ability to do so in a *"in an effective, competent, expedient and cost-effective manner"*, it was incumbent on BAE Systems to ensure the availability of the right personnel throughout. This is why good planning is so important.

(6) BAE Systems' project planning was poor.

11.34 In my judgment, BAE Systems' project planning for the NSC was poor from the outset. There are four particular criticisms that can be made.

Skills

11.35 First, BAE Systems gave inadequate attention at the outset to the skills required to carry out the ZHA and produce a Safety Case. BAE Systems failed to think about whether its staff were adequately trained and experienced in ZHA and Safety Cases. The courses they were sent on were a start, but insufficient (see above). Most were being expected to do something which they had not done before and of which they had little background knowledge of how to go about.

Scoping

11.36 Second, BAE Systems failed properly to scope the task or give sufficient consideration to the nature and extent of the work that the NSC would entail. Insufficient thought was given at the outset as to what, in fact, the task required and how, in practice, it was to be carried out. BAE Systems explained in its written evidence to the

[24] BAE Systems' written submissions to the Review.

[25] **Chapter 10A,** paragraphs 10A.78 and 10A.81.

Review that the NSC task had been discussed both internally, and also with the IPT, with a view to defining the scope of the work, in particular, at a meeting on 3 December 2001. However, in my view, this was no substitute for proper scoping of the work. It is instructive that BAE Systems did not even investigate its own archives until March 2004, *i.e.* during the course of Phase 2, notwithstanding with the express requirement to do so in PDS Task AV(PDS) 814 at the outset. BAE Systems' archives should have been sorted out, indexed and examined at the outset to see what relevant material they might, or might not, have contained. Further, BAE Systems also ought arguably to have carried out a 'dry run' of a specimen hazard and zone, with a view to ensuring both that the complexities of the process were properly understood and scoped, and that the results of Phase 1 were going to be adequate to support Phase 2. Only by doing these things would BAE Systems be in a position properly to begin to assess the likely scale of work, the manpower and resources required and the timescale involved. Richard Oldfield did, in fact, suggest that a 'dummy run' be carried out to check his estimates; but this was never done. BAE Systems rather stumbled into the task assuming that it was going to be a fairly straightforward documentary exercise. It was to prove anything but straightforward.

Guidance

11.37 Third, there was little, if any, guidance forthcoming from the Airworthiness Department in the early stages of the project as to: (a) whether the 'assessment' of each hazard was to be carried out in Phase 1 or Phase 2; (b) by whom such assessment was to be carried out; (c) the level of assessment and analysis required; and (d) the basis on which the platform was to be assessed, *i.e.* whether 'as-designed', 'as-built' or 'as-is' (see further below). Further, there appears to have been a lack of understanding that the 'assessment' phase and 'mitigation' phase should, in fact, have been separate processes. *"Mitigation"* was not used in the usual sense of the word, namely to indicate a fresh step taken to control or minimise a risk. Rather, it was used by BAE Systems to indicate the process of finding existing evidence of controls on the risk. This was, however, part of the assessment of the risk process. There remained a difference of view in evidence to the Review between *e.g.* Richard Oldfield and Chris Lowe as to what parts of the risk assessment process should have been done in Phase 1and Phase 2 respectively.

Man-hours

11.38 Fourth, BAE Systems' poor pre-planning led to it under-estimating the man-hours required for Phase 2 and under-resourcing Phase 2 (see further below). In these circumstances, it is perhaps unsurprising that BAE Systems' work in relation to Phase 2 subsequently began to unravel and fall behind.

11.39 In its evidence to the Review, BAE Systems pointed to the numerous meetings, e-mails and memos which it submitted demonstrated its good pre-planning. Quantity, however, does not equal quality. In my view, the BAE Systems' personnel responsible for the NSC simply did not think through the planning properly, or consult sufficiently with others in the company who may have had relevant experience, such as those involved in the Jaguar safety case. BAE Systems accepted, with hindsight, that its planning could have been better. In my view, it was a matter of foresight and common sense.

(7) BAE Systems' Phase 1 work was superficial and inadequate.

11.40 In my judgment, the way in which BAE Systems went about Phase 1 was superficial and inadequate.

No 'analysis' in Phase 1

11.41 First, the ZHA carried out by BAE Systems at RAF Kinloss and RAF Waddington in Phase 1 included little, if any, actual analysis on site. These visits constituted no more than general zonal inspections by the BAE Systems teams. The process was simply one of 'inspect and record' with a view to recording potential hazards and taking photographs as an *aide memoire*, as opposed to analysing, *e.g.*, how systems might interact to cause a hazard. Richard Oldfield described them in interview as an 'identification exercise' and said they involved no analysis.

Sketchy details and inadequate photographs in Phase 1

11.42 The 'inspect and record' process was itself sketchy. The worksheets contained the bare minimum of detail and the descriptions of hazards were often vague and imprecise. This was particularly true of the worksheet for Zones 514/614 which referred simply to *"Fuel Coup/Fuel, ECS, Flying con, elect cables".* Further, the photographs taken were often unclear and unlabelled. This caused difficulties later for people back in the office trying to carry out hazard analysis using other people's brief and often vague descriptions and unclear photographs. BAE Systems' continued denial of this to the Review flew in the face of the evidence of its own witnesses. It is unfortunate that, at no stage during Phase 2 was the opportunity taken to check hazards or information by re-inspecting a Nimrod, notwithstanding that Richard Oldfield indicated at a meeting on 7 July 2004 that aircraft were available for this purpose at Woodford and RAF Kinloss.[26]

No regard to actual condition in Phase 1

11.43 Second, the Phase 1 zonal inspections paid insufficient or incomplete regard to the actual condition of particular zones or systems, notwithstanding: (a) this was intended to be a zonal hazard analysis on a 30 year old 'legacy' aircraft; and (b) the guidance in the Nimrod MR2 & RMk1 Generic Hazard Checklist,[27] which clearly anticipated that account was to be taken of the actual condition of at least certain elements of the aircraft. Thus, whilst wire 'chaffing' was noted in accordance with the Checklist, no, or no proper, account was taken of other deterioration, in particular, the condition of the Refrasil insulation or the condition of the muffs around the Cross-Feed/SCP ducts. In order to explain why it failed to highlight the deteriorated condition of the insulation, BAE Systems sought in its submissions to the Review to argue that its hazard assessment had been *"as-designed"*. It was not clear precisely what it meant by this; but, in any event, it did not square with the assessment of *actual* condition required by the Checklist, or the obvious need to assess a 30-year-old legacy aircraft in its 'as-is' condition. I do not accept BAE Systems' suggestion that the Checklist was merely referring to the *potential* for cable chaffing arising from design. I also do not accept BAE Systems' assertion that the NSC was 'always intended and understood' to be *"as-designed"*. There is no contemporary evidence to support this. The words *"as-designed"* cannot be found anywhere in any of the contemporaneous documents. References to distinctions drawn with 'operational' safety cases are not to the point. The only proviso to be found was that in the Pro-Formas to the effect that the risks were assessed on the assumption that the aircraft were *"maintained in accordance with ADA procedures"*.[28] In any event, the notion of an *"as-designed"* safety case makes no sense in the context of a hand-built 30- year-old legacy aircraft. This was *ex post facto* rationalisation. In my view, there is little point or utility in a hazard assessment of a 30-year-old aircraft that does not take account of its 'as-is' condition.

11.44 It is to be noted that BAE Systems used fewer man-hours in Phase 1 than budgeted (and therefore made a greater (26.1%) profit on the Phase 1 work than forecast (12%). Those carrying out the Phase 2 hazard assessments were almost entirely dependent on the detail and quality of the descriptions and photographs done during Phase 1. Witness R [BAE Systems] accurately and prosaically termed the Phase 2 exercise as being simply an assessment of the risks *"as-described".* Any other description would be to imbue the Phase 2 exercise with a sophistication which it did not have.

(8) BAE Systems under-estimated the resources required for Phase 2.

11.45 In my judgment, BAE Systems' inadequate pre-planning led to it significantly under-estimating the man-hours required for Phase 2 and the consequential under-resourcing of Phase 2.

Inadequate man-hour estimates

11.46 The various systems departments were asked to provide man-hour estimates for Phase 2 of the work, but were not given a clear idea of the nature and scope of the work required. As a result, these departments duly provided initial estimates based simply on the time that it would take to conduct the necessary document search.[29] It

[26] **Chapter 10A,** paragraph 10A.78.

[27] Report No. MBU-DEF-R-NIM-FS-0538 Nimrod MR Mk2 – Baseline Safety Case (Phase 1) Zonal Hazard Analysis (ZHA), Appendix C, page C-3.

[28] See *e.g.* paragraph 6 of the Mech Systems Pro-Formas.

[29] **Chapter 10A,** paragraphs 10A.98, 10A.109, 10A.113-114, and 10A.128.

subsequently transpired, however, that much more detailed analysis was required *i.e.* to assess and to mitigate the hazards in the light of any documentary evidence found. This resulted in a clash of approach between the Mechanical Systems Department (Mech Systems) and the Airworthiness Department.[30] The man-hour estimates originally provided for Phase 2 proved to be inadequate by a considerable margin. Mech Systems, in particular, under-estimated the man-hours required by 610 hours. This, in turn, put pressure on resources. The situation would have been different if (a) a proper scope of work had been drawn up and agreed with each relevant specialist department, in order to ensure that everyone involved understood what was required from the outset and that adequate resources could be, and were, allocated to the project at all stages; and (b) clear written instructions had been given to each of the specialist departments by the Airworthiness Department, setting out what steps they were required to take, and suitable 'Pro-Formas' drawn up and agreed at an early stage. None of these things were done.

11.47 It should be noted that, at an early stage, both the BAE Systems Airworthiness Department and the Systems Departments expressed concern as to whether sufficient resources were available for the NSC.[31] The problem became more significant once it was realised that the archives contained much less available mitigating evidence than BAE Systems and Chris Lowe expected. There was also a lack of available suitably qualified personnel to carry out the analysis within the Systems Departments, in particular, in Electrical Systems. As explained in **Chapter 10A** and further below, this led to delays and increasing time pressures in completing the project.

(9) BAE Systems' personnel and task management of Phase 2 was poor and there were personality clashes which led to further delays.

11.48 In my judgment, BAE Systems' personnel and task management of Phase 2 itself was poor.

Lack of management guidance

11.49 There was a lack of guidance from BAE Systems' management for BAE Systems' staff in relation to how the requisite hazard 'identification', 'assessment' and 'mitigation' processes should be carried out, and what the Pro-Formas should contain. It was the management's job to set the tasks and give appropriate guidance to the staff as to how to go about it. When Witness K [BAE Systems] sought to obtain further guidance or query the validity or value of a suggested approach, his questions were 'swatted away' on more than one occasion by the Airworthiness Department which seemed intent on completing the project, in whatever fashion, within the required timeframe.

Personality clash

11.50 The contemporaneous exchanges and notes of meetings, in particular, the notebooks of Witness K [BAE Systems], reveal that there were significant tensions between the Airworthiness and Systems Departments. In particular, there was a significant clash of personalities between Chris Lowe and Witness K [BAE Systems], a fact confirmed by a number of the other BAE Systems witnesses who gave evidence to the Review. Chris Lowe was a Grade 4 Executive and more senior than Witness K [BAE Systems], a Grade E engineering desk level practitioner. Witness K [BAE Systems] was struggling, understandably in my view, to identify just what it was that the Airworthiness Department required the Specialist Departments to do given the *lacunae* which he had discovered in the archives by way of useful 'mitigating' evidence. The task was clearly not going to be as simple as originally envisaged. Both he and Mech Systems were unsure how best to go about addressing the hazards, or precisely what form the Pro-Formas should take. He rightly looked to Chris Lowe, as the Head of the Airworthiness Department, for guidance on his proposals. But Chris Lowe clearly regarded Witness K [BAE Systems]'s repeated questions as a source of irritation and, instead of engaging in a dialogue and discussion with him on the way forward, tended to respond in a somewhat overbearing and dismissive manner. As Witness P [BAE Systems] explained in interview, *"toys were definitely thrown out of the cot"*, and it was often a case of *"Chris' way or no way"*. It is clear that Chris Lowe did not easily brook dissent and tended to retreat into his shell when confronted, rather than properly managing professional disagreements with more junior employees.

[30] Otherwise known as Safety and Certification Department.

[31] See, *e.g.*, **Chapter 10A,** paragraph 10A.38.

Delays resulted

11.51 The tension between Chris Lowe and Witness K [BAE Systems] is of far more than mere anecdotal interest. As more than one BAE Systems witness explained to the Review, the relationship between Chris Lowe and Witness K [BAE Systems] ultimately broke down altogether, effectively semi-paralysing the progress of the NSC project for a period of some months between March and July 2004, leading to serious deadline pressures. It took three to four months, from early April to 7 July, to achieve agreement between the Mech Systems and Airworthiness Departments on the form of the zonal Pro-Forma. It is inevitable in any organisation that tensions and professional differences between employees and departments will occur from time to time; but these situations should be managed properly and resolved quickly and not allowed to fester and affect outputs, particularly where safety is concerned. Chris Lowe admitted in interview that he found Witness K [BAE Systems] '*irritating*' and they had '*issues*' and differences, but denied a breakdown in relations. I am satisfied that this clash of personalities between Chris Lowe and Witness K [BAE Systems] was a significant factor. It was not managed properly or sorted out. It did affect the project and cause delay.

(10) BAE Systems' promises as to completion were unreasonably optimistic.

11.52 In my judgment, BAE Systems' promises to the Nimrod IPT as to when the task would be completed were unreasonably optimistic. Chris Lowe should not have reported to the IPT and QinetiQ at the Fifth PSWG meeting on 18 May 2004 that Phase 2 of the NSC was *"considered to be progressing well"* and that BAE Systems was *"highly confident that they will produce the Baseline reports as programmed (end July 2004)"*. As Witness K [BAE Systems] noted privately in his notebook, it is difficult to see how Chris Lowe could properly have made this statement to the Fifth PSWG *knowing* as he did that:

(1) All hazards had still not yet been delivered to the Engineering Department (and should have been supplied by the end of February);

(2) BAE Systems still did not have a practical way ahead on ZHAs;

(3) The Engineering Department had had a four month window reduced to one month to complete its tasks;

(4) There were resource problems, particularly with Electrical Systems;

(5) Only about six to eight hazards out of 104 had been returned; and

(6) There remained a 'high volume' of work to be discharged.

11.53 Chris Lowe suggested that the progress report he gave to the Fifth PSWG meeting was '*not an unreasonable one*'. I disagree. He should not have made this statement to the client knowing what he did. It resulted in further pressure in the months to come.

(11) BAE Systems' management exerted unreasonable pressure on its personnel to meet the deadline and the final Phase 2 work was increasingly rushed and corners were cut.

11.54 In my judgment, there can be no doubt that Phase 2 became delayed and BAE Systems ran seriously short of time to meet the end of August deadline for completion, with the consequence that corners were cut. This was largely due to its failure properly to plan and manage the project in the first place. In the later stages, BAE Systems' management brought pressure to bear on its personnel to finish the task. I have concluded that, as a result, BAE Systems' work on Phase 2 of the NSC was increasingly rushed and quality inevitably suffered.

Delays and 'Final push'

11.55 By 7 July 2004, only 41 out of 104 hazards had been returned and 63 remained to be completed. Mech Systems had only completed 20% of its work. In order to speed matters along, BAE Systems then resorted to using 'generic' MRA4 data to sentence MR2 and R1 hazards (see further below). By 16 August 2004, the situation had become critical with some 50 out of 104 hazards completed. By this stage, there was a serious backlog in the Mech Systems and Electrical Systems departments. Nevertheless, BAE Systems management continued to press for completion of the Task by the end of August 2004, because the project was perceived as prestigious and important for those involved and for future BAE Systems business. Chris Lowe demanded a *"final push"* for completion by the end of the week. It is no coincidence that Hazard H73 was part of this final push. In a matter of hours on 26 August 2004, Witness T [BAE Systems] sent no fewer than four completed Pro-Formas (Hazards H69, H76, H77 and H93) back to the Mechanical Systems Department. On 30 August 2004, the day before the Acceptance Conference, second issues of six hazards (Hazards H70, H72, H73, H74, H75 and H77) were formally signed-off and subsequently approved by Eric Prince.

11.56 The dangers of putting undue time pressures on engineers was put by Counsel to the Review to Richard Oldfield:

> *"**MR PARSONS QC:** The danger with 'final pushes' is that there are often casualties, aren't there?*
>
> ***MR OLDFIELD:** I don't think that would ever be the case, in terms of the professionalism of completing the task from the engineers.*
>
> ***MR PARSONS QC:** If you put engineers under pressure to complete a task in a short period of time, there is a risk that corners will be cut and mistakes will be made?*
>
> ***MR OLDFIELD:** I think we were just emphasising the fact that we wanted one last effort to actually complete it, as best we could. There's – I wouldn't say there was any undue pressure that had been put on top of the engineers on that. There was no additional, you know, excessive man hours that was worked for that last final push. It was just a case of emphasising the need to put extra effort in, in the last – last couple of weeks before the acceptance conference."*

11.57 As I explain in further detail below, the quality of 'assessment' and 'mitigation' analysis done by BAE Systems in relation to the remaining hazards suffered as a result of these time, resource and management pressures.

(12) BAE Systems used inappropriate data to sentence risks (including Hazard H73).

11.58 In my judgment, BAE Systems resorted to using inappropriate data to sentence hazards. This was due to time pressures, and a general lassitude about how hazards were closed off.

Inappropriate use of MRA generic data

11.59 The months of July and August 2004 were undoubtedly a time of growing pressure for those involved in the NSC within BAE Systems, as explained above. By 7 July 2004, Mech Systems' task was only 20% done and only 41 out of 104 hazards had been returned and 63 still remained to be done. Completion was subsequently put back to the end of August 2004. On 8 July 2004, following discussion within BAE Systems initiated by Witness R [BAE Systems] as to whether there were any *"standard values"* which could be used to sentence hazards, Witness S [BAE Systems] circulated an e-mail to the specialist engineers attaching MRA4 generic probability data which he said had been extracted from the Nimrod MRA4 System Safety Working Practices (Annex G).[32] The generic failure types and probabilities were derived from the in-service data obtained from a number of other aircraft, such as the Tornado and the Hawk, and (apparently) gave a standard failure probability rating for a number of common failure types, including that for a failure of a *"fuel pipe and associated coupling"*, which was ascribed a failure probability of 1E-6.[33] Witness S [BAE Systems]'s email was copied to Chris Lowe, Richard Oldfield and Eric Prince.

11.60 Chris Lowe's evidence in interview on the use of MRA4 data was unsatisfactory. He said that he had been aware that the data existed and had been sent to Witness S [BAE Systems] and Witness K [BAE Systems], but professed not to have been aware at the time of the NSC as to *"exactly"* how they used that data, although he would

[32] AWN/NIM/897 Issue 7 (Revision 7, Version 2).

[33] This generic probability data had previously been agreed with the Nimrod MRA4 IPT for use for the Nimrod MRA4.

have had no objection to it being used as a *"reality check"*, but would have felt *"a little uncomfortable"* if it had been used as the primary source of data. Subsequently, he denied that he actually knew that it was being used at all. This denial surprised even Eric Prince who pointed out to the Review that Chris Lowe had actually recruited Witness S [BAE Systems] from the MRA4 project. I am satisfied Chris Lowe was dissembling. He must have been very well aware at the time that the generic MRA4 data was being used by the specialist departments to sentence NSC risks. He was the Chief Airworthiness Engineer in charge of the project and played a hands-on role. If he was not aware, he certainly should have been. At the First PSWG meeting on 18 March 2002, he had (rightly) ruled out the use of MRA4 hazard data, on the very good grounds that there were significant differences in the systems of the MRA4 and the MR2/ R1 and the platforms were of very different ages. He stated in interview that, if MRA4 generic data had been used to sentence risks because time was running short, then *"*[he didn't] *think it would be a good thing at all"*. In 2004, however, I find he was prepared to condone it, or turn a blind eye to it, for reasons of expediency.

11.61 Richard Oldfield said in interview that he was not aware that MRA4 data was being used as anything other than a 'sanity' check; and that if it was being used as the primary source of sentencing, he would have investigated it further since it was not part of the original proposal data and that he would have highlighted this to the customer. However, I reject BAE Systems' submission to the Review that that MRA4 generic data was only used as a '*secondary*' source of evidence or a '*reality check*'. It is clear from Witness R [BAE Systems]'s evidence that the MRA4 generic data was the *primary* source of data for sentencing risks such as Hazard H73, and that this is what is referred to as *"in-service data"* in the Pro-Formas. It should be noted that there is no evidence that the Nimrod IPT was ever informed by BAE Systems at the time that MRA4 generic data was being used to sentence MR2 and R1 hazards. MRA4 generic data was (rightly) not used in the subsequent review of the NSC (Safety Case 2, see **Chapter 15**).

Reliance on past data

11.62 Reliance on past data cannot be considered a substitute for critical hazard analysis as to the risk of a catastrophic event in the future (*c.f.* the clear statements to this effect in the current edition of the *White Booklet*)[34]. In simple terms, whilst an incident database may tell you what has happened in the past, it does not tell you what might, or could, happen in the future. It should be remembered that the day before the *Piper Alpha* disaster itself in 1988, and the *Challenger* disaster in 1986, the platforms involved were 'safe' based on an analysis of past incidents alone. BAE Systems expressly recorded both in its Feasibility Study and Fire & Explosion Report that the small Nimrod fleet size and limited flying hours of the MR2 and R1 gave rise to *"low confidence levels"* in any statistical data based on in-service failure rates of a unit or system. Witness L [QinetiQ] of QinetiQ said that this *caveat* was inserted at his insistence.

BAE Systems' alleged approach to sentencing

11.63 In its written responses to the Review, BAE Systems stated that, during the hazard assessment exercise, it began by reviewing the Nimrod data contained within its VC-10/Nimrod Incident Report database (which held details of reported incidents since 1974 and showed only 30 incidents of fuel leakage across the Nimrod fleet in the period up to 2004) and it 'supported' this review by also referring to the generic MRA4 data. In my judgment, there were a number of fundamental things wrong with this approach (if used, see below) to the sentencing of risks, leaving aside the objections of principle discussed above.

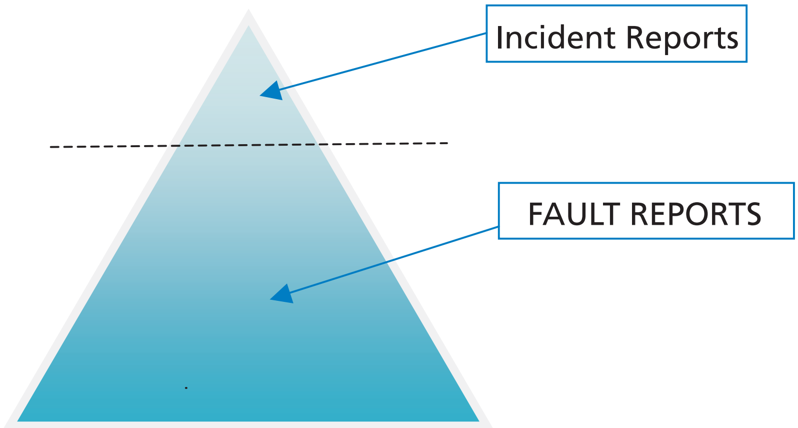
11.64 First, as the Review's examination revealed, the Incident Report database apparently used by BAE Systems contained insufficient detail to support any meaningful conclusion about the probability of fuel leaks in any particular zone or from any particular component (*i.e.* a fuel pipe or coupling).[35] Further, even if one were to accept BAE Systems' evidence that the Incident Report database contained only 32 reports in respect of the fuel system between 1971 and 2006 and that less than half of these concerned fuel leaks, that provides no basis for any conclusion that the risk of a leak was *"improbable"* (i.e. no greater than 1×10^{-6}). Taking a figure of 16

[34] **Chapter 9,** paragraph 9.67.

[35] For example, a search for the word "leak" identified a number of Incident Reports which, on closer analysis, had nothing to do with a fuel leak at all.

reports, based on total fleet flying hours of 400,000 hours, the probability would equate to 4 x 10^{-5} (*i.e.* 2.5 times greater than *"improbable"*). In any event, the Review has seen clear evidence of six leaks within a period of five years (1999 – 2003).[36] It is therefore my conclusion that there was no basis for any assessment of the probability of a fuel leak as *"Improbable"*.

11.65 Secondly, there appears to have been no attempt whatsoever to look at in service fault data (as required by BAE Systems' proposal), *i.e.* leaks that were reported as faults but not leading to in-flight or ground 'incidents'. Fault data comprises those routine technical defects discovered during maintenance which, in themselves, are not unusual and do not represent a particular threat to the aircraft safety, but which may nonetheless form part of a trend such as to give rise to a potential airworthiness issue (see the 'iceberg' illustration below). Such fault data is stored on the RAF's Maintenance Data System (MDS). Whilst it is known to be notoriously difficult to extract any meaningful data from this system, even a cursory examination would have shown *"Improbable"* to be a ludicrous label for fuel leaks. Had BAE Systems taken the trouble to examine the fault data (as they had promised they would do in their Proposal) they would (or ought to) have found the same information extracted by the BOI, *i.e.* a leak rate from fuel couplings of around 38 per year since the year 2000.



11.66 Thirdly, BAE Systems' use of generic MRA4 data was plainly inappropriate in the NSC. The obvious reason why generic data (taken from the Hawk and Tornado aircraft) was required to be used in relation to the MRA4 was because it was a new aircraft with no in-service data, hence a generic starting point was required. In the case of the Nimrod, however, there was in my view no justification for using generic data based on other aircraft types when there did, in fact, exist years of documented history specific to the Nimrod (albeit that even this data needed to be treated with caution).

BAE Systems continued denial

11.67 BAE Systems' response on these important issues was essentially one of denial that its approach was wrong. The extent to which this was merely forensic is unclear. BAE Systems has, however, continued to display a disturbing (apparent) lack of understanding of just how unsatisfactory its approach to the sentencing of risks in the NSC was. Nor has it appreciated the fundamental need to analyse fault data, as the following paragraph in its written submissions to the Review illustrates:

> *"104. It is true that an Incident Database might not capture all minor fuel leaks. On the other hand, what was relevant to the Safety Case project was the prevalence of fuel leaks with the capability of causing a catastrophic loss. It was reasonable to assume that the Incident Database would give an accurate picture of those (subject to limitations arising from the total flight time of the Nimrod fleet). Coupled with added confirmation derived from considering the Tornado/Hawk generic failure rate, a probability assessment of "Improbable" was tenable."* (emphasis added)

[36] Incident Serial No. Kin 114/99, Air Incident Serial No. Kin 120/99, Air Incident Serial No. Kin 95/00, Air Incident Serial No. Kin 104/00, Air Incident Serial No. Kin 43/03. and Air Incident Serial No. Kin 87/03.

Primary sentencing source was MRA4 data

11.68 The extent to which BAE Systems did in fact use the in-service incident database remains, however, unclear. A number of BAE Systems' personnel interviewed by the Review said that they had, or probably would have, consulted the Incident Report database. In view of the time pressures that they were under, however, and the frequency with which one finds seemingly 'cut and paste' statements along the lines of *"From in-service data the potential for fuel pipe leakage is given as improbable"* in the various Pro-Formas, I consider it more than likely that resort was had primarily, if not exclusively, to the generic MRA4 generic data as a simple way of assessing and sentencing hazards. They were increasingly busy personnel under time pressure who had the difficult job of assessing and sentencing hazards based on no more than a general description of a hazard and limited photographic evidence. It is clear from BAE Systems' Pro-Formas, and was admitted by BAE Systems in its written evidence to the Review, that the BAE Systems' personnel involved in Phase 2 did indeed proceed to sentence these risks (including Hazard H73) on the assumption that the risk of a fuel leak from a single fuel coupling on a Nimrod MR2 or R1 was 1×10^{-6} (*i.e. "Improbable"*), primarily on the basis of the generic MRA4 data. It should be noted that the Nimrod IPT were told at the Sixth PSWG meeting on 10 November 2004 that *"Hazard ... numerical probabilities have been deliberately not used as the basis for the Nimrod Hazard Log."* We now know that this was not correct since the numerical probability of 1×10^{-6} derived from the MRA4 generic data was used.

Assumption of fuel leak risk of 1×10^{-6} was unreasonable

11.69 In my judgment, it was wrong and unreasonable, in any event, for BAE Systems to have calculated the risk of a fuel coupling leak in Zone 614 (Hazard H73) as *"Improbable"* (1×10^{-6} to 10^{-7}).

11.70 In the first place, the MRA4 generic data figure was obviously wrong as far as its applicability to fuel coupling leak rates in the Nimrod MR2 and R1 fleets was concerned. It put the risk of a fuel leak from a single fuel coupling as 1×10^{-6} , *i.e.* the probability of a fuel leak from a coupling occurring on average only once-in-a-million flying hours. However, anyone with maintenance experience of the Nimrod fleets would intuitively have known this was far too optimistic and, if asked, would have pointed out that fuel coupling leaks were known to occur in the Nimrod fleets much more often than that. Moreover, a thorough and proper analysis of in-service incident and fault data should have shown BAE Systems that the risk of a fuel coupling leak was much greater than 1×10^{-6}.

11.71 In the second place, as Witness K [BAE Systems] agreed in interview with the Review, allowance should have been made for the fact that there were approximately nine or ten fuel couplings in the No. 7 Dry Bay Starboard in close proximity to, and which could have affected, the Cross-Feed/SCP pipe. Accordingly, the risk would be in the region of one order of magnitude greater, i.e. *"Remote"* (1×10^{-5} to 10^{-6}). BAE Systems sought to argue otherwise on the basis that *"only fuel leaks capable of being ignited should be considered"* in its submissions to the Review. Common sense would suggest, however, that all nine to 10 fuel couplings should be taken into account given: (a) the unpredictable nature of fluid paths means that any fuel leak ought to be considered at least potentially capable of being ignited; and (b) the fact that the heat sources in the No. 7 Tank Dry Bay are located at or near to the bottom of the bay, directly below the fuel pipes and couplings.

11.72 In the third place, the precautionary principle would suggest that, where the indications are borderline, the more stringent criteria should always be applied, *i.e. "Remote"* (1×10^{-5} to 10^{-6}). Indeed, the Nimrod Safety Management Plan (SMP) (which had been provided to BAE Systems by the IPT) expressly provided (at paragraph 27) that, where the indications were borderline, *"the more stringent criteria should always be applied to ensure appropriate management action is taken"*. BAE Systems, nevertheless, relied on the generic MRA4 statistical data to assume that a fuel coupling had a probability of 1×10^{-6} for the purposes of categorising the risk of Hazard H73 as *"Improbable"* (1×10^{-6} to 10^{-7}), when the more stringent criteria should have been applied, *i.e. "Remote"* (1×10^{-5} to 10^{-6}).

No cross-reference to functional hazard Pro-Forma Hazard H34

11.73 No regard or cross-reference seem to have been made to the warning in the functional hazard Pro-Forma completed for the whole fuel system by Mech Systems on 30 July 2004 (Functional Hazard H34) which listed a number of fuel leak incidents and stated:

> *"5. Conclusion…*
> *The design of the fuel system is such that the LRU failures can be tolerated, with the system being managed by the flight engineer. The trend of incidents with respect to leakage from fuel couplings and from the Jettison pipe flap areas poses more of a zonal hazard than a functional one."* (emphasis added)

Leak paths notoriously unpredictable

11.74 BAE Systems further sought to justify the classification of *"Improbable"* (1 x 10^{-6} to 10^{-7}) to the Review on the additional basis that "*any leak would still have to migrate to a source of ignition, which is clearly always less than a certainty*".[37] In my view, this sort of *ex post facto* rationalisation was grasping at straws and unhelpful. There was no indication that this was a part of the thought process at the time. Nor should it have been, given the notorious unpredictability of leak paths.

Causation – use of MRA4 generic data

11.75 It is clear, in my view, that the inappropriate use by BAE Systems of MRA4 generic data to sentence MR2 and R1 hazards was the key factor which led to an incorrect and overly optimistic probability being ascribed to Hazard H73. It is equally clear that, but for the inappropriate use of MRA4 generic data, the outcome would have been different. As Witness R [BAE Systems] admitted in interview, without the MRA4 generic data, Mech Systems would not have been able to progress the sentencing exercise and would have had to go back to the Airworthiness Department and ask for further information. It is likely that, in these circumstances, the Airworthiness and Mech Systems Departments would have been forced to look hard at the fault data in the RAF MDS. Moreover, when BAE Systems came to conduct its review of the Safety Case in 2008 (Safety Case 2), the maintenance personnel from the Nimrod Servicing Group estimated that the probability of fuel coupling leaks was far more frequent than the MRA4 generic data suggested.

(*13)* ***When presenting the results of its work at the 'Customer Acceptance Conference', BAE Systems misrepresented that it had completed the task and deliberately did not disclose to the Nimrod IPT or QinetiQ the actual percentage figures for the large proportion of hazards which it had left "Open" and "Unclassified" or otherwise draw attention to the large gap remaining in its analysis.***

11.76 In my judgment, BAE Systems is open to severe censure for giving the misleading impression at the Customer Acceptance Conference that it had completed the NSC task satisfactorily and for failing to disclose to the Nimrod IPT or QinetiQ the known percentage figures for the large proportion of hazards which it had left *"Open"* and *"Unclassified"* (many with only vague recommendations of '*further work*' being required) and otherwise failing to draw its customer's attention to the large gap remaining in its analysis. I am satisfied, for the reasons given below, that this was a conscious and deliberate decision on the part of the senior BAE Systems personnel present because the figures were embarrassing and they wanted to avoid any argument with the Nimrod IPT at the meeting as to whether the NSC task should be signed off or not.

[37] BAE Systems' Written Submissions to the Review.

Purpose of meeting

11.77 The Customer Acceptance Conference at BAE Systems' offices at Chadderton on 31 August and 1 September 2004 represented the finale in the NSC process as far as BAE Systems was concerned. BAE Systems suggested in its submissions to the Review that the purpose of the Customer Acceptance Conference was simply to review and agree 'the completion' of the contract task and the existence of *"Unclassified"* or *"Open"* hazards did not affect this. This is not correct. The purpose of the meeting was, in fact, two-fold : (a) for BAE Systems to present *"the results"* of its NSC Phase 2 work; and (b) for BAE Systems to demonstrate *"to the satisfaction of the Nimrod IPT Customer"* that the contractual requirements of PDS Task 06-3409 had been satisfied, and to obtain agreement to 'sign-off' and final payment for the task. This is apparent from BAE Systems' own minutes.

Dilemma

11.78 It was initially envisaged that the Customer Acceptance Conference would comprise a detailed review of the Hazard Log contents, together with the other reports and the final BLSC reports. As the Customer Acceptance Conference approached, however, the key BAE Systems management personnel involved in the NSC, namely Chris Lowe, Richard Oldfield and Eric Prince, increasingly faced a dilemma. As each of them well knew (and as was clear to most of the BAE Systems staff involved in the NSC project): (i) work on all the hazards had been somewhat rushed and some had still not been completed (*e.g.* Hazards H78, H79 and H63); (ii) drafting of the BLSC Phase 2 Reports was not finished, in particular the Executive Summary, Conclusion and Annexes B and C thereof; (iii) over 30% of the hazards remained *"Unclassified"* and uncategorised, with no recommendation beyond *"Further analytical techniques are required"* before they could be classified; and (iv) over 40% of the hazards remained *"Open"* and unsentenced, many with no recommendation beyond *"Further analytical techniques are required"* before they could be sentenced and closed. In these circumstances, Chris Lowe, Richard Oldfield and Eric Prince must have been naturally concerned at the risk that the IPT and/or QinetiQ might be reluctant to agree to 'sign off' on PDS Task 06-3409 if they became aware of (i), (ii), (iii) and/or (iv).

Switch in format

11.79 In light of the above, as explained in **Chapter 10A,** there was a belated switch in the format of the meeting. Shortly before the Customer Acceptance Conference, a decision was taken within BAE Systems that the format of the Customer Acceptance Conference should be switched from a detailed review of the Hazard Log contents and the final BLSC reports to a 'high level' summary of BAE Systems' Phase 2 work and a demonstration of Cassandra. The draft agenda discussed with Frank Walsh on 22 July envisaged the entire first day being spent on *"Functions & Zonal Hazard Log"*. The proposed agenda circulated with the call notice on 27 July included on the first day a *"review"* of the final BLSC Reports and on the second day a *"full review"* of the hazard log contents. The 'Provisional Agenda' circulated on 19 August, however, simply included a *"Review of Hazards Log and Mitigation of Identified Hazards"* on the first afternoon; to which was then added *"...and Summary of Recommendations"*. BAE Systems in evidence accepted that there was a change in the "*intended emphasis*" of the meeting but suggested that this decision was taken solely because it was thought there would be insufficient time to go through all the hazards in a two day meeting. I do not think this was the real, or only, reason. In my view, it suited BAE Systems' purposes not to go into too much detail when presenting *"the results"* of its Phase 2 work at the meeting in case the Nimrod IPT or QinetiQ asked too many awkward questions which might elicit facts such as (i), (ii), (iii) and/or (iv) discussed above.

'Rehearsal' meeting

11.80 BAE Systems appear also to have held an internal 'rehearsal' meeting on or shortly before 31 August 2004, at which this revised format was given a run through. It is striking that no details or documents relating to it were forthcoming.

Richard Oldfield's notes shows the precise figures were known

11.81 It is clear that the senior BAE Systems representatives present were well aware when they went into the Customer Acceptance Conference that a large number of hazards remained *"Open"* and *"Unclassified"*. Richard Oldfield's manuscript notes on his copy of the draft of Annex B show he had calculated the *precise* numbers and percentages of hazards which remained *"Unclassified"*, namely 12 out of 66 Functional Hazards (18%) and 22 out of 39 Zonal Hazards (56%) respectively. The latter was a very high percentage. I have no doubt that Chris Lowe and Eric Prince were equally aware of the figures.

Presentations

11.82 I have come to the conclusion that BAE Systems' presentations at the Customer Acceptance Conference were carefully tailored to skirt round some of the (uncomfortable) facts outlined above, and encourage the Nimrod IPT and QinetiQ to the belief that PDS Task 06-3409 could be 'signed-off' forthwith and that final payment could be made without unnecessary argument.

11.83 As set out in **Chapter 10A**, at the Customer Acceptance Conference, the Nimrod IPT and QinetiQ representatives were given three main presentations:

161.1. First, a PowerPoint presentation by Richard Oldfield entitled *"Programme status as at 31 August 2004"* in which he effectively represented that PDS Task 06-3409 had been completed, on the basis that '*extant*' mitigation evidence had been *"sourced for* [all] *105 hazards"* and entered into CASSANDRA and that the six deliverable reports, including the final BLSC Reports for both Nimrod types, were all *"complete"*.

161.2. Second, a PowerPoint presentation by Chris Lowe on the six reports. He gave a presentation of the BLSC Reports comprising only the general sections but not the Executive Summary or Conclusion (which had not yet been written, or at least not completed). He then presented full contents of the other Reports, including the Fire & Explosion Report, highlighting the conclusion that the Nimrod types could be considered *"ALARP"* so far as Fire & Explosion was concerned subject to minor recommendations.

161.3. Third, Witness C [BAE Systems] then gave a demonstration of how the CASSANDRA hazard log worked and put up on screen the draft versions of what were to become Annexes B and C to the BLSC Reports (the latter, with Chris Lowe's assistance).

11.84 In the light of Richard Oldfield's and Chris Lowe's upbeat PowerPoint presentations, at the very least, clarification of the figures and ALARP position was plainly called for. As Counsel to the Review succinctly put it to Richard Oldfield in interview:

> *"**MR PARSONS QC:** ...[T]he most important thing to tell the customer, surely, is: "We have done all we can do, but you cannot say this aircraft is ALARP, you cannot sign off the safety case, because 56 per cent of the zonal hazards are unmitigated".*
>
> ***MR OLDFIELD:** That was the purpose of those briefing notes* [i.e. his manuscript figures].
>
> ***...***
>
> ***MR PARSONS QC:** So why does it not appear in a PowerPoint, in minutes, in notes, anywhere?*
>
> ***MR OLDFIELD:** I can't understand that myself. ... I would suspect that during the conference, that would have been said, but there's no definitive record. .. I may well have done it in the voiceovers for the presentation. ..."*

11.85 I reject Richard Oldfield's belated and faint suggestion in interview that he did present his manuscript figures at the meeting. There is no evidence that at any stage in the meeting the figures were disclosed to the Nimrod IPT or QinetiQ by him or anyone else at BAE Systems. If they had been, I have no doubt that they would have been recorded in Witness K [BAE Systems]'s notebook and the subject of comment.

11.86 I am satisfied on the evidence that at no stage during any of these presentations did any of the BAE Systems representatives inform the Nimrod IPT and QinetiQ as to how much '*extant*' mitigation had in fact been found, or draw attention to the large percentage of the 105 hazards which it had, in fact, left *"Open"* and/or *"Unclassified"* and the quantity of work remaining. On the contrary, the impression given was that the task was complete and the Nimrod could be 'deemed ALARP', subject to minor recommendations. The picture presented to the Nimrod IPT and QinetiQ by BAE Systems at the Customer Acceptance Conference was, therefore, materially inaccurate, incomplete and misleading.

Glaring and inexcusable omission

11.87 In my view, the failure to tell the customer the precise figures was a glaring and inexcusable omission. As pointed out in interview, the single most important thing which a customer at a task 'hand over' meeting such as this would want to know, and was fully entitled to be told, was precisely how many hazards the company carrying out the task had managed successfully to 'classify and close', and how many remained to be 'managed' and the potential level of risk that these remaining hazards carried. In my view, it was the clear duty of the company to give the customer the full facts and figures as to precisely how much hazard mitigation work had been completed and how much remained to be done. It is not good enough to flash draft tables up on the screen and suggest (as Witness C [BAE Systems] did to the Review) that *"the information to enable them* [the customer] *to come up with that identical calculation was provided to them"*, *i.e.* a suggestion that the customer ought to have worked out the figures for itself. It was the duty of those at BAE Systems presenting *"the results"* of their NSC Phase 2 work to do so fully, openly and frankly. They did not do so.

Uncomfortable bystanders kept 'schtum'

11.88 There was compelling evidence by some of the other, more junior, BAE Systems representatives present at the meeting, namely Witness K [BAE Systems], Witness T [BAE Systems], Witness C [BAE Systems] and Witness P [BAE Systems], that they felt like *"uncomfortable bystanders"* at the meeting, but did not feel it was their place to speak out with their BAE Systems management superiors present and in charge of conducting the meeting. They therefore kept *"schtum"*. They were nonetheless clearly concerned about the time that they had been allotted to complete the task, the quality of work and the fact that it was not finished. The hope was that the 'customer' would not ask any awkward questions. Luckily for BAE Systems, no-one did.

'Pools win'

11.89 In my view, the senior BAE Systems management personnel present, Chris Lowe, Richard Oldfield and Eric Prince, were intent on securing the sign-off of the NSC task within the deadline and harvesting the prestige, and further business, that they hoped would follow from the successful completion of the project. This was to be a *"pools win"* for BAE Systems. This is why they sought to give the misleading impression to the Nimrod IPT and QinetiQ representatives present that PDS Task 06-3409 had now been completed: mitigation evidence had been '*sourced*' by BAE Systems for most of the 105 hazards and entered into CASSANDRA; the areas where mitigating evidence was not '*extant*' and risks remained '*unclassified*' were relatively minor and, in any event, covered by appropriate BAE Systems' recommendations; the six BAE Systems 'deliverable' reports had effectively been completed and merely needed final approval and signatures; and both the Nimrod types could be considered *"acceptably safe to operate and maintain"*. Therefore, the aims and objectives of the NSC project and the "Top Level Goal" had successfully been demonstrated as achieved. Accordingly, the IPT could safely 'sign-off' PDS Task 06-3409 and make final payment.

Annex B on screen

11.90 I specifically reject the suggestion, made on behalf of BAE Systems, that it was somehow sufficient or fair to the customer that Witness C [BAE Systems] had put Annex B up on the screen and this was somehow enough to alert participants to the fact that such a large percentage of hazards had been left *"Open"* and *"Unclassified"*, as suggested *e.g.* in re-examination during interview by BAE Systems' lawyer:

> *"**BAE Systems' Lawyer: …** I am referring to the information as to the number of hazards that are shown open and unclassified, which is what Richard Oldfield's calculation relates to. Even if those statistics were not expressly relayed, my question is whether the information on which they are based was presented to the customer.*
>
> ***MR LOWE:** It was, in the form of that table."*

11.91 In my view, flashing a long table up on a screen without summarising its contents could not be considered an 'open and transparent' way of BAE Systems presenting the results of its work to its customer. Nor, in my view, did it give the Nimrod IPT and QinetiQ representatives present a fair opportunity to grasp the net result of the table. The BAE Systems representatives should have been quite upfront and told the Nimrod IPT and QinetiQ, fairly and squarely, how many hazards were being left "*Open*" and how many "*Unclassified*".

Example entry – Hazard H54

11.92 It is right to make clear that there was no attempt by BAE Systems to disguise the fact that there were hazards which had been left *"Unclassified"*; it was merely the scale of the problem that they were not keen to draw the customer's attention to or highlight, in particular, the very high number of *"Unclassified"* hazards. On Richard Oldfield's calculations 56% of the zonal hazards were *"Unclassified"*, *i.e.* more than half. It is noteworthy that the illustrative 'example' CASSANDRA entry shown by Witness C [BAE Systems], Hazard H54, was itself an *"Unclassified"* hazard, but otherwise an impressive entry to display because it included one of the longest hazard descriptions (running to 32 lines), contributions from four separate departments, and references to 13 photographs of the zone in question (Zone 127). The Pro-Forma for Hazard H54 also contained two full pages of 'analysis' which included 17 repetitions of *"From in-service data the potential for fuel/hydraulic pipe/bleed air duct leakage is Improbable"*.[38]

Motive - embarrassment and desire to avoid arguments

11.93 I am driven to the regrettable conclusion that Richard Oldfield and his senior BAE Systems' colleagues, Chris Lowe and Eric Prince, deliberately kept quiet about precisely how many hazards remained *"Open"* and *"Unclassified"* and hoped the customer would not ask any awkward questions. Their motive was obvious: the precise figures were embarrassing and might give rise to arguments with the Nimrod IPT about whether the task had been satisfactorily completed. Moreover, the figures did not sit well with the positive impression created by the presentations. It is unfortunate that the Nimrod IPT and QinetiQ did not ask some intelligent questions.

Not tolerable

11.94 The fact that the Nimrod IPT had not been told the full picture at the meeting was put in interview to BAE Systems' Engineering Integration Manager at the time, Witness B [BAE Systems].[39] His reaction in interview to being told the full picture was instructive:

[38] The author was Witness R [BAE Systems] and the counter signatory Eric Prince, both on 2 August 2004.

[39] Witness B [BAE Systems] was Richard Oldfield's line manager and reported to the TTRO Chief Engineer. He had Nimrod MR2 and R Mk1 delegated Design Signatory approval but had little or no active role in the NSC, the management of which was entirely delegated to Richard Oldfield. His signature on the BLSC Reports was merely to ensure compliance with Design Engineering procedure DE101 and did not relate to technical content. In my view, he had no material responsibility for the outcome of the NSC.

*"**MR HADDON-CAVE QC:** Let's go back, if we may, to the acceptance meeting; to my original difficult question. There's no evidence that the customer was told at this acceptance meeting that 40 per cent were open, being left open; over 30 per cent were being left unclassified. And the deliverables were not, in fact, handed over at this meeting. That is what the evidence appears to show.*

If you had been sitting at that meeting, given your position, your senior position, would you have tolerated that being the case; the customer not being told [these things] *at the acceptance meeting?*

WITNESS B [BAE Systems]: *If that wasn't the case, then it would not be tolerable. But it really surprises me, if that is the case, and I find it very difficult to believe."*

Ethics

11.95 Appropriate standards of professional and ethical behaviour in any field demand that a consultant or sub-contractor presents the results of its work to a customer in an open and transparent way and one which ensures that the customer has a full and fair picture of the outcome and what he has got for his money. In my view, adherence to the highest standards of transparency was particularly important in the case of the NSC given: (a) the very high proportion of hazards that remained unresolved; (b) the potential concern that this gave rise to from a safety perspective for the Nimrod fleet; (c) the substantial amount of further work that it was clear would now be required to categorise and mitigate all the risks; (d) the fact that this represented a marked change from the optimistic assertion in BAE Systems' original proposal that it could complete the NSC work in an *"effective, competent, expedient and cost-effective manner"*; (e) the importance of the Nimrod IPT properly understanding the scale of the task in order properly to plan the way forward in order to complete the NSC and achieve 'ALARP' for the Nimrod fleet as soon as possible; and (f) this was a matter which directly related to *safety and airworthiness*.

Causation

11.96 Whether or not it would have made any difference to the final outcome if BAE Systems had come clean with the Nimrod IPT and drawn attention to the large number of *"Open"* and *"Unclassified"* hazards, is a matter for speculation. It is possible that this might have led the Nimrod IPT to conduct a careful re-examination of the whole of BAE Systems' work on the NSC; but I am inclined to the view that Frank Walsh and/or George Baber would simply have given BAE Systems more time to complete *e.g.* Electrical Systems' work, and the outcome would have been no different. It was in the interests of everyone involved that the NSC was signed off without too much further delay or fuss. (I conclude elsewhere in this Chapter that had BAE Systems carried out a proper and careful Safety Case exercise in the first place and/or not rushed it, the catastrophic fire hazard in Hazard H73 could and would have been identified).

(14) BAE Systems' representation that it had carried out an "independent review" of its NSC work was an exaggeration.

11.97 In my judgment, BAE Systems' representation that it had carried out a full *"independent review"* of its NSC work was an exaggeration.

11.98 The Minutes of the Acceptance Conference drawn up by Richard Oldfield stated that Chris Lowe had advised the meeting that an *"independent review"* of the NSC had recently been carried out by BAE Systems' airworthiness function, which review had *"confirmed the robustness of the safety case argument"*. As explained in **Chapter 10A,** however, this so-called *"independent review"* in fact amounted to no more than a senior Airworthiness figure, Witness A [BAE Systems], being asked to 'cast his eye' over three of the six deliverable reports, namely the Certification Statement, Fire & Explosion Report, and Review of Accident History. He was not given, nor did he see, the main BLSC Reports or the Hazardous Materials Report. Therefore, as Counsel to the Review put to Chris Lowe in interview, to call this an *"independent review"* which confirmed the *"robustness"* of the safety case argument was somewhat '*over-egging the pudding*'. Chris Lowe's reply that *"robustness"* merely referred to process, and not content, lacked conviction. BAE Systems suggested in its submissions that

Richard Oldfield had made a mistake when drawing up the minutes and should have used the term *"internal review"* which appeared in his own manuscript notes of the meeting. If this were indeed the case, then it points to Richard Oldfield exaggerating the significance of the review for the purpose of the minutes. I reject BAE Systems' alternative argument that, because the item appeared under *"Any Other Business"* in the minutes, it should not be regarded as particularly important.

11.99 In my view, either Chris Lowe or Richard Oldfield exaggerated the significance of the internal *"independent review"* in order to give comfort to the customer. It was a requirement of JSP553 and Def-Stan 00-56 that an 'Independent Safety Auditor' (ISA) be appointed to audit documents such as the NSC which raised Class A and B risks.[40] In fact, QinetiQ was acting as 'independent advisor' to the Nimrod IPT but was never formally appointed as ISA and never carried out an audit of the NSC. It was technically permissable for BAE Systems to have carried out its own *"independent review"*.[41]

(15) BAE Systems' BLSC Reports gave the impression to the cursory reader that the aircraft could be "deemed acceptably safe to operate" without substantial further work.

11.100 In my judgment, BAE Systems' BLSC Reports gave an unfortunate unqualified impression that the aircraft could be *"deemed acceptably safe to operate"* without substantial further work.

11.101 Although the Executive Summaries of the BLSC Reports contained express references to Annexes B and C and the number of hazards remaining open *"(qty 43)"*, they concluded with the following, apparently unqualified, eye-catching statement (partly in bold):

> *"From the above, it is thus declared that all potential hazards have been identified, assessed and addressed and that all appropriate standards had been met. Accepting this the top level goal of the Nimrod MR Mk2 type Equipment Safety Case that* ***"The aircraft type is deemed acceptably safe to operate and maintain within specified contexts"*** *has been demonstrated as having been achieved."*

11.102 BAE Systems submitted that this was merely '*awkward writing*' and that the BLSC Reports were not, as a whole, misleading. It is true that (even) a moderately careful reading of the BLSC Reports would and should have elicited the correct picture. But it is troubling that the wording was be framed in such a way as potentially to mislead the incautious, or busy, reader who might have occasion merely to glance at the end of Executive Summary. This would have served to have reinforced the impression given at the Customer Acceptance Conference.

'Blurb' and the 'thud factor'

11.103 In my view, much of the documentation produced by BAE Systems in respect of the NSC contained a great deal of what might politely be described as 'padding' or *"blurb"*.[42] Like so many consultants' reports, this was designed to give the client the impression that he was getting a substantial piece of analysis. This is sometimes known in the consultant trade as the *'thud'* factor: clients are thought to be more impressed when 'weighty' consultants reports land on their desks and feel they are getting 'value for money'. The BAE Systems reports contained much unnecessary repetition. For instance, pages on Safety Case 'strategy' and Goal Structured Notation (GSN) are lifted from the Phase 1 Proposal and repeated in the BLSC Reports, adding little value but length to the latter and making them less digestible.

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[40] See JSP553, Chapter 2, paragraph 2.58 and Def-Stan 00-56, paragraph 5.3.4.

[41] Although Def-Stan 00-56, paragraph 5.3.4.4 provides that: *"Where, exceptionally, it is necessary for the Independent Safety Auditor to belong to a company that is part of the same trading group as the Contract, the proposed arrangement shall be justified and shall be agreed with the MOD PM."*

[42] *"Blurb"* was the term coined by Witness R [BAE Systems] in a draft Pro-Forma (Hazard H80) which he had completed and was passing on to a colleague in Electrics for further work.

11.104 It should be noted that the BAE Systems' Pro-Formas were also endlessly repetitive and consequently difficult to read. Many contained similar or identical '*design information*' (section 4) often running to several pages. It is clear that these were the product of cut-and-paste and little analysis, *e.g.* the Mech Systems Pro-Forma for Hazard H73 set out in section 4 the relevant parts of the BCARs and AvP 970 relating to '*fire zones*', but failed to point to the serious breaches of those regulations arising from the risk of single point failures highlighted in section 2. Further, section 6 runs to an impressive 18 paragraphs, each ostensibly analysing one of the 18 '*key potential hazards*' listed in Section 3 (hazards 3A to 3R), giving the semblance of detailed and careful analysis to the client. But on closer inspection, however, the paragraphs are largely repetitive of one another and thin on real analysis. As Witness R [BAE Systems] admitted, section 6 could have comprised of a single sentence referring just to *"From in-service data, the potential for fuel/ hydraulic pipe leakage is given as **Improbable**".*

(16) When presenting its work to the Platform Safety Working Group, BAE Systems again deliberately kept quiet about the large percentage of hazards it had left *"Open"* and *"Unclassified".*

11.105 In my judgment, when presenting its work to the PSWG, BAE Systems again deliberately kept quiet about the large percentage of hazards it had left *"Open"* and *"Unclassified".*

11.106 At the Sixth PSWG meeting on 10 November 2004, BAE Systems gave a number of presentations which reinforced the impression given at the Customer Acceptance Conference, namely that the NSC work had been fully and satisfactorily completed and final payment could be made. Chris Lowe, assisted by Richard Oldfield, gave a presentation regarding the BLSC in which he said that all foreseeable hazards had been *"identified and assessed and addressed"* and *"eliminated or reduced ...[ALARP]"*, and where mitigation evidence was insufficient or incomplete there were (appropriate) *"recommendations"*. There was also a brief demonstration of how the CASSANDRA log worked. Chris Lowe is further recorded as having informed the meeting that *"The Safety Case report concluded that the Nimrod ac were safe to operate through to the Out of Service date, within the declared Statement of Intent and Operational Usage"*. Again, the BAE Systems representatives did not draw attention to the fact that over 40% of the hazards had been left *"Open"* and over 30% *"Unclassified".* It would have been inconvenient to do so.

11.107 As explained in **Chapter 10A**, the Nimrod IPT and QinetiQ had accepted the assurances of BAE Systems at the Customer Acceptance Conferences and subsequently, it appears, had failed properly to read or review the six Reports served in the meantime. Thus, the BAE Systems presentations at the Sixth PSWG meeting would not have met with much inquiry by the audience.

Why was no query raised at so few recommendations being actioned?

11.108 Why was no query raised at the fact that Frank Walsh had brought no more than a handful of 'unresolved' recommendations arising from the NSC to the Sixth PSWG meeting?[43] BAE Systems' BLSC Reports had contained over 25 pages of outstanding recommendations which could not conceivably all have been 'resolved' in the three weeks since receipt of the Reports.[44] In interview, Richard Oldfield professed not to have been surprised that so many hazards had been resolved in a short time by the Nimrod IPT. Chris Lowe said in interview that it would not be *"unreasonable"* to think that Frank Walsh had closed off or was about to close all of the open hazards by this stage. In my view, this evidence was mildly disingenuous. It was objectively unreasonable to suppose that Frank Walsh had already, or was in the process of, closing off all the *"Open"* hazards, not least because a large proportion remained *"Unclassified"* and bore the vague and open-ended recommendation that *"further analytical techniques"* would be required just to classify them. Why was no query raised by anyone? The answer, as I explain above, lies in the fact that neither BAE Systems nor Frank Walsh, had any real expectation that a large amount of work would be done, or was required to be done, before the NSC was approved for 'sign off' by the PSWG. However, whereas Frank Walsh's lack of expectation was the result of ignorance, BAE Systems' lack of expectation was the result of knowledge: knowledge that much of the NSC was essentially a 'paperwork' exercise for an aircraft in which there was a 'high level of confidence' anyway; knowledge that

[43] See Annexes A and B to the Minutes of the Sixth PSWG meeting on 10 November 2004.

[44] See Annex C to the BLSC Report.

they had essentially been 'going through the motions' of producing rafts of recommendations which looked impressive in the Reports but of which only a fraction would be actioned; and knowledge that the Customer Acceptance Conference had probably successfully lowered the guard of Frank Walsh and the Nimrod IPT and QinetiQ representatives present, and created a belief that not a lot of work remained to be done.

Frank Walsh could not have checked all the Pro-Formas

11.109 I reject Chris Lowe's (frankly unreal and self-serving) suggestion that he expected Frank Walsh to have read and checked all the Pro-Formas before signing off the NSC:

> ***CHRIS LOWE:*** *"... Frank would have a full set of everything. He would not sign anything off without reading the evidence. I mean, I am sure that he would not sign off anything without reviewing every ounce of evidence that was there."*

11.110 This would have been impossible. Not only did Frank Walsh not have access to the Pro-Formas save by physically travelling to Chadderton and using the terminal there; but the task would have been beyond any one person. As Frank Walsh pointed out, if he or the Nimrod IPT had been expected to check all of the Pro-Formas, they might as well have done the NSC themselves without BAE Systems.

Suited everybody to sign-off

11.111 It is fair to point out, however, that it suited everybody at the Sixth PSWG for the NSC to be regarded as complete and signed off without further delay or difficulty. The 'high level of confidence' in the Nimrod fleet was shared around the table. The requirement to produce a Safety Case was a regulatory 'box' which was overdue under BP1201 and needed to be 'ticked'. Successful completion meant that publicity and prestige all-round for the first major 'equipment safety case', especially for Chris Lowe and the IPTL, George Baber (and possibly a 'pools win' for BAE Systems).

(17) BAE Systems' analysis, assessment and categorisation of Hazard H73 was seriously erroneous.

11.112 In my judgment, BAE Systems' analysis, assessment and categorisation of Hazard H73 were seriously erroneous.

BAE Systems personnel involved

11.113 The Mech Systems Hazard Response Pro-Forma for Hazard H73, relating to the catastrophic fire risk in No. 7 Tank Dry Bay Port and Starboard arising from the Cross-Feed/SCP duct (Zones 514/614), was drawn up by Witness R [BAE Systems] who had been seconded from another part of BAE Systems to assist with the task of completing the Pro-Formas. He completed his part of the Pro-Forma for Hazard H73 on 23 August 2004. An Electrical Systems 'Appendum' was then added by Witness T [BAE Systems]. The final contents were approved by Eric Prince on 30 August 2004.

Six errors

11.114 The Pro-Forma for Hazard H73 was manifestly erroneous in at least six respects:

(1) Despite expressly referring to certain relevant parts of the BCARs and AvP 970 in section 4, the Mech Systems Pro-Forma failed to point out the serious breaches of those regulations inherent in the design and/or to highlight the risk posed by an exposed ignition source.

(2) The Mech Systems Pro-Forma stated that the Cross-Feed duct *"is only pressurised when the cross-feed pipe is open, i.e. during engine start"* (*i.e.* on the ground), and failed to take into account the lengthy periods the cross-feed duct could be pressurised in the air (at a working temperature of up to 420°C) when feeding the SCP or being used routinely to re-start engines shut down in flight.

(3) The Mech Systems Pro-Forma stated that *"the Bleed ducting is insulated and so surface temperatures will be below bleed air temperatures"* but failed to note that: (a) there were gaps between the insulation; (b) some parts of the bleed ducting have no insulation; and (c) the insulation was in poor condition in some areas.

(4) The Mech Systems Pro-Forma stated that *"From in-service data the potential for fuel pipe leakage is given as Improbable"*. I have already discussed above: (a) the obviously erroneous nature of this assumption; (b) the fact that anyone familiar with Nimrod maintenance would have known that it was erroneous; and (c) the inappropriateness of using MRA4 generic data in the first place.

(5) The Mech Systems Pro-Forma stated that *"From in-service data the potential for bleed air duct leakage is given as Improbable"*. BAE Systems confirmed to the Review that this assessment was also based on the generic MRA4 data, which gave a failure probability for ECS[45] pipes and clamps as $2E^{-7}$ (i.e. 2×10^{-7}), and for ECS pipe seals as 1.5E-7 (i.e. 1.5×10^{-7}). The author of the Hazard H73 Pro-Forma, used these generic failure probabilities in his assessment of bleed air duct leakage in order to conclude that the risk of bleed air duct leakage was within the range of 1×10^{-6} to 1×10^{-7} (i.e. *"Improbable"*). As stated above, however, this assessment ignored both the early BAe reports of the 1980s and the evidence presented to the Review which clearly shows that there was a significant history of hot air duct leakages (see **Chapter 7**). Against this background, it is most difficult to see how a categorisation of *"Improbable"* could ever have been appropriate.

(6) The Mech Systems Pro-Forma failed to pick up on the zonal risk presented by the location and proximity of the starboard blow-off valve immediately forward of the No. 7 Tank Dry Bay, such that fuel expelled from the blow-off valve could track back into the No. 7 Tank Dry Bay and ignite.

BAE Systems' arguments

Fire zone

11.115 BAE Systems argued that there was nothing in the Pro-Forma for Hazard H73 which would suggest that Zone 614 should be treated as a *"fire zone"*. This is, however, to ignore: (a) section 4L which specifically cites the requirement of AvP 970 that anywhere where a *"single point failure"* could lead to a fire should be treated as a *"fire zone"*; and (b) section 3 which sets out no less than 15 different *"single point failure"* scenarios which could lead to catastrophic fire, explosion or overheating. In my judgment, there is no doubt that Zone 614 should have been identified and treated as a 'fire zone'. The factual inaccuracies led, however, to the author ignoring, or otherwise discounting, the actual risk represented by the Cross-Feed/SCP duct as a serious 'live' ignition source and the risk of a fuel or hydraulic leak onto the Cross-Feed/SCP duct as a single point failure.

Ignition source probability

11.116 There were repeated suggestions from various BAE Systems witnesses, including Witness R [BAE Systems] himself, that when drawing up section 6 of the Pro-Forma for Hazard H73 a 'worst case' scenario for the ignition source was assumed, *i.e.* a probability of '1', on the basis that the Cross-Feed/SCP duct was un-insulated and 'live' all the time. In my judgment, this was another piece of *ex post facto* rationalisation by BAE Systems designed to downplay the significance, in particular, of the most glaring factual error in the Pro-Forma namely, the statement that *"....the duct is only pressurised when the cross-feed valve is open, i.e. during engine start"* (on the ground), when, in fact, the Cross-Feed/SCP duct was routinely used in flight to power the SCP or to re-start engines after shut-down in flight. If a probability of '1' had been assumed for the ignition source, there would have been no need for any detailed analysis of the Cross-Feed/SCP duct, when it was open or shut, or whether it was insulated or not. It should be noted that, in section 6 of the Pro-Forma for Hazard H73, Witness R [BAE Systems] went on to refer specifically to the *"extreme"* situation when the Cross-Feed/SCP duct would be supplied by the engines on *"full power"* on a hot day but discounted the risk because *"...analysis has shown that the surface temperature of the insulation in all cases will be below that required for spontaneous combustion of the fuel"*.

[45] Bleed-air has a number of uses, one of which is to supply the environmental control systems which feed air into the aircraft cabin.

The engines would only be on full power in the air. This passage would appear, therefore, to conflict with the earlier (erroneous) suggestion that the Cross-Feed/SCP duct was only pressurised during *"during engine start"* (on the ground).

Blow-off valve – not taken into account as potential source of fuel

11.117 There was some suggestion on behalf of BAE Systems that the Pro-Forma for Hazard H73 did not cover the risk presented by fuel from the blow-off valve because the outside of the fuselage was not considered to be a 'zone' and, accordingly, no specific zonal analysis was done on this area on the starboard side forward of the No. 7 Tank Dry Bay starboard. This is surprising for a number of reasons. First, No. 1 blow-off valve is located in Zone 127 and, therefore, should have been the subject of inspection and analysis as to what hazard it might represent to other proximate zones. Second, the ZHA Checklist specifically highlighted the risk which migrating fluids might represent to other zones. Appendix C3/4 contains a table of 'generic' hazards. The table includes a '*hot surfaces*' section which refers to *"Pipes"* and specifically contemplates *"Potential for fluid migration from other bays vertically and laterally"*. Accordingly, if any such hazards were identified, the potential for migration of fluids from other bays *"vertically and laterally"* should have been carefully checked. Third, some of the risks associated with Air-to-Air Refuelling (AAR) were contemplated and touched upon in the Mech Systems Pro-Forma relating to the fuel system and in the Fire & Explosion Report,[46] albeit not the specific risk associated with fuel venting from No. 1 blow-off valve. Fourth, the risk of fuel entering apertures in the fuselage during venting from No. 1 blow-off valve during AAR had been highlighted during BAE Systems' work on the AEW3 project in 1983 and further investigation by way of dye tests recommended. The failure of BAE Systems to recall this during the ZHA was a lack of corporate memory by the DA.

Causation

11.118 It was further argued by BAE Systems in their submissions to the Review that the errors which it made in relation to the use of the Cross-Feed duct and the insulation (and which it admitted) were not, however, causative of the accident to XV230. This was because the overall probability assessment in the Hazard H73 Pro-Forma was, in any event, driven by the probability of a fuel leak, which was assessed as *"Improbable"*.[47] I do not accept this. First, as explained above, the assumption that a fuel leak was '*improbable*' was erroneous and derived from inappropriate data. Second, and in any event, even if a fuel leak was '*improbable*', it was in my view nonsensical to assume a risk of '1' for the ignition source and then focus solely on the (im)probability of a fuel leak (as BAE Systems suggested in evidence they did), since any fuel leak would, by definition, cause a catastrophic fire. Having identified Zone 614 as a '*fire zone*', rather than simply assigning a probability to the fuel source, BAE Systems ought to have focused its attention on addressing the risk of a catastrophic fire itself.

Personal responsibility of Witness R [BAE Systems]

11.119 It is quite clear that, when drawing up the Pro-Forma for Hazard H73, Witness R [BAE Systems] totally failed to grasp the true nature of the risk presented by the juxtaposition of the Cross-Feed/SCP duct with the fuel couplings in the starboard No. 7 Tank Dry Bay. The proximity of heat and fuel in this zone represented a serious catastrophic threat to the aircraft. Witness R [BAE Systems], however, assessed the probability of Hazard H73 as only 'improbable' (1×10^{-6}-10^{-7}), which equated to a classification of a Category 'C' risk, *i.e.* 'tolerable'.

11.120 Why did Witness R [BAE Systems] get it so wrong? And why did the Pro-Forma he drew up for Hazard H73 contain such significant errors? In my view, the answer lies in four overlapping reasons:

11.118.1 First, he was someone relatively inexperienced, who had been brought in at a late stage from another department to a project with which he was previously unfamiliar; he did not have a great knowledge of the Nimrod and its systems, and had never actually inspected an MR2 or R1; he was under time pressure; and he was given inadequate guidance as to how to go about the task.

[46] *e.g.* The Mech Systems Pro-Forma for Hazard H34 referred to five incidents during AAR and stated *"These incidents have been the result of damage caused during the refuelling process or 'dirty basket'. As a functional failure the ability to refuel in flight is not considered flight critical."*

[47] BAE Systems stated in writing to the Review: *"Given that the risk of a fire/explosion arising from a fuel leak can, as a matter of logic, never be higher than the risk of a fuel leak itself, it follows that the errors made on the Mechanical Systems pro-forma (i.e. the suggestions that all of the bleed air ducting was insulated and that the ducting was only pressurised during engine start) had no impact on the overall zonal hazard (H73) probability assessed by the Mechanical Systems Department, which was one of improbable."*

11.118.2 Second, the information which he had to work on was scant and superficial. The descriptions of the potential hazards derived from the Phase 1 inspection work did point to potentially serious fire and explosion risks arising from the close proximity of fuel and heat systems.[48] But the descriptions were brief, contained little explanation or analysis, and did not materially distinguish between the MR2 and R1 (only the former had the SCP duct). Moreover, the photographs gave little real clue as to the real geography of the No. 7 Tank Dry Bay, or the actual continuity or condition of the duct insulation and 'muffs'.

11.118.3 Third, the rigour of his approach was undermined by the prevailing mind-set that the aircraft *was* safe and the NSC task was essentially one of documenting this 'assumed' safety.[49] As Witness R [BAE Systems] himself explained in interview, he saw his '*target*' as essentially one of showing that the risks were 'improbable'. His approach to the task was, therefore, flawed from the outset: rather than conducting a thorough-going analysis of the real risks, the exercise which he was, in reality, engaged in was simply looking for evidence to prove or demonstrate what was already assumed to be the case. In common with his other colleagues carrying out the Phase 2 desk analysis, he was not really looking out for, let along expecting to find, latent or even patent risks; but rather he was looking to demonstrate and document what was assumed to be the case, that there were no significant risks. The Nimrod fleet had, after all, had a long and benign service history from an airworthiness point of view.

11.118.4 Fourth, the advent of the MRA4 generic data as a simple tool for sentencing risks obviated the need for detailed or careful risk analysis. The fact that Witness R [BAE Systems] was permitted to ask for, and then to use, MRA4 generic data as the primary data to sentence risks such as Hazard H73 meant that, at a stroke, he was able to achieve his '*target*' of demonstrating 'improbability' (1×10^{-6}), without needing to be too concerned about any further analysis or the accuracy thereof. His probability conclusion was essentially driven by a single piece of information: the MRA4 generic data. Section 6 of the Pro-Forma could have been reduced to the single reference to 'in-service' data.[50] I reject his suggestion that he assumed a '*worst case*' probability of '1' for the ignition source and that '*accuracy*' about when the Cross-Feed/SCP was on '*did not matter*'. As I explain above, this was part of BAE Systems' *ex post facto* rationalisation. But, in my view, the fact that he was allowed to use the MRA4 generic data as a convenient panacea clearly short-circuited the risk analysis process, and partly explains his undoubted lack of rigour in relation to the ignition part of the equation in section 6 of the Pro-Forma.[51]

11.121 Witness R [BAE Systems] was clearly personally at fault in relation to the erroneous content and conclusion in the Pro-Forma for Hazard H73. His most significant factual mistake was to assume the Cross-Feed/SCP duct was only used during engine starts on the ground (which he was unable to explain save on the basis that he confused the MR2 and R1).[52] His probability conclusion was out by at least two orders of magnitude. In my judgment, however, his conduct and personal responsibility must be judged in the light of the factors outlined above. He was a relatively junior employee; he was placed in a difficult situation not of his own making; unbeknown to him, there were factors which militated against him reaching the right answer; he was not particularly familiar with Nimrods; his work was not closely supervised or checked; at all material times, he was trying his best. For all these reasons, I have concluded that it would be unfair and disproportionate in all the circumstances to make any finding of significant culpability against him and name him in this Report. In my view, the real fault and responsibility for the failure of the NSC lie with his superiors higher up the chain at BAE Systems, and with the Nimrod IPT and QinetiQ.

[48] See section 2 of the Mech Systems Pro-Forma for Hazard H73: potential for fuel leaks from *"...No. 7 Tank main feed fuel pipe immediately above the HP, High Temp engine bleed take-off port or associated ducting"* and the potential for hot air, fuel and hydraulic leaks and possible fire exists *"in an area closely packed"* (emphasis added) with cables, hydraulics, electrics and hot air ducting.

[49] See *e.g.* BAE Systems' Proposal for Phase 1 of the NSC dated August 2002: *"By virtue of a range of traditional methods (certification and qualification/ integrity testing), there is already a high level of confidence in the prevailing level of safety of Nimrod types. However, there is currently a lack of structured argument and supporting evidence formally recorded and maintained."* (emphasis added)

[50] Section 6 of the Hazard H73 Pro-Forma contained the repeated sentence: *"From in-service data the potential for fuel pipe leakage is given as **Improbable**."*

[51] On 5 August 2004 he had been sent a coloured diagram of the duct system showing temperatures and the SCP system on the MR2. The same would also have been apparent from the Aircraft Manual (AP).

[52] This would explain the SCP duct but not the use of the Cross-Feed duct for in-flight engine re-starts.

Conclusion on Hazard H73

11.122 In my view, the Mech Systems Pro-Forma for Hazard H73 was a hurried, sloppy and muddled piece of work, carried out by a junior individual, under time pressure, without sufficient guidance or management oversight. Some of the mistakes in this Pro-Forma were very basic indeed, in particular the mistake in relation to the Cross-Feed/SCP duct only being pressurised *"during engine start"* which displayed a startling lack of knowledge by BAE Systems about its own aircraft. Anybody who knew anything about Nimrods would have known that this was plainly wrong. If a proper, considered and careful job had been done on the Pro-Forma for Hazard H73, and the MRA4 generic data had not been used as a 'cure-all' panacea, the outcome would have been different and the catastrophic risk dormant in Zones 514/614 would have been revealed.

XV227

11.123 It is unfortunate that thought was not given to the earlier 1980s duct failure history when drawing up the Hazard H73 Pro-Forma which stated *"From in-service experience the potential for bleed air duct leakage is **Improbable**"*. As stated above, this ignored both the early BAe reports of the 1980s and the evidence presented to the Review which clearly shows that there was a history of such hot air duct failures. As described earlier, BAe had provided a synopsis of the potential hazards which eventually faced XV227 some 20 years previously. The transformation of this prediction into fact seems not to have provoked any deep thought within the Nimrod IPT.

11.124 BAE Systems used MRA4 generic data which gave a standard failure probability rating for a number of common failure types. A failure of a *"ECS pipe with 2* (V-band clamp/ bolted type flange)"* was ascribed a failure probability of 2E-7, namely:

Failure Type	Failure Probability
…	
Hydraulic pipe and associated coupling	1E-6
Fuel pipe and associated coupling	1 E-6
ECS pipe with 2* (V-band clamp/ bolted type flange).	**2E-7**
ECS pipe seal	1.5E-7

11.125 It is most difficult to see how a categorisation of *"Improbable"* could ever have been, appropriate in the light of the BAe reports of the 1980s and XV227 incident and the large number of Rib 2 hot air leaks which occurred in the late 1980s and early 1990s (see **Chapter 7**). It is impossible, in my view, to see how it could be at all appropriate following XV227 and the subsequent failure on XV229. It is highly unfortunate to say the least that this question was not properly re-visited when the XV227 incident should have brought sharp focus to it. Instead, all those involved appear to have been content that the NSC *"recognised"* the sort of bleed-air duct failure that occurred on XV227.

(18) The general standard of BAE Systems' analysis, assessment and categorisation of the hazards was lamentable: the Pro-Formas: (1) lacked consistency; (2) contained numerous significant factual errors; (3) contained numerous examples of poor or inefficacious mitigation; (4) demonstrated generally low levels of analysis; and (5) showed the increasing effects of time constraints.

11.126 In my judgment, the very poor quality of the Hazard H73 Pro-Forma was symptomatic of the generally lamentable standard of the NSC Pro-Formas prepared by BAE Systems. BAE Systems' NSC work was riddled with errors of fact and analysis. This was a direct result of the failures of attitude, approach, planning, management and execution outlined above.

Review's audit of the Pro-Formas

11.127 My concern at the catalogue of errors in the Mech Systems Pro-Forma for Hazard H73 led me to decide that a careful audit should be carried out of all the other Pro-Formas produced by BAE Systems. A thorough and painstaking audit was accordingly carried out by the Review of all the other Pro-Formas prepared by BAE Systems in respect of the other 104 hazards. This revealed that the errors in the Hazard H73 Pro-Forma were not one-off, but representative of a wider malaise affecting the whole of the work of BAE Systems on the NSC. The Review's analysis of the hazard Pro-Formas revealed: (1) a lack of consistency; (2) significant errors of fact; (3) erroneous or poor identification of hazard mitigation; (4) generally low levels of analysis; and (5) the increasingly deleterious effect of time constraints on the quality of the Pro-Formas, and the use of much 'cut-and-paste' and vague phrases such as *"further analytical techniques are required…"*. I expand on each of these findings below.

(1) Lack of consistency

11.128 The aim of the hazard Pro-Formas was, it must be assumed, to produce a consolidated, consistent, structured analysis of the risk presented by hazards associated with each particular function or zone. The Pro-Formas actually prepared by BAE Systems, however, varied significantly in their form, content and the analysis undertaken by different BAE Systems engineers. It is therefore most difficult to see how the underlying aim could be achieved. In particular:

11.126.1 The Pro-Formas used by Mech Systems and Electrical Systems were superficially similar, but there were significant differences in the headings used in their tables. For example, section 3, column 4 of the Mech Systems Pro-Forma was headed *"Failure Level"*, while the comparable Electrical Systems Pro-Forma column was headed "*Failure Mechanism/Possible Effect*". Similarly, section 2, column 6 of the Mech Systems Pro-Forma was headed *"Cause"*, while the comparable Electrical Systems Pro-Forma column was headed *"Possible Effect*". This led to different information being entered and a differing output from the two tables.

11.126.2 The manner in which key potential operating hazards were determined from subsumed Phase 1 installation hazards was not consistent between the Electrical and Mech Systems Pro-Formas. For example, although both the Mech Systems and Electrical Systems Pro-Formas for Hazard H55 listed 12 subsumed hazards, the former deduced 19 key potential operating hazards, while the latter deduced only three. This cannot be explained simply by asserting that the difference followed directly from the differing modes of examination of the two engineering divisions.

11.126.3 There was repeated confusion at Section 2, Column 5 of the Mech Systems and Electrical Systems Pro-Formas as to which Nimrod was being referred to: the terms *"MR"* (or *"Mk2"* or *"MR2"*), *"R"* (or *"RMk1"* or *"R1"*), *"Nimrod"* and *"Both"* were used. As a result of this, the Mech Systems Pro-Forma, for example, attributed a given hazard to the MR2, whilst the Electrical Systems Pro-Forma attributed it to the R1, or faults were attributed to one mark only when they applied to both, or *vice-versa*.

11.126.4 The Pro-Formas produced by Aerodynamics were of a different template entirely and contained little analysis and minimal contribution to the safety argument. Indeed, the majority of information within the supplemental sheets to the Aerodynamic analysis consisted of no more than a summary of the Aircrew Manual Book 3 Notes to Users.

In short, therefore, there were numerous differences and discrepancies, and a divergence of data and analysis between the different Engineering divisions' Pro-Formas.

(2) Factual Errors

11.129 The factual errors identified in relation to Hazard H73 were not a one-off. The Review's analysis of the other Pro-Formas revealed that they also contained significant factual errors which materially affected the accuracy of the analysis. By way of example:

11.127.1 The Electrical Systems Pro-Forma for Zone 114 (the No. 6 fuel tank compartment) stated that it is "*serviced by visual and automatic smoke detecting systems in conjunction with an installed manual fire extinguishing system*", but that the analogous Zone 111(the No 5 fuel tank compartment) "*has no dedicated fire prevention systems installed*". Both zones exist between the aircraft's under floor bays, which have smoke detectors and a fire extinguishing system, but none of these systems are intended to detect, or extinguish, a fire within the fuel tank compartments. [53]

11.127.2 Similarly, Mech Systems stated that for Zone 128 (the rear hinged fairing) fire "*was considered in the initial design and a fire detection (and protection on the R1) system was introduced*"; there is no fire detection system in the MR2 rear hinged fairing and it is separated from the bomb bay (which has such a system) by a solid bulkhead. [54]

11.127.3 The Electrical Systems Pro-Forma for Zone 128 stated that "*the MR2 bomb bay fire protection system does not extend as far back as the rear hinged fairing*". This is not correct. The bomb bay is actually fitted with a fire *detection* system, not a fire protection system. [55] (Significantly, both these Pro-Formas for Zone 128 were countersigned by the same person).

11.127.4 Both the Electrical and Mech Systems Pro-Formas for Zone 211 (nose equipment compartment) indicated hazards from signal cartridges and fire extinguishers. There are, however, none in this zone; they are in the neighbouring Zone 212.[56]

11.127.5 The Electrical Systems Pro-Forma for Hazard H46, Zone 114 stated that the "*yellow hydraulic pump motor assembly*" was installed within this zone. This is incorrect: it is actually within the neighbouring Zone 113.[57]

11.127.6 Similarly the engine fire extinguisher bottles are stated in section 2 of the Mech Systems Pro-Forma for Hazard H68 as being within Zone 423/433, while they actually reside within Zone 513/613 (albeit the error is pointed out in section 6).[58]

[53] In its written submissions to the Review, BAE Systems sought to explain this error by explaining that all of the analysis of fire hazards in the Pro-Forma related to Hazard H45 (Zone 113) rather than Hazard H46 (Zone 114) and that the Pro-Forma for Hazard H46 was, in fact, a joint Pro-Forma for Zones 113 and 114. Even assuming that to be the case, it is an understatement, in my view, to say (as BAE Systems acknowledged) that *"the format of this proforma is not user friendly and could give rise to confusion when reviewed by a third party"*.

[54] BAE Systems agreed that this statement was inaccurate but suggested that, as the engineers involved in Phase 2 did not consider mitigation such as fire detection/suppression when calculating hazard probabilities, the error would not have had any impact on the overall probability assessment for the hazard.

[55] BAE Systems' response to this criticism was to acknowledge that the Pro-Forma could have been more clearly worded, but to assert that *"it was not intended in the proforma for the term 'protection' to mean 'suppression'. In this case, the term 'protection' was used as a generic term meaning detection and/or suppression (and therefore was making reference to the detection systems in the zone)."*

[56] BAE Systems acknowledged that the hazards cited were incorrectly designated in zone 211 whereas they should have been designated in zone 212 but sought to downplay the significance of this error by stating that the two subsumed hazards were nonetheless reviewed and analysed as part of zonal hazard analysis Hazard H56 and that it analysis of zonal Hazards H56 and H57 (which concerned zones 211 and 212 respectively) would not have altered had the two subsumed hazards been correctly designated.

[57] In response to this criticism, BAE Systems again sought to justify the error on the grounds that the Electrical Systems Pro-Forma for Hazard H46 was in fact a joint Pro-Forma in respect of zones 113 (Hazard H45) and 114 (Hazard H46), and the analysis within the Pro-Forma of the pump related to Hazard H45 (and zone 113).

[58] BAE Systems denied that the statement in this Pro-Forma was incorrect, stating that the subsumed Hazards H55 and H56 did not state that the fire extinguisher bottles were located in the engine bay, but rather covered the potential risk of a leak of halon gas into the engine bay. It is difficult to see, however, how the discharge of halon gas into the engine bay could be a 'potential risk' since discharge into the engine bay was their very function to *obviate* risks.

(3) Erroneous or poor mitigation analysis

11.130 The Pro-Formas also contained numerous examples of erroneous mitigation of hazards, or mitigation of hazards which might be considered poor or inefficacious. In particular:

11.128.1 The Electrical Systems Pro-Formas frequently used the formula "*it is assumed that appropriate crew drills have already been considered in dealing with such an event*", when considering the possible reaction to an incident. However, this formula was even used when considering events which the crew clearly cannot influence; for example, fire within the No. 5 and No. 6 fuel tank compartments, the nose gear compartment and the MR2 doppler compartment.[59]

11.128.2 The Mech Systems Pro-Formas used a similar phrase: "*emergency procedures and general airmanship are provided for the crew to address the failure as appropriate*" and referred the reader to the Aircrew Manuals as the source of emergency drills.[60] However, the advice was given for such events as fire or explosion in Rib 1, the No. 7 Tank Dry Bay, the No. 4A fuel tank: all areas for which there are no published drills, as the crew have no access and there are no fire detection or extinguishing systems. This strongly suggests that the documents, such as Aircrew Manuals, cited as sources of drills were not examined in any detail and that the listing of references was little more than an archive search for documents, with no intent to utilise them in any analysis.

11.128.3 Numerous Pro-Formas stated that "*From In-service data the potential for fuel pipe leakage (or hydraulic pipe leakage/ bleed air duct leakage) is* ***Improbable***". I have already discussed at length above the errors in this statement.[61]

11.128.4 As indicated below, it appears that not all of the data specified in the checklist contained in the Proposal to Nimrod (ES) IPT (NIM/HX/P1.3/002 dated November 2003) was used in relation to every hazard.

(4) Low levels of analysis

11.131 The levels of analysis contained in the Pro-Formas varied, but were generally thin, with some containing little more than the results of a document search. There is no shortage of examples but the following are indicative of the overall vestigial quality of much of the analysis carried out by BAE Systems:

11.129.1 As indicated in the Pro-Forma for Hazard H73 itself, a number of zonal hazards were identified in the Mech Systems and Electrical Systems Pro-Formas at Sections 2 and 3, which contravened the design references quoted at Section 4. No attempt appears to have been made to determine whether or not these hazards were indeed design contraventions, or the result of degradation over time, or the result of maintenance lapses.[62] For example, wiring was noted in Zone 114 installed "*adjacent and in line with the tail plane de-icing hot air duct*", with "*evidence of heat exposure*" to wiring conduits, in possible contravention of BCARs.

[59] BAE Systems acknowledged that the italicised formula did not add substantively to the Pro-Forma but suggested that *"a reference to crew drills does not imply the presence of a fire suppression system in the zone, nor does it imply that the crew have access to the area"*. I do not accept either submission.

[60] As above, BAE Systems again acknowledged that the italicised formula did not add substantively to the Pro-Forma but stated that, as the emergency procedures and general airmanship of the crew were not, in any event, taken into account as mitigation when determining the overall probability for the hazard, the statement would not have affected the overall probability assessment.

[61] In its written submissions to the, BAE Systems stated that *"On the basis of the Incident Database (as supplemented where appropriate by the generic Tornado/Hawk component data accepted for application to the MRA4 platform), BAES had no reason to believe at the time of the Safety Case that leaks (whether fuel, hydraulic or bleed air) were common on the aircraft"*. As stated above, however, the use of MRA4 data was inappropriate and the frequency of fuel leaks well known by those maintaining Nimrods.

[62] BAE Systems' response to these criticisms was that the NSC assessed the Nimrod aircraft on an "as designed" basis and that it was not the purpose of the hazard assessment to review compliance with design standards. BAE Systems thus suggested that *"it is not surprising that no reference is made in the proformas to design or maintenance faults"*.

11.129.2 There are many other similar examples in other Pro-Formas. For example, a number of fouling/ chaffing hazards were identified within Zone 113. Mech Systems recommended a design investigation consider "*the probability of system failure resulting from the identified foul/ chaffing hazard*" as "*probable*". However, the overall hazard from the zone was determined as "Improbable" "*...not considering the above foul/ chaffing hazard*". Thus, a zonal hazard was determined ignoring some of the evidence obtained during the zonal hazard analysis, despite it being acknowledged as possibly design related.[63]

11.129.3 The analysis of both the No. 5 and No. 6 fuel tank compartments made no specific reference to the possibility of fuel leakage from these tanks (the tanks are double skinned), but there was a possibility of fuel leakage from the tanks and their associated pipe work; in particular, the key potential hazards identified for the No. 5 fuel tank compartment made no reference to fuel as a possible hazard source at all.[64]

11.129.4 Although the Mech Systems Pro-Forma for Zone 122 used the standard formula "*from In-service data the potential for hydraulic pipe leakage is given as improbable*" it was contradicted by a subsequent statement that analysis of photographs showed *"evidence of hydraulic leakage"*. This in turn was contradicted by the Electrical Systems Pro-Forma which noted that there was "*no evidence of hydraulic fluid leakage in this zone*".[65]

11.129.5 A further example of the apparently shallow level of analysis is evident within Mech Systems' Section 3, where on a number of occasions the "*failure level*" for "*fire/ explosion*" was given as "*single*" (Hazard H71, Section 3, Para L is one example of many). The immediate implication of this is that those zones should be considered for fire zone status, *viz.* a single failure may occasion a fire or explosion, as in the engine bays.[66]

11.129.6 The numbering of zones between the two marks of Nimrod was inconsistent, such that, for example, the MR2 nose compartment is Zone 122, while that in the R1 is Zone 121; Zone 123 is the nose wheel bay in the MR2, but No. 1 Antenna Bay in the R1. This caused confusion in the NSC.[67] Furthermore, the confusion engendered by this approach may have led to no analysis being conducted for the Nimrod R1's nose compartment.

(5) Effect of time constraints

11.132 There is clear evidence that the quality of analytical output in the Pro-Formas was affected by increasing time constraints as the end of August deadline drew closer. This is most clearly demonstrated by the fact that the input from Electrical Systems for Hazards H66 to H80 took the form of "*appendum*" or (in the case of Hazards H78 and H79) "*electrical comment*" paragraphs being added to end of the Mech Systems Pro-Forma, rather than

[63] In its response to this criticism, BAE Systems stated that *"whilst on its face the Review's comment is accurate, in that the 'Improbable' assessment was only valid to the extent that foul/chaffing hazards had been addressed, this does not take account of the separate 'Probable' assessment. Nor does it reflect the fact that the IPT were informed of the 'Open' nature of the hazard and the recommendation to review all aircraft for foul/chaffing hazards"*.

[64] BAE Systems stated that fuel tank No. 5 was not treated as a source of fuel on the basis that the design isolated the fuel from the cabin by a double-skinned tank. As regards the potential for inter-cell vent connection leaks, BAE Systems suggested that this was probably not raised as a potential source of fuel during Phase 1 as it would not have been viewed as credible that fuel could leak in this way into the zone (meaning that it was therefore not raised as a hazard in Phase 2 and not analysed in the Pro-Forma). I consider that this statement contains more than just an element of *ex post facto* rationalisation on the part of BAE Systems.

[65] In response to this criticism, BAE Systems pointed to the fact that the final probability assigned to hydraulic pipe leakage was, in fact, 'Remote' and that the author therefore decided to increase the likelihood of hydraulic pipe leakage from that given by the in-service data. BAE Systems went on to state *"It is believed that the basis for this increased assessment was the photographic evidence of leaking at section 5"*. Again, this statement to my mind constitutes little more than *ex post facto* rationalisation on the part of BAE Systems. There is in any event no audit trail of this decision contained within the Pro-Forma.

[66] BAE Systems denied this, stating that the use of the term '*single*' identified the pre-mitigation failure level (*i.e.* without taking into account the presence of mitigation such as insulation) and that the actual failure mechanism in reality (once mitigation was taken into account) would not be a single failure. I do not accept this.

[67] BAE Systems acknowledged that there was a potential for confusion in this respect and further acknowledged that such inconsistencies had resulted in certain hazards being rationalised within the wrong zones. It nonetheless sought to downplay the significance of this, stating that "[this] *notwithstanding, all hazards identified during Phase 1 were analysed and assigned a probability, and therefore would have been taken into account in ascertaining overall probabilities"*.

separate Electrical Systems Pro-Forma being prepared. Further, eight Electrical Systems appenda[68] completed near the end consist of, at most, a few short paragraphs, invariably involving the phrase "*further analytical techniques are required*" or *"further analytical techniques are considered necessary"*. There is little evidence of even the *initial* analytical techniques implied. Indeed, four of the appenda[69] consist of a single sentence. Various BAE Systems witnesses admitted in their evidence to the Review that Electrical Systems ran out of time.[70]

11.133 The independent Electrical Systems Pro-Formas that do exist state that hazards "*have been reviewed without recourse to any reported incident details*". This is contrary to the indications given by BAE Systems in its Preliminary Hazard Identification Report[71] and their Phase 2 Proposal[72] that "*service history i.e. Incident and Fault Reports*" would be used in the construction of the Safety Case. The Electrical Systems Pro-Formas, however, explicitly exclude incident reports and fault reports as being used for any analysis. It is, therefore, difficult to see what data was used to compile the Electrical Systems Pro-Formas. Indeed, the Electrical Systems comments made in respect of Hazard H78 include that there was no photographic evidence. On what, basis, therefore, was any 'analysis' carried out?

11.134 Similarly, the suggested Electrical Systems addendum for Hazard H3, consists of an unreferenced e-mail, highlighting what appears to be a scan of one document and the comment "*there does not appear to be any significant concern…..if there was any major shortcoming…… it would have surfaced by now*". Again, this bears all the hallmarks of a complacent, tick-box approach against a background of assumed safety, in which the fact that an accident has never happened before is taken as sufficient evidence of safety *in lieu* of any proper, rigorous analysis.

11.135 Electrical Systems was not alone in this unsatisfactory approach. For instance, a number of Aerodynamics Pro-Formas bear the phrase "*this search does not constitute a complete list…as the search for relative archive information was finite*". These words bear the clear implication that time constraints were placed upon staff, who were aware that they had not examined all that they could have done.[73]

BAE Systems' disappointing response to Review's audit

11.136 BAE Systems' response to the Review's audit of the Pro-Formas was disappointing to say the least. Its written response comprised a line-by-line denial of many of the criticisms made and served to demonstrate that BAE Systems' primary concern was not to address the errors identified by the Review, but rather to defend its own position. As will be apparent from the extracts I have cited in the footnotes above, most of its responses to the errors fell into one of two categories; it either sought to deny the error existed at all, or was forced to recognise the error (because it was obvious), in which case it sought to downplay its significance, or causative effect. In relation to both categories, in my view, the vast majority of the points made by BAE Systems lack any real substance and smack of a visceral reluctance on the part of BAE Systems to admit any mistakes at all.

Hazard H51

11.137 This is perhaps most starkly illustrated by a response by BAE Systems to a criticism raised by RAF Kinloss regarding the Electrical Systems Pro-Forma for Hazard H51. The Pro-Forma in question stated in terms: *"The fire bottles located in the* [Doppler] *zone are associated with the bomb bay".*[74] There are no fire bottles in the zone in

[68] Hazards H66, H67, H70, H72, H73, H74, H75 and H77.

[69] Hazards H70, H73, H74 and H77.

[70] Notwithstanding the evidence of BAE Systems' witnesses, in its written submissions to the Review, BAE Systems maintained its position that the appendum was merely *"a more efficient manner in which to record the Electrical Systems contribution … as opposed to the alternative of creating two free-standing proforma documents, the results of which would then need to be merged"*. BAE Systems denied that it implied any decrease in the quality of the Electrical Systems' analytical output. As explained above, I do not accept that submission.

[71] Issue 1, dated April 2003, paragraph 4.2.

[72] November 2003, paragraph 3.2.

[73] BAE Systems denied this, stating that the scope of its task under the Phase 2 Proposal was to source and review extant mitigating material that was readily available and that it was therefore agreed with the IPT that the search to be conducted by BAE Systems would be 'finite' in nature.

[74] See page 4 of 4 (Section 8) of Electrics Pro-Forma for Hazard H51 dated August 2008.

question, Zone 124, in the MR2.[75] BAE Systems nevertheless responded to this straightforward (and indubitably correct) factual criticism in the following (somewhat Alice-in-Wonderland) fashion:

> *"The Equipment Safety Case did not take into account any mitigation from these fire bottles in the final analysis, but merely referenced them as a clarification point for the reader to confirm that in actual fact there is no fire protection in Zone 124."* [76]

11.138 In summary, factual accuracy is key to the validity of any Safety Case. It is not acceptable to produce Pro-Formas with a *plethora* of factual errors.

(19) BAE Systems' Fire/ Explosion Report was superficial and slapdash and failed properly to address the risk of a catastrophic fire in the No. 7 Tank Dry Bays (i.e. Hazard H73).

11.139 In my judgment, the Fire & Explosion Report prepared by Chris Lowe was a superficial and slapdash piece of work. It contained numerous errors and omissions. It failed to identify and highlight the catastrophic risk of an 'uncontrollable' fire risk in the starboard No. 7 Tank Dry Bay. It was done without reference to the BLSC Reports or the Pro-Formas and might have been better if it had been prepared by or jointly with someone in Mech Systems as originally envisaged.

Comprehensive stand-alone report dealing with Fire and Explosion risks

11.140 The very purpose of the Fire & Explosion Report was to identify and categorise all catastrophic fire and explosion risks in the Nimrod fleet. It was clearly intended to be a stand-alone report, which covered all functional and zonal fire and explosion risks to the Nimrod fleet. Accordingly, a reader could be forgiven for thinking that its findings, recommendations and conclusions would: (a) deal carefully and comprehensively with any zonal fire and explosion risk to the aircraft types; and (b) be consistent with other NSC reports, in particular the BLSC Reports and Pro-Formas. Unfortunately, neither was the case. The Fire & Explosion Report: (a) singularly failed to identify serious fire and explosion risk that the No. 7 Tank Dry Bay starboard represented; and (b) was irreconcilable with the BLSC Reports and Pro-Formas with which it, confusingly, overlapped but bore little relation.

Eight shortcomings

11.141 In my view, the Fire & Explosion Report prepared by Chris Lowe suffered from the following significant shortcomings: (1) it failed to consider or bear any relation to any of the zonal hazard Pro-Formas (including Hazard H73) or even follow the same zonal pattern; (2) it failed to identify aviation fuel as one of the flammable material sources;[77] (3) it failed to highlight the catastrophic nature of an 'uncontrollable' fuel fire risk in the wing bays;[78] (4) it failed to provide for adequate mitigation for many risks beyond the vague recommendation of having regard to the *"Swissair Flight 111 recommendations"*;[79] (5) it failed to have regard specifically to the risk of fuel tracking back from No. 1 blow off valve;[80] (6) in the key table (Table 2) '*Worst case Fire Hazard by Zone*', it left out the risk of an uncontrolled fire in the wing bays and simply addressed the scenario of a "*Wheelbrake fire or tyre explosion*" and classed it as *"Marginal", "Remote", "Closed"*;[81] (7) it came to an 'ALARP' conclusion, subject to a review of nine recommendations,[82] that was unjustified and irreconcilable with the Pro-Formas and the BLSC Phase 2 Reports: *"It is thus recommended overall fire/ explosion risk imposed by both types is considered tolerably low to the extent of being considered to be … ALARP"* and therefore both types *"acceptably safe to*

[75] There are fire bottles in Zone 124 in the R1 however. BAE System may have mistaken the Nitrogen purge bottles in Zone 124 in the MR2 for fire bottles; if so, they were also wrong to assume they discharged into the bomb bay rather than the Doppler compartment.

[76] MBU-DES-LT-NIM-SC-0169-Annex 1- Issue 1, dated 30 March 2009.

[77] Page 103.

[78] Page 107 and page 124.

[79] Page 107.

[80] Page 113.

[81] Page 124.

[82] Page 126 under the heading *"SUMMARY OF RECOMMENDATIONS DERIVED FROM ZONAL FIRE/EXPLOSION ASSESSMENT"*.

operate";[83] and (8) it contained a number of factual errors, *e.g.* No. 7 tank was described as being of a bag tank design (which is incorrect) and it was further stated that this non-existent rubber bag aided thermal insulation,[84] the '*smoke/fire of unknown origin*' crew drill was quoted as mitigation for a fire hazard in a compartment (Nos. 5 and 6 tank compartments) to which the crew have no access,[85] and the same drill was quoted as mitigation for the No. 1 fuel tank area, which is in fact outside the pressure hull.[86]

'Zone 7.23'

11.142 The Fire & Explosion Report identified 25 zonal hazards, all of which were *"Closed".* Six zones were classed as 'B' fire and explosion risks and categorised as *"Catastrophic"/"Remote"/"Closed"*; and the remaining 19 were classed as 'C' fire and explosion risks, including *"Zone 7.23"* which included the *"Dry Bays"* which were categorised as *"Marginal"/ "Remote"/"Closed"*. The report's summary table (Table 2)[87] entry for *"Zone 7.23"* read as follows:

SECTION 7.0 PARAGRAPH	**ZONE DESCRIPTION *CONSIDERED WORST CASE SCENARIO***	**SEVERITY**	**PROBABILITY**	**HRI**	**HAZARD STATUS**
7.23	Wings-Dry Bays and Main Undercarriage (Including Undercarriage & Wheelbrakes), *Scenario – Wheelbrake fire or tyre explosion*	MARGINAL	REMOTE	C	CLOSED

Contradictory with BSLC Reports

11.143 A crude attempt was made to marry the Fire & Explosion Report with the BLSC Reports, but on close inspection they are hopelessly contradictory. Table 2 to the Fire & Explosion Report concluded that there were six zones which should be classed as 'B' fire and explosion risks (i.e. *"Catastrophic"/"Remote"/"Closed"*)) and that the dry bay zones should be classed as 'C' fire and explosion risks (i.e. *"Marginal"/ "Remote"/"Closed"*). This summary table was merely inserted as a sub-annex (B.2) to Annex B in the BLSC Report under a single hazard (Hazard H83) entitled *"Fire &/or Explosion"* in Annex B to the BLSC Report and oddly categorised as *"Catastrophic/ Remote/B/ Open"* notwithstanding all 25 hazards in Table 2 to the Fire & Explosion Report were *"Closed"*. However, anyone reading Table B.2 to Annex B in the BLSC Reports would have been forgiven for thinking all relevant fire and explosion risks had been classified and *"Closed".* This is, after all, what Table B.2 said; and there was little in the main text of the BLSC to suggest to the reader the existence of any further fire and explosion risks. A close inspection of Annex C would, however, have revealed a further eight hazards (Hazards H70 to H78) which involved fire and explosion risks and of which it was said *"further analytical techniques..."* were required in order to categorise the fire and explosion risk. A review of the Pro-Formas, however (which did not form part of the BLSC Reports and were only accessible at the BAE Systems Chadderton terminal), would have revealed that there were, in fact, a total of approximately 31 other hazards listed in the BLSC Report which related to fire and explosion risks, of which approximately 18 hazards (including Hazard H73) remained *"Catastrophic"/ "Unclassifed"/"Open"*. The entry for Hazard H73 (Zones 514/614) in the Annex B (reproduced below) is irreconcilable with the entry for the (partially) equivalent zone (*"Zone 7.23"*) in Table B.2 (reproduced above):

[83] Page 125.
[84] Page 99 and page 100.
[85] Page 43.
[86] Page 47.
[87] Page 123 – 124.

HAZARD I/D	ZONE DESCRIPTION	*SEVERITY*	PROBABILITY	HRI	RECOMMENDED HAZARD STATUS
H73	**Zone 514/614 Interacting System Hazards – No. 7 Fuel Tank**	CATASTROPHIC	*UNCLASSIFIED*	–	OPEN

11.144 Equally, there was nothing in the Fire & Explosion Report to reflect the fact that the BLSC Report concluded that numerous fire and explosion risks (including Hazard H73) required *"further analytical techniques..."* before they could be classified at all. It is clear that the marriage of these two reports was hurried and ill-considered.

No satisfactory explanation

11.145 Chris Lowe had no satisfactory explanation for these contradictions. It is clear that he drew up the Fire & Explosion Report in isolation and without reference to Mech Systems or the Pro-Formas. Little or no thought appears to have been given to the problems engendered by carrying out two overlapping hazard exercises. Chris Lowe sought to argue in interview that the two reports were somehow 'complementary'. They were not. They were plainly contradictory and confusing. Eric Prince admitted in interview that he thought the idea was that fire and explosion risks picked up in the zonal hazard analysis would be fed into, and drawn together by Chris Lowe, in the Fire & Explosion Report, so that one would only have to look in one place for fire and explosion risk on the Nimrod. This, of course, was the point: it was never done. The reason is that the various reports were put together in a hurried, incoherent and sloppy manner.

(20) BAE Systems was in breach of contract for: (1) failing to exercise reasonable skill and care; (2) failing to use appropriate data when sentencing risks; and (3) leaving the NSC task incomplete.

11.146 In my judgment, BAE Systems was in breach of contract in relation to the NSC task[88] which they were contracted to fulfil by the Nimrod IPT, in three major respects. First, in failing to exercise reasonable skill and care in carrying out the task. Second, in failing to use appropriate data when sentencing risks. Third, for leaving the NSC task incomplete.

Failure to exercise reasonable skill and care

11.147 In my view, for the reasons set out above, BAE Systems' planning, management and execution of the NSC fell well below the standard that was to be expected of a DA entrusted with this sort of task and amounted to a breach of contract. This manifested itself in the generally poor quality of the NSC work ultimately produced by BAE Systems.

Failure to use appropriate data when sentencing risks

11.148 In my view, BAE Systems was in breach of contract for failing to assess and mitigate hazards by reference to all the appropriate data which the Proposal contractually required it to consider, namely: (a) design configuration; (b) test reports; (c) technical analysis reports; (d) maintenance/operating procedures and appropriate training; and (e) service history, including incident and fault reports.[89] In particular, BAE Systems did not consider the fault reports at all. This was a major omission: the reports would have revealed far more leak problems than the mere incident reports. The *"check list"* in the Proposal was mandatory. BAE Systems admitted that it had not checked fault data but sought to excuse its omission on the basis that '*it was not mandatory to use all the list sources of information if that was not necessary to mitigate a hazard down to a (recommended) "Managed" status*'. I disagree. The *"check list"* was not optional. The fault data would have shown that the risk of a fuel leak was much more likely than *"Improbable"*. BAE Systems resorted to using inappropriate data to sentence risk, namely the MRA4 generic data, because it was easy and time was running short.

[88] PDS Task 06-3409.

[89] Feasibility Study, dated November 2003, paragraph 3.2.

(3) *Leaving the NSC task incomplete*

11.149 In my view, BAE Systems failed to complete its contractual task. The terms of BAE Systems' Proposal required BAE Systems to *"mitigate"* each rationalised hazard identified in Phase 1 using *"existing evidence"* which was *"readily available", i.e.* by reference to the *"check list"* of five categories of mitigating evidence. It was only where *"extant"* mitigating evidence was not *"readily available"* that such hazards were to be classed as *"Open"* and the further work required to enable the hazard to become *"Managed"* could be regarded as being outside the scope of the contract and requiring separate tasking.[90]

11.150 The problem for BAE Systems was not that any of the five categories of mitigating evidence was not *"readily available"* but simply that it ran out of time to carry out the necessary technical analysis of the material that was available. This is clear in respect of, *e.g.,* over a dozen of the 32 hazards which BAE Systems left *"Open"* and *"Unclassified"* which bore the express open-ended recommendation that *"further analysis", "further investigation"* or *"further analytical techniques"* were required to categorise the risk (see Hazards H62, H66, H67, H70, H71, H73, H74, H75, H76, H77, H78, H79, H80). In my view, phrases such as *"further analytical techniques are required"* might properly be described as 'weasel' words. They were elaborate, quasi-scientific phrases designed to disguise the simple fact that further work was required and BAE Systems had run out of time to do it. It was not a question of any of the categories of mitigating evidence not being *"readily available"*. Eric Prince said in evidence to the Review that he came up with this wording following a discussion with Witness T [BAE Systems] about the precise form of words to be inserted into the Pro-Formas in cases where there was substantial further electrics work to be done. As was pointed out to Eric Prince in interview, this was not a question of a lack of readily available electrical diagrams or routing plans or other evidence, but simply a question of analysing the various possible interactions. Witness T [BAE Systems] simply ran out of time to do this. BAE Systems failed to complete what it was contractually required to do and handed over the job to the (unsuspecting) Nimrod IPT only partly done.

(21) *If BAE Systems had carried out the NSC task properly, the accident to XV230 would have been avoided.*

11.151 In my judgment, if BAE Systems had: (1) exercised reasonable skill and care in the planning, management and execution of the NSC task; (2) used appropriate data when sentencing risks; and (3) completed the task using all the *"readily available"* evidence, the accident which subsequently befell XV230 would have been avoided. The risk of a catastrophic fire in No. 7 Tank Dry Bay starboard as a result of the Cross-Feed/SCP ducting would have been identified, assessed and mitigated to ALARP well before the incident in September 2006.

11.152 In my view, the juxtaposition of the Cross-Feed/SCP duct and the fuel pipes and couplings in No. 7 Tank Dry Bay starboard represented a clear risk of a 'single point' failure leading to a catastrophic fire, such that No. 7 Tank Dry Bay starboard should have been immediately obvious a 'fire zone' requiring suitable mitigation measures. All this would and should have been apparent to anyone carrying out a careful ZHA using appropriate (*e.g.* fault) data. If care had been taken in the preparation of the NSC in the period 2003 to 2004, I have no doubt that Hazard H73 would have been categorised as a Class 'A' risk and suitable urgent management action would have been taken to manage it well before September 2006, with suitable mitigating measures being introduced, such as switching off the SCP, or providing better insulation for the hot air pipes.

(22) *BAE Systems is a company in denial.*

11.153 In my judgment, BAE Systems is a company in denial. Denial has been the hallmark of BAE Systems' response, both to the Nimrod Review and in respect of the XV230 incident itself. Denial of design defects; denial of fault in respect of the NSC, other than minor errors; denial of mistakes, save with the benefit of 'hindsight'; denial of any real responsibility, causal or otherwise. This has been troubling and a cause of real concern for the Review.

11.154 BAE Systems promised, at the outset, to 'co-operate' with the Review. I regret that, in my view, there has not been co-operation from BAE Systems in the true sense of the word. Instead of carrying out a thorough internal investigation and presenting all its findings and evidence to the Review in a speedy, open and transparent

[90] See paragraph 3.2 of the Phase 2 Proposal, dated November 2003.

manner, earnestly seeking to find out what went wrong, and why, in order to learn lessons and improve matters for the future, BAE Systems engaged with the Review largely in a defensive manner, as if it was conducting litigation, with its primary concern appearing to be that of protecting its own position. BAE Systems says it has recorded more than 20,000 man hours 'assisting' the Nimrod Review and providing evidence regarding XV230. It appears, however, to have spent a significant amount of that time building a wall of denial and, at times, obfuscation, which the Review has had to dismantle, brick by brick.

11.155 It is surprising and unfortunate that BAE Systems does not appear to have carried out its own internal investigation into the loss of XV230. Instead, it seems to have relied upon the same people who were responsible for the NSC to inform its responses to the Review. This may be one of the reasons why BAE Systems' general stance has been defensive and characterised by an unwillingness to accept even the obvious, notwithstanding that the evidence upon which the criticisms of the NSC are based was almost exclusively BAE Systems' own documentary and witness evidence. Further, it has only been possible to piece together the history the NSC as a result of personal archives and notebooks of BAE Systems personnel that came to light very late in the day.[91] The picture which has emerged is markedly different from that set out in BAE Systems' written submissions to the Review. The statement, for instance, that at the customer acceptance "BAES *presented the Baseline Safety Case Reports for both the Nimrod MR Mk2 and the R Mk1"* and there followed *"a review of the reports presented by BAES"*, is not borne out by BAE Systems' own internal evidence. BAE Systems' lengthy, legalistic and defensive submissions and witness evidence were tested in detail and found to be at variance with reality and the contemporaneous documents.

11.156 BAE Systems' internal 'Product Liability' guidance to employees provides: *"Do maintain effective, complete and detailed records of documentation, particularly those relating to safety".* Despite this, however, the documentation disclosed by BAE Systems in response to a series of requests by the Review, whilst voluminous, was incomplete and patchy. The same guidance also warns employees that *"All of our documentation, including e-mail, is open to inspection in the event of a product liability claim"* and discourages the use of *"loose phrases or speculative remarks in documentation"*.[92] But for the fortunate retention by Witness K [BAE Systems] of his personal files and notebooks, much of the NSC story would not have come to light.

11.157 Regrettably, the defensive stance adopted by BAE Systems has lengthened the Review by many months.

11.158 It is important that the UK's main defence industry contractors, and in particular BAE Systems as the prime industry 'partner', understand and embrace the true meaning of 'co-operation' with accident inquiries such as the Nimrod Review, which are charged with establishing the facts and responsibility, in order to learn rapid and lasting lessons for the future in the national interest.

(23) BAE Systems has failed to live up to its expressed UK ethics 2002 policy of "accountability, integrity, honesty, openness and respect".

11.159 In my judgment, BAE Systems has failed to live up to its expressed ethics policy. In 2002, BAE Systems formalised its UK ethics policy, setting out five key principles of ethical business conduct: *"accountability, integrity, honesty, openness and respect"*. In my view, all five principles were breached in the present case.

11.160 In 2008 BAE Systems engaged the Woolf Committee to report on its company ethics.[93] The Woolf Report emphasised the importance of tackling the 'ethical and reputational risks' that arise through the interaction with the Government as major contractors and the need to *"embed a culture of openness and transparency"*.[94] In my view, BAE Systems was not 'open and transparent' when presenting the result of its NSC work to the Nimrod IPT and QinetiQ.

[91] Most of BAE Systems' most significant disclosure was not handed to the Review until two working days before the commencement of the first round of interviews; and most of the notebooks were disclosed on a piecemeal basis throughout the course of those interviews, and subsequently.

[92] The 'focal point' for 'Product Integrity' within the Air Sector is said to be the Head of Airworthiness.

[93] *"Ethical business conduct in BAE Systems plc – the way forward",* May 2008 (the Woolf Committee Report).

[94] Ibid, paragraph 5.11.

11.161 In 2008, BAE Systems also engaged Praxis High Integrity Systems (Praxis) to review the Baker[95] and Columbia[96] Reports for BAE Systems Military Air Solutions (MAS).[97] Praxis said that the safety culture within MAS was '*very strong*' and a defence to problems such as safety workload from '*overly aggressive delivery milestones*' and ensuring '*due process is followed*'. [98] The story of the NSC would suggest that the safety culture in MAS may not be as strong or uniform as thought. Praxis warned that challenges lay ahead *"as MAS operates over more sites and with varied staff backgrounds such as ex-RAF staff".* [99] It drew the following parallels:

> *"Both Baker and Columbia reports focus heavily on the cultural issues leading to the accidents. NASA had a strong culture which declined over time under re-organisation, outsourcing and cost pressure. BP suffered from very different safety cultures at different sites. BAE Systems currently has a strong safety culture, but is diversifying and changing, e.g. multiple sites. Therefore nature of the business, the lack of cultural measurement and the importance of the safety culture are key parallels with Baker and Columbia reports."* [100]

11.162 In my view, the above gives rise to a concern that BAE Systems has failed to implement its expressed ethical business culture company-wide. The responsibility for this must lie with the leadership of the Company.

Criticisms of BAE Systems' personnel

11.163 The key BAE Systems' personnel involved in the NSC in 2001-2005 were those at management level, Chris Lowe, Richard Oldfield, and Eric Prince. They bear primary responsibility for the catalogue of failures by BAE Systems in relation to the NSC.

11.164 The respective personal responsibilities of Chris Lowe, Richard Oldfield and Eric Prince for the NSC must be judged against a background of a busy office and increasingly heavy workloads for each of them given their numerous other duties and, *e.g.,* the increasing demands for technical support for the Afghanistan and Iraq conflicts. It is also fair to say that the NSC was one of the first major Safety Cases to be drawn up for legacy platforms and, therefore, there was inevitably a learning curve for each of them. In my judgment, however, the conduct of all three individuals fell substantially below what could reasonably have been expected from professionals in their respective positions with their respective responsibilities and they should, therefore, be named and held accountable.

Chris Lowe - BAE Systems' Chief Airworthiness Engineer

11.165 Chris Lowe was BAE Systems' Chief Airworthiness Engineer at the time. He was responsible: (a) for Airworthiness governance for the work undertaken at Chadderton by the Nimrod MR2 and R1 team; (b) as Functional Head of Safety Engineering; and (c) for leadership of the Airworthiness Department and supervision of Airworthiness staff. He played a key role in the NSC between 2001 and 2005. He was heavily involved in the preparation of the major NSC documents, including in particular, the Feasibility Study (March 2002), the Preliminary Hazard Identification Report (April 2003), Phase 2 Proposal (November 2003), Phase 2 Certification Statement (June 2004), Fire & Explosion Report (August 2004), Nimrod MR2 and R1 Equipment Safety Case Baseline Reports (September 2004). He facilitated the FTA workshop (November 2002) and played a leading role at the Customer Acceptance Conference (31 August-1 September 2004) and the Fifth and Sixth PSWG meetings (18 May and 10 November 2004). He had done an MSc in Safety Engineering at Lancaster University which had included a dissertation on aircraft fire and explosion in aircraft in 2003.[101]

[95] *The Report of the US BP Refineries Independent Safety Review Panel*, January 2008 (the Baker Report).

[96] *Columbia Accident Investigation Board Report*, August 2003 (CAIB Report). See further **Chapter 17**.

[97] *Independent Review of the Baker and Columbia Reports*, April 2008 (the Praxis Report).

[98] Ibid, paragraph 6.3.1.

[99] Ibid, paragraph 6.3.1.

[100] Ibid, paragraph 6.3.2.

[101] *"A Review of the Overall Fire/Explosion Risk in Commercial Transport Airframe Design Operation",* Author Christopher Lowe, Lancaster University Engineering Department, 2003.

11.166 There is little doubt that Chris Lowe was the dominant figure in the BAE Systems NSC management team. He bears the heaviest responsibility for the poor planning, poor management and poor execution of the NSC. He attempted in interview to distance himself from the project, suggesting that he was only keeping a '*top level*' eye on what was going on, and Witness C [BAE Systems] was responsible for the day-to-day running of the hazard assessment programme. But, in my judgment, he was clearly very much hands-on during both Phase 1 and Phase 2 of the NSC and aware of what was going on. He clearly considered himself as more knowledgeable about Safety Cases than those around him. Most deferred to him. He was ambitious, both for himself and for the company. He believed this to be an opportunity to demonstrate that his department was involved in prestigious, cutting-edge work. He saw the NSC as a '*showcase*' project which would enhance his standing and open up new commercial possibilities for BAE Systems. His department was nominated for the Chairman's Bronze Award for innovation. On the back of the apparent success of the NSC, in December 2004, he made a sales pitch to the Nimrod IPT to do 'Operational' Safety Cases.

11.167 Unfortunately, he underestimated the nature of the task and overestimated his own abilities. He did not take kindly to suggestions from those who, on occasion, thought they knew better (like Witness K [BAE Systems]). He was, at all material times, fully aware of the time problems that the project was running into. He turned a blind eye to the use of MRA4 generic data. He insisted on a '*final push*' to get completion. What really mattered was producing an impressive-looking set of reports on time which could be trumpeted by his department as a success. He was ultimately prepared to draw a veil over the incomplete nature of the work. The actual content, quality and completeness of the work was not paramount important because he, like most others, assumed the Nimrod to be '*safe anyway*' because of its service history.

Richard Oldfield – NSC Project Leader

11.168 Richard Oldfield played a key role in the NSC between 2001 and 2005. He was appointed in 2001 as Task Leader on the NSC. He played an important part in compiling the proposals for Phase 1 and 2 and acted as Project Manager within TTRO Engineering. He was in charge of the zonal hazard assessments carried out on both the MR2 and RMk1. He played a leading role at the Acceptance Conference on 31 August/1 September 2004 and the Sixth PSWG. He too (deliberately) did not come clean about the figures for *"Open"* and *"Unclassified"* hazards and the large gap left in their analysis. It was his responsibility to monitor and manage the progress of the NSC project. He failed to manage the project properly. He bears a significant responsibility for the poor planning, poor management and poor execution of the NSC.

Eric Prince – Flight Systems and Avionics Manager

11.169 Eric Prince was the Flight Systems and Avionics Manager at the time, responsible (a) for Technical governance for Avionics, Mechanical Systems and Electrical Systems design and development on Nimrod MR2 and R1 and (b) as Team Leader for Electrical, Mechanical and Avionics systems Department. He played a key role in the NSC between 2001 and 2005. He attended the Fault Tree Analysis Workshop (19-21 November 2002). He was involved in the Zonal/Functional hazard assessment Pro-Forma process, including sign off of Hazards H73 and H34 (February to September 2004). He was the line manager for Witness K [BAE Systems]. He attended the Customer Acceptance Conference (31 August to 1 September 2004). He bears a significant responsibility for the poor planning, poor management and poor execution of the NSC. He too was prepared to see the customer be given a deliberately misleading impression as to the completeness of the work.

Nimrod Safety Case 2

11.170 I deal with criticisms of BAE Systems' subsequent work in 2008-2009 on Nimrod Safety Case 2 in **Chapter 15.**

CRITICISMS OF THE NIMROD IPT in relation to the Nimrod Safety Case

Introduction

11.171 In my judgment, the Nimrod IPT bears considerable responsibility for the lamentable quality of the NSC and the singular failure of the NSC to capture the catastrophic fire risk presented by the Cross-Feed/SCP duct risk. If the Nimrod IPT had performed its duties in relation to the NSC appropriately and carefully, it is likely that the NSC would have properly identified, assessed and addressed this fire risk and the loss of XV230 would have been avoided.

11.172 The Nimrod IPT was responsible for ensuring the safe through-life management of the Nimrod fleet. Safety Cases were mandated by BP1201. The Nimrod IPT outsourced the task of preparing the NSC to BAE Systems (see further below). It was, therefore, the Nimrod IPT's responsibility to project manage the task and ensure that a proper Safety Case was produced for the Nimrod fleet. QinetiQ acted as 'independent advisor' in relation to the NSC and supported the sign-off of the NSC. The Nimrod IPT finally completed the NSC in February 2005.

11.173 As explained above and in **Chapter 10A**, there were significant flaws in the NSC which was produced in the period 2001 to 2005. The NSC failed to identify the serious fire risk in No. 7 Tank Dry Bay starboard which the Cross-Feed/SCP duct posed to the Nimrod fleet (Hazard H73) and which subsequently caused the loss of XV230 in September 2006.

11.174 As explained above, the Review identified a number of errors in the NSC in relation to Hazard H73 alone and decided to conduct a detailed investigation into the entire NSC and found: First, the errors identified by the BOI and the Review in relation to Hazard H73 were not one-off, but appear to have been symptomatic of a generally poor standard of accuracy and analysis in the NSC. Second, the NSC Baseline Safety Case Reports (BLSC Reports) produced by BAE Systems left over 30% of the hazards *"Unclassified"* and 40% of the hazards remained *"Open"*, many with no recommendation beyond simply that *"Further analytical techniques are required"* before they could be categorised, sentenced and closed. Third, the Fire & Explosion Report did not accord with the BLSC Reports produced by BAE Systems. Fourth, the NSC had not reduced the risks to the Nimrod fleet to ALARP.[102]

11.175 Unfortunately, the Nimrod IPT failed to grasp the opportunity which then presented itself properly to categorise and mitigate catastrophic Hazard H73.

Key Personnel

11.176 The key personnel in the Nimrod IPT with responsibilities for the NSC were: (1) the Nimrod IPT Leader (IPTL), Group Captain (now Air Commodore) George Baber, who was also the Nimrod Project Engineer (PE); (2) the Head of Air Vehicle, Wing Commander Michael Eagles, and (3) the Safety Manager, Frank Walsh (see further below). References hereafter to the Nimrod IPT are generally to these key personnel.

Lack of guidance

11.177 As set out in **Chapter 9**, JSP318B prescribed a Safety Management System (SMS) for military aircraft and set out the aims and objectives of such a system. Whilst JSP318B mandated a clear policy, it is fair to say that the majority of the MOD personnel required to implement that policy had received little (if any) relevant guidance and training, and nor was it clear to them where they were meant to look for support. The IPTs felt they lacked advice and guidance generally regarding safety matters. A Safety Process Review in 2002 initiated by the Defence Procurement Agency reported: *"The universal plea was for early, authoritative advice on what had to be done, by whom, when and in what format with regard to safety on their project"*.[103] The lack of practical guidance does not, however, excuse the basic failures of the Nimrod IPT to follow its own procedures or ensure the safety of the Nimrod fleet.

[102] *i.e.* Risks were not reduced to As Low As Reasonably Practicable (see **Chapter 9**).

[103] Safety Process Review, dated 23 December 2002, Advantage Technical Consulting: Section 3 Interview Phase, paragraph 3.2 on IPTs, especially paragraph 3.2.2.

Summary of criticisms of the Nimrod IPT in relation to the NSC

Major failures of the Nimrod IPT

11.178 In my judgement a number of significant criticisms of the Nimrod IPT in relation to the NSC in the period 2002 to 2005 are borne out. There were two fundamental failures by the Nimrod IPT in particular:

(1) First, *a fundamental failure of project management*: the Nimrod IPT failed properly to project manage the production of the NSC by BAE Systems and, in particular, to act as an 'intelligent customer' when the NSC task was handed over by BAE Systems, ostensibly properly completed.

(2) Second, *a fundamental failure to mitigate catastrophic risks carefully*: the Nimrod IPT failed carefully to sentence the large number of hazards which had been left *"Open"* and *"Unclassified"* by BAE Systems and failed to ensure that catastrophic risks were properly assessed and managed in accordance with appropriate procedures.

11.179 The criticisms of the Nimrod IPT can conveniently be summarised by, and considered under, the following headings:

(1) The Nimrod IPT's attitude to the NSC was flawed from the outset: it assumed that the Nimrod was 'safe anyway' because of its long record.

(2) The Nimrod IPT inappropriately delegated the management of the NSC task to a relatively junior person without adequate oversight or supervision.

(3) The Nimrod IPT failed to ensure adequate operator involvement in BAE Systems' work on Phases 1 and 2 of the NSC.

(4) The Nimrod IPT failed properly to project manage the NSC, or to act as an 'intelligent customer' at any stage.

(5) The Nimrod IPT failed to read the NSC Reports carefully or otherwise check BAE Systems' work.

(6) The Nimrod IPT subsequently signed off BAE Systems' NSC in circumstances where it was manifestly inappropriate to do so.

(7) The Nimrod IPT proceeded to sentence the remaining hazards on a manifestly inappropriate and inadequate basis.

(8) The Nimrod IPT failed to follow its own Safety Management Plan.

(9) The Nimrod IPT failed properly to appoint an Independent Safety Auditor to audit the NSC.

(10) The Nimrod IPT failed properly to manage the NSC post its production and failed to treat it as a "living" document.

(11) The Nimrod IPT failed to ensure that resources within the Nimrod IPT were properly utilised to ensure the airworthiness of the Nimrod fleet and to ensure that safety and airworthiness was the first priority.

11.180 The wider organisational causes of the failure of the Nimrod IPT in relation to the NSC are dealt with later in **Part IV** of this Report.

Detailed analysis and criticisms of Nimrod IPT

(1) The Nimrod IPT's attitude to the NSC was flawed from the outset: the Nimrod IPT assumed that the Nimrod was 'safe anyway' because of its long record.

11.181 In my judgment, the Nimrod IPT's attitude to the NSC was fundamentally affected by the prevailing malaise (outlined earlier) that, because the Nimrod had operated safety for over 30 years, it could be assumed that the Nimrod was 'safe anyway' and that, therefore, the NSC exercise did not really matter. Thus it was that the Nimrod IPT's approach to the NSC was flawed and undermined throughout: the safety of the Nimrod fleet was *assumed* and NSC task viewed as essentially a 'box' under BP1201 which had to be 'ticked'.

11.182 It was suggested by George Baber in interview that the Nimrod IPT should be given credit for going further than was strictly required by BP1201 by producing an 'explicit' Safety Case rather than relying on the Release to Service (RTS) as an 'implicit' Safety Case under BP1201. In my view, there is nothing in this point. It would have been remiss not to have produced an 'explicit' Safety Case for a legacy aircraft such as the Nimrod. And having determined to do so, there was no excuse for not doing a proper job.

(2) The Nimrod IPT inappropriately delegated the management of the NSC task to a relatively junior person without inadequate oversight or supervision.

11.183 In my judgment, the Nimrod IPT inappropriately delegated the management of the NSC task to a junior person who was given inadequate supervision or oversight. There was a failure of management by the key personnel within the Nimrod IPT and a failure to perform and adhere to their respective roles and responsibilities.

Respective Roles and Responsibilities

11.184 The roles and responsibilities of the three key personnel in the Nimrod IPT were as follows:

11.182.1 The Nimrod IPTL and PE, George Baber, had specific and general overall responsibilities for safety under the Nimrod SMP.[104] He had overall responsibility for management of the personnel in the Nimrod IPT and for ensuring that Nimrod IPT personnel properly performed, and adhered to, their respective roles and responsibilities. He was a Letter of Delegation (LOD) holder[105] and had authority to decide whether Class 'A' and 'B'risks had been managed to ALARP.

11.182.2 The Head of Air Vehicle, Michael Eagles, had primary responsibility for managing the development of the NSC. Under the Nimrod SMP, the Head of Air Vehicle had *"Ownership of the Nimrod SC and HL"* and responsibility for advising the IPTL *"on safety matters".*[106] He was an LOD holder, with responsibility for identifying and approving equipment hazards on the Hazard Log, and had authority to decide whether Class 'C' and 'D' risks had been managed to ALARP.[107]

11.182.3 The Safety Manager, Frank Walsh, had more general safety responsibilities under the Nimrod SMP.[108] He was not an LOD holder and had no authority to sentence risks himself. It was felt that this gave him independence.

Failure to perform

11.185 Michael Eagles failed to perform his role as Head of Air Vehicle in relation to the NSC. He failed to manage the production of the NSC personally. He effectively delegated management of the project wholesale to the Safety Manager, Frank Walsh. He failed to ensure the Heads of Branch provided engineering support in respect of the NSC. He failed to play any real role in ensuring the NSC project was fully and satisfactorily completed.

[104] Paragraph 10, page A-4 of the Nimrod SMP.

[105] Letter of Delegation from Director General Equipment Support (Air) to George Baber, dated 14 and 22 May 2002.

[106] Paragraph 9, page A-4 of the Nimrod SMP.

[107] Letter of Delegation from George Baber to Michael Eagles, dated 23 October 2003.

[108] Paragraph 10, page A-4 of the Nimrod SMP.

He effectively left Frank Walsh to liaise with BAE Systems, manage the production of the NSC and monitor the outcomes largely on his own, with very little supervision or guidance. This was highly unsatisfactory. Frank Walsh was barely qualified to be a Safety Manager. He had never been involved in a Safety Case. He had never managed such a hazard assessment project before. He was a relatively junior officer. He knew very little about Nimrods. The fact that he had been through a selection process in order to be appointed Safety Manager, in my view, meant little.

Failure to manage

11.186 George Baber was privy to, and encouraged, the inappropriate arrangement whereby Frank Walsh, rather than Michael Eagles, *de facto* wholly *"owned"* and managed Phase 2 of the NSC project and its outcomes, and Michael Eagles had little or no input. George Baber knew that: (a) Michael Eagles was heavily engaged in the period 2003-2005, in negotiating NISC 2 and NISC3 (Nimrod Integrated Support Contracts) with BAE Systems, a task which George Baber had placed upon him (this was an important part of the 20% reduction in output costs which George Baber as IPTL was required to deliver);[109] (b) Michael Eagles had limited time for his other duties as Head of Air Vehicle; and (c) Michael Eagles had effectively relinquished responsibility for the project management of the NSC to Frank Walsh. It was effectively Frank Walsh alone who advised George Baber regarding the sentencing of risks in the NSC and signing-off of the project.

11.187 Accordingly, George Baber and Michael Eagles put Frank Walsh in a position whereby he was acting beyond his level of responsibility, authority and capability. He was, in practice, in sole charge of: (a) managing and closing the NSC project; and (b) giving specialist advice to George Baber as the IPTL and PE on sentencing Category 'A' and 'B' hazards. This was not a position that he should have been put in. He was simply not qualified. He did not have the authority to do so. He did not have the experience, skills or judgment to understand what he was really doing. Most of the time, he appears to have been simply out of his depth. This all should have been apparent to George Baber and Michael Eagles. Neither managed Frank Walsh adequately. In particular, neither ensured that he was seeking and obtaining input from the appropriate engineering specialists or desk officers when project managing the NSC and making recommendations for sentencing risks.

Failure to adhere

11.188 Frank Walsh did not adhere to his (limited) role and responsibilities as Safety Manager. He exceeded his responsibilities, authority and capabilities with regard to the NSC project and the sentencing of risks (see further below). He failed to recognise the limitations of his responsibilities, authority and capability with regard to the NSC project and the sentencing of risks and failed to seek appropriate guidance from his superiors. He failed to seek input from the appropriate engineering specialists or desk officers when project managing the NSC and making recommendations for the sentencing of risks.

(3) The Nimrod IPT failed to ensure adequate operator involvement in BAE Systems' work on Phases 1 and 2 of the NSC.

11.189 In my judgment, the Nimrod IPT is at fault for failing to ensure any real involvement of the operators of the Nimrod aircraft (*i.e.* RAF maintenance and flight crew from RAF Kinloss and/or RAF Waddington and/or from the Nimrod IPT itself) at any stage during Phases 1 and 2 in the production of the NSC.[110]

Lord Cullen on operator involvement

11.190 Lord Cullen in the *Piper Alpha* report had clearly emphasised the need for operator involvement in a Safety Case. This was reiterated by the MOD in the *White Booklet*.[111] In my view, operator involvement in the process of developing a safety case for a 'legacy' platform such as the Nimrod was axiomatic to its success, not least because those charged with maintaining and flying the aircraft over the years had detailed, practical knowledge of the aircraft and the working of its systems, which the designers would not have.

[109] See **Chapter 13.**

[110] Save for the Fault Tree Analysis.

[111] **Chapter 9,** paragraph 9.67.

Joint working group never set up

11.191 BAE Systems' Feasibility Study recommended that a joint BAE Systems/Nimrod IPT NSC working group be set up *"to partake in the identification, determine causes and effects and mitigation of all hazards, and contribute toward the consequent population of the hazard log"*.[112] This was re-iterated at the Inaugural Platform Safety Working Group (PSWG) meeting on 18 March 2002. A joint working group was, however, never set up. This was the fault jointly of both the Nimrod IPT and BAE Systems. The result was an almost total lack of involvement in Phases 1 or 2 by the operators.

(4) The Nimrod IPT failed properly to project manage the NSC, or to act as an 'intelligent customer' at any stage.

11.192 In my judgment, the Nimrod IPT failed properly to project manage the NSC, or to act as an 'intelligent customer' at any stage of the process. The Nimrod IPT's handing and monitoring of the outsourcing to BAE Systems of this work was woeful, and the antonym of 'intelligent'.

11.193 The Nimrod IPT's failures in this regard manifested themselves most significantly at the key hand-over meeting, namely the Customer Acceptance Conference (and, subsequently, at the Sixth PSWG, as to which, see further below).

Customer Acceptance Conference on 31 August/ 1 September 2004:

11.194 As explained in more detail in **Chapter 10A**, on 31 August and 1 September 2004, a 'Customer Acceptance Conference' was convened at Chadderton by BAE Systems, to which representatives of the Nimrod IPT (and QinetiQ) were invited. The purpose of the meeting was for BAE Systems to present the results of Phase 2 of the NSC and to demonstrate to the satisfaction of the Nimrod IPT (and QinetiQ) that the contractual requirements of PDS Task 06-3409 had been satisfied. It was, therefore, a very important meeting.

Weak team

11.195 The Nimrod IPT fielded an inappropriately weak team for the Customer Acceptance Conference on 31 August/1 September 2004. This was symptomatic of the Nimrod IPT's generally feeble management and lack of active 'hands on' engagement with the NSC project as a whole. The Nimrod IPT representatives at the meeting were Michael Eagles, Frank Walsh, Witness W [MOD], Witness X [MOD], and Witness Y [MOD], the IPT's Resident Project Officer at Chadderton. However, Michael Eagles was only ever scheduled to attend the first day; after which he duly absented himself and left Frank Walsh in charge. This was highly unsatisfactory. Michael Eagles was the most senior IPT representative present and had key responsibility for the management of the production of the NSC under the SMP. He should have remained for the entire meeting and been present to take the crucial decision on behalf of the Nimrod IPT as to 'sign-off' of BAE Systems' Phase 2 work. Save for Frank Walsh, none of the other Nimrod IPT representatives had much familiarity with the NSC project. Witness X [MOD] had been asked to stand in for Witness Z [MOD] (who was unavailable), something which Witness X [MOD] explained to the Review he was uncomfortable about, given his lack of involvement in the project. He was right to feel uncomfortable: without a background working knowledge of the project it would be difficult to tell whether what was being presented by BAE Systems was satisfactory and fulfilled the brief. As it happened, the representative QinetiQ sent to the meeting was also new and unfamiliar. Thus, protection of the Nimrod IPT's interests at the meeting effectively hinged on one person: Frank Walsh.

Not an 'intelligent customer'

11.196 The Nimrod IPT did not act as an 'intelligent customer' during the meeting. It did not ask relevant intelligent questions. It did not satisfactorily test or challenge what 'outcomes' of Phase 2 BAE Systems was presenting. Its representatives remained largely passive and inactive during the meeting and were, it seems, content to accept what was said in BAE Systems' PowerPoint presentations without demur or, it appears, the application of any critical faculty. The Nimrod IPT left itself vulnerable.

[112] See paragraph 10.2 of the Feasibility Study.

BAE Systems' presentations

11.197 As set out in **Chapter 10A**, at the Customer Acceptance Conference, the Nimrod IPT and QinetiQ representatives were given three main presentations by BAE Systems:

11.195.1 First, a PowerPoint presentation by Richard Oldfield entitled *"Programme status as at 31 August 2004"* in which he effectively represented that PDS Task 06-3409 had been completed, on the basis that *"extant"* mitigation evidence had been *"sourced for 105 hazards"* and entered into CASSANDRA and that the six deliverable reports, including the final BLSC Reports for both Nimrod types, were all *"complete"*.

11.195.2 Second, a PowerPoint presentation by Chris Lowe on the six reports. He gave a presentation of the BLSC Reports comprising only the general sections but not the Executive Summary or Conclusion (which had not yet been written, or at least not completed). He then presented the full contents of the other Reports, including the Fire & Explosion Report, highlighting the conclusion that the Nimrod types could be considered *"ALARP"* so far as the risk of fire and explosion was concerned, subject to minor recommendations.

11.195.3 Third, Witness C [BAE Systems], then gave a demonstration of how the CASSANDRA Hazard Log worked and put up on the screen draft versions of what were to become Annexes B and C to the BLSC Reports (the latter, with Chris Lowe's assistance). Draft Annex B comprised a table which listed all the *"Unclassified"* hazards.

11.198 Notwithstanding the fact that a detailed review of the Hazard Log contents, together with the other reports and the final BLSC reports, had originally been promised, BAE Systems did not give a detailed review of the 105 hazards or state how much *"extant"* mitigation had, in fact, been found. BAE Systems did not volunteer the fact that it had left over 40% of the hazards *"Open"* and over 30% *"Unclassified"*. Nor did BAE Systems hand over hard copies of the six 'deliverable' reports at the meeting.

Failure to ask any intelligent questions

11.199 Despite the fact that the meeting represented the best opportunity to test whether Phase 2 had been satisfactorily completed by BAE Systems, at no stage did Michael Eagles or Frank Walsh (nor any of the Nimrod IPT representatives present, nor QinetiQ) raise any queries in relation to the above, or ask BAE Systems any of the intelligent questions which arguably should have been asked in relation to this key area, *i.e.*: Why was there no review of how each of the hazards had been classified, mitigated and sentenced? How many hazards had BAE Systems actually left *"Unclassified"* and/or *"Open"*? Why? How could PDS Task 06-3409 be considered completed when hazards remained *"Unclassified"*? How could the aircraft be considered ALARP when hazards remained *"Open"* and *"Unclassified"*? Instead, the Nimrod IPT (and QinetiQ) representatives appear to have been content simply to sit, passively, throughout the Customer Acceptance Conference and accept every PowerPoint bullet and assurance given by BAE Systems at face value, without demur, without detail and without challenging or querying anything said.

The dangers of PowerPoint

11.200 If the IPT and QinetiQ representatives present had been on the ball, they would and should have spotted, and seriously queried, the large number of hazards on the latter pages of the draft Annex B table marked *"Unclassified"*. It is unclear, however, precisely how long these particular pages were up on the screen for, and whether the word *"Approved"* in the right hand column against every hazard may have de-sensitised the viewers. It was at the end of a long day of PowerPoint presentations. It may, therefore, be not altogether surprising that the Nimrod IPT and QinetiQ representatives were not particularly alert. Furthermore, they had not been led to expect any particular problems. Indeed, quite the opposite: the presentations gave the distinct and comforting impression of 'job done' and 'aircraft ALARP', subject to looking at certain (minor) recommendations. To this extent, the effect of these presentations may have lulled them into a false sense of security.

11.201 If intelligent questions had been asked during the Customer Acceptance Conference, it is likely that they would have elicited answers which would have revealed what was appears to have been the actual status of the project, namely: (i) BAE Systems had left over 40% of the hazards *"Open"* and unsentenced, many with no recommendation beyond simply that *"Further analytical techniques are required"* before they could be sentenced and closed; (ii) BAE Systems had left over 30% of the hazards *"Unclassified"* and uncategorised, with no recommendation beyond simply that *"Further analytical techniques are required"* before they could be classified; (iii) BAE Systems had not completed drafting the BLSC Phase 2 Reports, in particular the Executive Summary, Conclusion and Annexes B and C thereof; (iv) BAE Systems had not completed work on all the hazards (e.g. Hazards H78, H79 and H63); and, in the circumstances, PDS Task 06-3409 and the 'Top Level Goal' of the NSC could not be said to have been fully and satisfactorily completed.

'Consensus'

11.202 Nevertheless, the Nimrod IPT (and QinetiQ) became party to a 'consensus' on the final day of Customer Acceptance Conference that *"the aims and objectives of the project had successfully been achieved"* and Frank Walsh formally agreed on behalf of the Nimrod IPT that *"PDS Task -06-3409 could be considered closed by the issue of the minutes of this Conference".*

11.203 In my judgment, Michael Eagles (as Head of Air Vehicle, responsible for the project management of the NSC) and Frank Walsh (as Safety Manger), are liable to criticism for failing to take any, or any adequate, steps to satisfy themselves that the NSC work had been satisfactorily carried out and completed by BAES. As a result, the Nimrod IPT singularly failed to ensure that the NSC task has been fully and properly completed by BAE Systems. The task was far from complete or satisfactory, and manifestly so. The Nimrod IPT displayed a remarkable lassitude.

Cosy and complacent atmosphere

11.204 How and why did this regrettable situation come about? In my view, it is not difficult to discern. There are, I believe, four principal reasons. First, the acceptance of the Phase 2 work at the meeting effectively hinged on Frank Walsh and he was out of his depth (as explained above). Second, the relationship between BAE Systems and Frank Walsh had become 'too cosy'. As he and Chris Lowe were at pains to explain in evidence to the Review, they had worked 'very closely' together in the months leading up to the Customer Acceptance Conference. As Richard Oldfield told the Review: *"We were very close to Frank Walsh on this programme. The primary point of contact was Frank Walsh."* This closeness manifested itself in a joint reluctance to accept criticism from third parties. This is illustrated, *e.g.*, by BAE Systems' and Frank Walsh's response to an *"Air Environment IPTs Hazard Log Review"* dated 7 April 2005 produced by Echelon Consulting Limited. The Echelon report noted *inter alia* (section B.4) that the *"Nimrod IPT's reliance on the BAES Fault Tree has relegated Cassandra to a position where it is little more than a high-level management reporting tool"* and that *"the detail contained in the hazards and accidents descriptions is insufficient to reason about the legitimacy of the relationship".*[113] Frank Walsh sent a copy of the report to BAE Systems on 20 April 2005, prompting an angry response from Chris Lowe.[114] That response was echoed by Frank Walsh who, on 26 April 2005, wrote to Chris Lowe stating *"I believe that I have returned Echelon to their box and screwed the lid on ...".*

11.205 Third, there was a co-incidence of interest between the Nimrod IPT and BAE Systems. They shared the same goal, namely it suited everyone to get the project signed off within the deadline: the Nimrod IPT because it was required to have a Safety Case within the timeframe prescribed in BP1201 and its own SMP; BAE Systems because it wanted to be finished on time and be paid for its work; and both, because they wanted to 'trumpet' the fact that they had successfully completed the first major military aviation platform case.

[113] It is worth noting that the Echelon report further stated in paragraph 8 of section B4: *"The initial hazard and accident classifications (e.g. accidents all Cat 'C's) is unhelpful, and occurs because the initial hazard probabilities reflect significant prior mitigation not recorded in the log. This was apparently carried out to reduce the amount of data in the log, and was approved by QinetiQ, but it does not allow visibility of their nature. It also means that the 'extra' controls being added – which are apparently the newly identified ones – do not visibly affect the risk rating, and this is reflected in having hazard post-control statuses the same as the initial, while often accident post-control statuses are undefined. The use of status histories to add extra controls is also unhelpful. Again, it is assumed that approach adopted for initial hazard and accident classifications reflects that used by BAES when populating the Fault Tree."*

[114] In an internal e-mail dated 21 April 2005, Chris Lowe stated to Richard Oldfield and his superiors *"Please see this* [expletive] *sent to NIM IPT Safety* desk by Echelon ... Frank is indeed fuming ...".

11.206 Fourth, as emphasised above, the efficacy of NSC project was fatally undermined by an assumption that the Nimrod was safe anyway; and, therefore, the actual content of the Safety Case did not matter as much as compliance with the rule which said one must be produced within a certain timescale.

(5) The Nimrod IPT failed to read the NSC reports carefully or otherwise check BAE Systems' work.

11.207 In my judgment, the Nimrod IPT failed to read the NSC reports carefully or otherwise check BAE Systems' work.

11.208 The Nimrod IPT's approach was no more pro-active or intelligent following eventual receipt of the six NSC reports from BAE Systems. In **Chapter 10B**, I expressed my doubts in relation to whether George Baber or Michael Eagles ever read any of the six reports at any stage, since they had been content to leave the matter entirely in Frank Walsh's hands. Whilst Frank Walsh must eventually have delved into the detail of the reports and realised the extent of the work that remained to be done, in my view this was not until some considerable time after the six finalised reports were delivered to the IPT on 21 September 2004.

Failure to read BLSC Reports carefully or at all

11.209 In my view, if at this stage, *i.e.* immediately upon delivery, someone at the Nimrod IPT had read or carefully checked the BLSC Reports they would and should have picked up on the fact that there was a large hole in BAE Systems' NSC work, namely 43 of the 105 hazards had been left *"Open"*, 32 *"Unclassified"*, many with only vague recommendations along the lines of *"Further analytical techniques are required…",* and immediately drawn this to the attention of George Baber and the PSWG, as well as raising it with BAE Systems.

11.210 Within the Nimrod IPT, primary responsibility for checking the NSC 'deliverables' lay with Frank Walsh (as Safety Manager and primary point of contact with the BAE Systems NSC team) and Michael Eagles (as Head of Air Vehicle with overall responsibility for the production of the NSC under the SMP). In my judgment, both must be criticised for their failure to do so: Michael Eagles because he was ultimately charged with the responsibility for doing so, and Frank Walsh because he had in fact allowed himself to be placed in a position whereby he was effectively running the project on his own, and was certainly capable of reading and understanding the BLSC Reports. There can be no excuse for not carefully reading reports which one had gone to the time, trouble and expense of obtaining from consultants.

Why?

11.211 How and why did the situation come about whereby the Nimrod IPT failed properly to review the NSC reports? In my view, whilst regrettable, the Nimrod IPT's failure properly to read the NSC reports is not altogether surprising when viewed in context. A number of factors were at play at the time. First, the IPT had to a large extent been lulled into a sense of false security by the comforting PowerPoint presentations given by BAE Systems at the Customer Acceptance Conference. Second, Frank Walsh had formally agreed with BAE Systems at the meeting that the PDS task '*could be considered closed*' and no doubt reported this back to Michael Eagles. In a very real sense, therefore, the Nimrod IPT had already been 'sold the pass' and switched off as far as the NSC task was concerned. Third, reliance was placed on QinetiQ as the IPT's independent advisor, who had been present at every stage of the project and participated at the Customer Acceptance Conference, and who was not only party to the 'consensus' that the aims of project had been achieved, but also praised BAE Systems' work. Fourth, the six reports certainly would have *looked* impressive: they ran to many hundreds of pages, had frontispieces with an impressive array of signatures, contained an impressive number of tables and flow charts, and being delivered together *en bloc* would had a considerable 'thud' factor. Fifth, the Nimrod IPT was stretched. It was tasked with providing clearances for Urgent Operational Requirements for Nimrod deployed on operations, dealing with its additional responsibilities for Depth maintenance, dealing with the continuing extension of the Nimrod MR2 out of service date due to delays in the MRA4 programme, as well as covering its wide portfolio including the Battle of Britain Memorial Flight and the 'Helix' project. Michael Eagles, in particular, was tied up most of the time negotiating the second Nimrod Integrated Support Contract (NISC 2) with BAE Systems and simply *"didn't have the time to be hands on"* in relation to the NSC. Sixth, the NSC is symptomatic of a widespread malaise of the 'tick box' mentality, whereby reports are outsourced to consultants and, on receipt, simply put in a drawer without being read or checked, and the relevant box ticked.

11.212 It must also be remembered that the Pro-Formas under-pinning the NSC were not readily available to the Nimrod IPT (or QinetiQ) at the time that the six NSC reports were delivered to them, as they were only accessible from the BAE Systems terminal at Chadderton. This, however, does not excuse the failure of George Baber, Michael Eagles and Frank Walsh to call for the production of any of the mitigating evidence behind the NSC Reports produced by BAES, or to ensure that such evidence was carefully checked by the relevant Nimrod IPT engineering specialists, Heads of Branch and QinetiQ as the Nimrod IPT's independent advisor in relation to the project. Had they done so, I have no doubt that they would have uncovered that the Pro-Formas prepared by BAE Systems included numerous errors of fact and analysis, including the Pro-Forma in relation to Hazard H73.

(6) The Nimrod IPT subsequently signed off BAE Systems' NSC task in circumstances where it was inappropriate to do so.

11.213 In my judgment, the Nimrod IPT subsequently signed off BAE Systems' NSC task in circumstances where it was inappropriate to do so. The formal sign-off followed the Sixth PSWG meeting on 10 November 2004, where the Nimrod IPT's earlier lack of activity was repeated.

Sixth PSWG meeting on 10 November 2004

11.214 On 10 November 2004, George Baber chaired the Sixth PSWG meeting at RAF Wyton. On behalf of BAE Systems, Chris Lowe and Richard Oldfield, gave a PowerPoint presentation regarding the BLSC in which he said all foreseeable hazards had been *"identified and assessed, and addressed... [and] eliminated or reduced to [ALARP].."* and that *"...where the existing level of mitigation against a hazard was determined as insufficient/ incomplete, the report conclusions contain recommendations"*. There was also a brief demonstration by Witness C [BAE Systems] of how the CASSANDRA Hazard Log worked.

11.215 Again, the BAE Systems' representatives did not go into any relevant details as to how much of the Phase 2 project had been completed and what remained to be done, and did not volunteer precisely how many hazards remained *"Open"* or *"Unclassified"*.

11.216 Again, the Nimrod IPT representatives present (including the IPTL, George Baber) were content to sit, passively, and accept at face value the PowerPoint presentations by BAE Systems. They did not raise any queries in relation to what was presented by BAE Systems or ask BAE Systems any of the intelligent questions which should have been asked. Instead, George Baber simply thanked BAE Systems for its work in producing the Safety Case Report and Hazard Log and Frank Walsh was tasked to produce a document and a suitable date for the IPTL formally to 'sign-off' the NSC, which he formally did on 15 December 2004.

11.217 In his written submissions to the Review, George Baber sought to suggest that this was not the sort of meeting where detailed questioning of BAE Systems on their work would have been 'feasible or appropriate' and it was never intended that the NSC task would be formally accepted at the Sixth PSWG meeting *"and indeed, it was not"*. This does not square, however, either with the minutes or with his letter of 15 December 2004 in which he expressly referred to the fact of 'acceptance' of the NSC Reports 'at' the Sixth PSWG. Moreover, it would not have required detailed questioning of BAE Systems to elicit that there was a large hole in its work.[115]

[115] George Baber's suggestion that, whilst 43 *"Open"* hazards out of 105 is a high proportion, it is not a large proportion when compared with an original total of *"2,000 open hazards in Phase 1"* betrays a misunderstanding of the Phase 2 rationalisation of hazards.

Why was no query raised at so few recommendations being actioned?

11.218 It is fair to say, however, that many at the meeting may have assumed that Frank Walsh had been through all the recommendations and determined which would be actioned. Why did Frank Walsh bring no more than a handful of 'unresolved' recommendations arising from the NSC to the Sixth PSWG meeting and why was no query raised?[116] BAE Systems' BLSC Reports had contained over 25 pages of outstanding recommendations which could not conceivably all have been 'resolved' in the three weeks since receipt of the Reports.[117] The answer lies in the fact that neither Frank Walsh nor BAE Systems had any real expectation that a large amount of work would be done, or was required to be done, before the NSC was approved for 'sign off' by the PSWG. This was, however, in my view, for different reasons (I discuss BAE Systems' position above). Frank Walsh's lack of expectation was the result largely of ignorance: he had not been led to believe at the Customer Acceptance Conference that there was a great deal of work still to be done; he had not carefully read the BLSC Report(s) themselves by this stage; he had confined his attention to the Certification, Hazardous Materials and Fire & Explosion Reports and the CASSANDRA Hazard Log; he did not appreciate the number of *"Open"*/*"Unclassified"* hazards or the volume of recommendations made by BAE Systems at this stage. He tended, in any event, to be sceptical of recommendations by BAE Systems that they carry out further work.

11.219 It is fair to say, as George Baber submitted, that *"the overall impression that BAE Systems were giving was that they had done a good job".* But, in my view, it was his and the Nimrod IPT's responsibility properly to satisfy themselves that BAE Systems had *in fact* done a good job and done what it was contracted to do.

11.220 In my judgment, George Baber (IPTL, PE and Chairman of the PSWG), Michael Eagles (Head of Air Vehicle) and Frank Walsh (Safety Manger), fundamentally failed in their duty to take adequate steps: (a) to ensure that the PSWG properly considered all Category 'A' and 'B' risks identified in the NSC in accordance with the Nimrod SMP; and (b) to ensure that the NSC work had been satisfactorily carried out and completed by BAE Systems.

No ISA audit

11.221 Contrary to JSP553 and Def-Stan 00-56, no independent audit had been carried out of BAE Systems' NSC reports by a properly appointed ISA. For this reason alone, the work should not have been signed off.

(7) The Nimrod IPT proceeded to sentence the remaining hazards on a manifestly inappropriate and inadequate basis.

11.222 In my judgment, the Nimrod IPT proceeded to sentence the remaining risks which had been left *"Open"* and *"Unclassified"* by BAE Systems on a manifestly inappropriate and inadequate basis.

Missed opportunity

11.223 Ironically, as stated above, BAE Systems' failure was the Nimrod IPT's opportunity. BAE Systems' failure to complete the task gave the Nimrod IPT an opportunity to rectify the position by identifying the risk posed by the Cross-Feed/SCP duct. As explained in **Chapter 10A**, Mech Systems had failed properly to analyse the risk posed by the Cross-Feed Pipe/SCP in Zone 614 (Hazard H73), and classified the overall zonal hazard probability as *"improbable"*. Hazard H73 would, therefore, have been 'closed' but for the Electrical Systems Appenda which stated *"Further analytical techniques are considered necessary in order to categorise the risk of the fire/explosion hazard identified in sections 3A, 3H and 3P above"*. Consequently, the effect of the Electrical Systems Appenda, and other similar 'holding' statements, consequent on the fact that BAE Systems had run out of time to finish the Task, was to leave Hazard H73 and numerous other hazards *"Open"* and *"Unclassified"*, thus passing a substantial proportion of the NSC task back to the Nimrod IPT. This meant that the Nimrod IPT had a fresh opportunity, theoretically at least, to capture the risks which BAE Systems had not spotted, including the risk inherent in Zone 614. Unfortunately, as a result of the total failure on the part of George Baber and Frank Walsh to exercise due care, skill and attention when sentencing the remaining risks, and a failure to follow the Nimrod SMP, the Nimrod IPT failed to grasp this opportunity.

[116] See Annexes A and B to the Minutes of the Sixth PSWG meeting on 10 November 2004.

[117] See Annex C to the BLSC Reports.

George Baber's lack of care and attention when sentencing risks

11.224 Responsibility for the sentencing of risks ultimately resided with George Baber. As IPTL, PE and an LOD holder, George Baber was personally responsible for sentencing all Category 'A' and 'B' risks to ALARP in accordance with BP1201. It was his duty to do so carefully. Consequently, he should have ensured that, before sentencing any such risks in relation to the NSC: (a) he had adequate advice and evidence before him to make a proper, informed decision; (b) he was satisfied that the relevant Specialist Desks and Heads of Branch in the Nimrod IPT had had appropriate input; (c) he had read and given close personal attention to the material before him; and (d) it was appropriate in all the circumstances to categorise the risk as *"Managed"*.

11.225 I have concluded, however, that George Baber did none of these things. Instead, he effectively allowed Frank Walsh to decide whether Category 'A' and 'B' risks should be sentenced even though Frank Walsh had no responsibility, authority or capability to do so. The picture is clear from Frank Walsh's email to George Baber dated 20 January 2005, in which Frank Walsh asserted that *"All the hazards in Cassandra"* except one (Hazard H2) had controls and references in place *"to show that they were ALARP"* and he that believed they should be set to 'Managed'. The e-mail concluded: *"If you agree I will instruct BAES to amend Cassandra."* There is then no further paper trail of the sentencing of risks until Frank Walsh's letter to BAE Systems of 1 February 2005, in which he authorised BAE Systems to set the post control status of the hazards in Cassandra in accordance with the attached Annex A (see **Chapter 10B**). The evidence of the Nimrod IPT desk officers (which the Review accepts as truthful and accurate) was that they were never consulted in relation to the sentencing of hazards in the NSC in general, or the drawing up of Annex A in particular.

11.226 I have, therefore, concluded that George Baber approved Frank Walsh's request in his letter of 20 January 2005 notwithstanding: (a) the absence of any detail or supporting material with the e-mail to have enabled him to make a proper, informed decision; and (b) the absence of any input from the Nimrod IPT Specialist Desks or Heads of Branch or Michael Eagles. Consequently, on 1 February 2005, Frank Walsh wrote to BAE Systems authorising them to set the post control status of the hazards in CASSANDRA in accordance with Annex A.

Frank Walsh's belated appreciation of the 'hole'

11.227 As set out in **Chapter 10B**, I have also concluded that it was only by the time Frank Walsh came to prepare Annex A that he finally looked carefully at Annex B to the BLSC Report and realised that there were, in fact, no less than 32 hazards which had been left *"Unclassified"* and *"Open"* by BAE Systems and therefore needed sentencing. Upon making this discovery, however, he did not do the proper thing, as in my view he ought to have done, namely alert his superiors to this matter which he had overlooked and obtain the assistance of the desk officers in carefully sentencing the outstanding risks. Instead, I have been driven to the conclusion that he acted as if nothing was wrong and quietly sought to find a basis himself upon which the remaining risks could be sentenced and obtain the blessing of a busy IPTL. This was highly regrettable.

Frank Walsh's 'idiotic error'

11.228 Unfortunately, Frank Walsh's basis for sentencing the remaining 40% of the risks, including H73, was woefully inadequate and erroneous. The errors contained in his Annex A were multiple, serious and in my view, obvious even to the moderately informed reader. As suggested by Michael Bell[118] in his cross-examination at the Inquest, it was an *"absolutely idiotic error"* to suggest that so many zones in the wings would have fire detection and suppression systems. Why did Frank Walsh draft the letter in this way and attach Annex A? The most likely explanation is that he did not know what he was doing. He was simply out of his depth. He had never done this sort of exercise before, having never come across a Safety Case or Hazard Log of this type before. He had had little or no training or guidance as to how to go about it or the level of rigour that was required. He simply wanted to get the matter sorted quietly and without fuss.

[118] Brother of XV230 crew member, Gerard M. Bell, Deceased.

Why did George Baber sign?

11.229 On 22 February 2005, George Baber signed the letter prepared by Frank Walsh which formally requested BAE Systems to set the status of the CASSANDRA hazards in accordance with Annex A to Frank Walsh's letter of 1 February 2005 as *"Managed"*. Why did George Baber sign the letter with such a manifestly erroneous Annex? The answer is almost certainly because he did not read or properly consider Annex A before signing the letter, which was put in front of him by a junior officer whom he assumed did know what he was doing and he did not check that it was correct. George Baber's evidence in interview on this issue was that, whilst he was unable specifically to recall whether he had seen Annex A at the time of Frank Walsh's letter of 1 February 2005 (but did not think that he had), he was adamant that he would not have signed the letter of 22 February 2005 without reviewing Annex A and stated that he clearly remembered a meeting with Frank Walsh at which he sat down and went through the letter. He explained that *"I would not just sign off a bit of paper without sitting down with somebody. It is just not the way I operate".* He went on to state that he trusted Frank Walsh, *"took what he said at face value"* and that he had never *"been so hoodwinked in* [his] *life"*.

11.230 In my view, however, given how busy George Baber was at the time, it was most likely that he had just signed the letter without checking the contents of Annex A at all. If he had given proper consideration to what he was signing, he would, and should, have realised two things. First, the inappropriateness of the letter stating that the *"Catastrophic"/"Remote"* risks should be classed as *"Managed".* 23 of the hazards had been given a Post Control Status of *"Remote"* and, therefore, were to be classified as category 'B' or *"Undesirable"* risks in the HRI, *i.e.* they required management action to introduce control measures and *"shall only be acceptable once reduced to ALARP***"**. There was, however, no evidence of any approved management 'actions' being in progress to allow these 23 hazards to be referred to as *"managed"*. They could not be left with a 'managed' status of *"Remote"* although this is what the letter itself indicated. Second, the manifest oddity on the face of Annex A, in particular having 21 out of 33 absolutely identical *"Interacting Systems"* entries, all of which had *"Aircraft fire detection and suppression"* systems in their zones, which would entail an impossible number of fire bottles. If he had paused for thought for a moment he would, and should, have appreciated something was not quite right. It is regrettable that he did not.

11.231 I reject George Baber's suggestion that there was nothing *"implausible"* about what he was being asked to sign. I also reject his suggestion that he was entitled to take the information *"on trust"* from Frank Walsh and to take what he was told *"at face value"*. This was not good enough. It was his personal, non-delegable, duty as IPTL, PE and LOD holder to satisfy himself as to the correctness of what he was signing and to ensure that these risks were properly sentenced. This was particularly the case given that Frank Walsh lacked any real experience of the Nimrod aircraft and was not even an airworthiness LOD holder.

Frank Walsh's further (quiet) mistake

11.232 On 16 March 2005, Frank Walsh e-mailed BAE Systems with a revised Annex A. This comprised a *"Further Review"* of the 23 hazards listed in Annex A classified as *"Remote",* together with the 17 hazards in Annex B of the BLSC Report classified as *"Remote"* but *"Closed"*, all of which he purported to sentence as *"Improbable"* primarily on the basis that *"A review of past incidences indicates no major occurrences of these hazards."* I have concluded that, by this stage, Frank Walsh had realised that these 40 hazards could not simply be left as *"Remote"* but had to be 'managed' down to *"Improbable"* in order to justify the assertion of ALARP. I find that he did this entirely on his own and without the knowledge of either Michael Eagles or George Baber. Again, in my judgment, Frank Walsh should have alerted his superiors to this matter which he had overlooked. The fact that he did not see fit to do so is, again, regrettable and unfortunate.

Why did Frank Walsh act in this manner?

11.233 Why did Frank Walsh act as he did? The answer in my view lies in four factors. First, his inexperience and lack of understanding as to the importance of what he was dealing with and being asked to do. Second, a reluctance to 'own up' to having overlooked matters and not wanting to be found out. Third, a belief (as he effectively admitted to the Review) that because BAE Systems had already gone through the hazards and done the work, none of the hazards was really a problem and, in so far as 'further work' was said to be required, this was essentially BAE Systems looking for excuses to do further unnecessary work. Fourth, the general malaise that the Nimrod fleet was 'safe anyway' and, therefore, the NSC was merely a 'tick-box' paperwork exercise.

(8) The Nimrod IPT failed to follow its own Safety Management Plan.

11.234 In my judgement, the Nimrod IPT failed to follow its own Safety Management System (SMS). The IPT's safety system was rightly described by Frank Walsh himself in evidence to the Review as having *"broke"*.

SMP three-stage process

11.235 George Baber, Michael Eagles and Frank Walsh all ignored, or short-circuited, the Nimrod Safety Management Plan (SMP) processes. The Nimrod IPT should have followed the three-stage *"Hazard Management Process"* laid down in Annex A-1 of the SMP[119] to sentence all hazards identified and raised by BAES but left 'open'.[120] This was initially averred by George Baber in his written evidence,[121] and accepted by Michael Eagles and Frank Walsh and other witnesses. But when it was pointed out that the procedure had not been followed, George Baber, Michael Eagles and Frank Walsh sought to suggest that the SMP procedure did not in fact apply to the initial population of CASSANDRA. There was, however, no other procedure could be said to apply or be relevant. In these circumstances, I am satisfied that the Annex A-1 process should have been followed. Michael Eagles accepted that Annex A-1 of the SMP was 'the only show in town' so far as relevant procedures for handling the NSC were concerned.

By-passed

11.236 Regrettably, the Nimrod IPT essentially by-passed or ignored the *"Hazard Management Process"* in the SMP. The SMP required an initial 'proposed' risk categorisation to be carried out by the appropriate LOD: however, the 'proposed' risk categorisation was not carried out by the appropriate LOD holder (Michael Eagles) but was carried out by Frank Walsh, who was not an LOD holder. The SMP required advice to be taken from the relevant Engineering Heads of Branch (HOB): however, in relation to the vast majority of hazards (including Hazard H73), no advice whatsoever was taken (by Frank Walsh) from relevant Engineer HOB. The SMP required all 'A' and 'B' and borderline 'C' risk categorisations to be reviewed by the meetings of the Aircraft Safety Reviews (ASR) and PSWG: however, at no stage were the vast majority of the hazards left open by BAE Systems (including Hazard H73) even considered by the ASR or the PSWG, let alone reviewed. The key role of the PSWG was recognised early on. At the Inaugural PSWG meeting on 18 March 2002, Witness C [BAE Systems] said that if the IPT did not want to task BAE Systems to sentence a risk *"the hazard will go to the PSWG" and IPTL ultimately has the say whether he accepts the risk. The function of the PSWG was "to examine and sentence hazards across both marks at platform level."*

11.237 These were by no means the only respects in which the SMP was ignored. In particular, as explained above, despite having *"ownership"* of the NSC, Michael Eagles played little or no role in its development, either directly or indirectly, and had little direct contact with BAE Systems. Instead, he left the task almost entirely to Frank Walsh, exercising minimal supervision of his actions. Frank Walsh, for his part, failed to voice any objection to this and further failed to document the hazard identification process as required by the SMP.[122]

11.238 I am confident that, if it had followed the SMP, the Nimrod IPT would have picked up the fundamental mistake in Frank Walsh's Annex A relating to the presence of a fire detection and suppression system in so many zones of the aircraft, including Zone 614. It may also have been that the discovery of this egregious mistake would have led to greater challenge to the project as a whole, and a fundamental re-examination by the Nimrod IPT of the work that BAE Systems had done. I am bound to say, however, that I am not sanguine that this would, ultimately, have led to a different outcome because of the general lassitude and lack of real interest in the content of NSC by those involved.

[119] Set out in **Chapter 9** at paragraph 9.77.

[120] Ibid, paragraph 15, page C-5, provided that hazard identification could come from any source, *e.g.* individual IPT members, industry or users.

[121] Although George Baber somewhat equivocated in his oral evidence when it was pointed out that the process had not been followed.

[122] Ibid, paragraph 14.

(9) The Nimrod IPT failed properly to appoint an Independent Safety Auditor to audit the NSC.

11.239 In my judgment, the Nimrod IPT failed properly to appoint an *"Independent Safety Auditor"* (ISA) to audit the NSC, as required by Def-Stan 00-56 and JSP 553. The outcome might have been different if the IPT had ensured that an ISA had been properly appointed and tasked to carry out a full audit of the NSC (or if QinetiQ, who at all material times acted as 'independent advisor' in relation to the NSC, had fulfilled this role - see further below).

ISA mandated

11.240 The requirement to appoint an ISA in relation to the preparation of the NSC was mandated both by the relevant military regulations and the SMP.[123] The IPTL was specifically required to ensure that the NSC was independently assessed; both an audit to ensure compliance with the SMP and a technical evaluation of the NSC Report. The audit and technical evaluation of a safety case of a major platform would be a significant piece of work and would involve potentially months of work checking the detail with aircraft engineers. The assessment was to be carried out by an *"Independent Safety Auditor"* (ISA),[124] or an alternative independent competent organisation.[125] Further, an *"Independent Safety Auditor"* (ISA) was to be formally tasked in all cases where a Preliminary Hazard Analysis identified class A or B risks (and class B risks were deemed 'tolerable') and Def-Stan 00-56 specified that terms of reference for the ISA and an audit plan should be drawn up.[126]

QinetiQ's appointment as ISA expected

11.241 In apparent accordance with these requirements, it was suggested at an early stage[127] that QinetiQ might be appointed as *"Independent Safety Auditor"* and play a *"key role"* with regard to the Nimrod safety management, a central feature of which was the NSC. At subsequent QinetiQ Task Review Meetings, it was minuted that, although QinetiQ's role in relation to the NSC was *"still to be defined"*, their involvement was *"not in doubt"* and when the NSC was completed QinetiQ *"would have the opportunity to review the work done by BAES"*.[128]

11.242 At the Third PSWG meeting on 8 May 2003, it was agreed that QinetiQ would be appointed *"Independent Safety Assessor"* in relation to Phase 1 of the NSC; and it was further decided that a meeting would be arranged between BAE Systems, QinetiQ and Frank Walsh to discuss the approach to Phase 2. As Nimrod IPTL, George Baber subsequently reported to the thirteenth meeting of the Fixed Wing Airworthiness Management Group on 13 June 2003:[129]

> *"The Cassandra Hazard Log has been populated by BAE Systems under Phase 1 work, Phase 2 of the task, scheduled for completion 31 Jan 04 will be to mitigate the hazards. <u>QinetiQ has been appointed as the Independent Safety Assessor</u>".* (emphasis added)

QinetiQ never formally tasked as ISA

11.243 This was, however, incorrect. QinetiQ's appointment as ISA in relation to the NSC was never, in fact, formalised, *i.e.* proper terms of reference drawn up and agreed and an audit plan prepared in accordance with Def-Stan 00-56. Rather, as set out in **Chapter 10A,** QinetiQ was merely informally tasked by the Nimrod IPT to act in a more limited role as 'independent advisor' to the Nimrod IPT regarding the development of the NSC.

11.244 The reason why not is due to a curious mixture of oversight, assumption and reluctance: oversight regarding carrying out the formalities; the assumption that QinetiQ was already tasked and acting as ISA; and reluctance

[123] JSP318B (Edition 4) (replaced by JSP553 in 2003), Def-Stan 00-56 and Nimrod SMP paragraph 14, p. A-5.

[124] In accordance with Def-Stan 00-56.

[125] See JSP553, Chapter 2, paragraph 2.58: *"…the IPTL is to ensure the contractor's safety case is independently assessed"*.

[126] See Def-Stan 00-56, paragraph 5.3.4.

[127] Minutes of the QinetiQ Task Review Meetings on 9 October 2001 and 5 February 2002.

[128] Minutes of the QinetiQ Task Review Meetings on 11 June 2002 and 4 March 2003.

[129] Nimrod Airworthiness Report of June 2003.

by the Nimrod IPT to allow QinetiQ to become too involved. As regards the latter point, there are indications of a disturbing, suspicious attitude towards QinetiQ displayed by George Baber at the Fourth PSWG Meeting on Friday 21 November 2003 at RAF Wyton, QinetiQ when he accused QinetiQ of just *"touting for business"* and also by Frank Walsh, who rejected QinetiQ's re-write of the Nimrod IPT's Local Business Instructions (LBI) for the Safety Cases for modifications to the Nimrod fleet as *"gold-plated"* and *"out of proportion"*.

11.245 If QinetiQ had been formally tasked to carry out a full audit of the NSC, the outcome might have been different.

(10) The Nimrod IPT failed properly to manage the NSC post its production and failed in any meaningful sense to treat it as a "living" document.

11.246 In my judgment, the Nimrod IPT failed properly to manage the NSC post its production and failed in any meaningful sense to treat it as a "living" document. Whilst highly regrettable, against the background of 'assumed' safety and the paperwork nature of the exercise (see above), it is perhaps not altogether surprising that there was a less than thorough or pro-active management of the risks identified by the NSC following its completion.

XV227 duct failure - 'wake up call'

11.247 In my view, the above criticism is borne out by the manner in which the Nimrod IPT dealt with the two duct failures on XV227 and XV229 *vis-à-vis* the NSC. As explained in **Chapter 7**, on 22 November 2004, Nimrod MR2 XV227 suffered a major hot air duct failure in a section of the Cross-Feed/SCP duct just aft of the 'elbow' at the bottom of No. 7 Tank Dry Bay due to corrosion.[130] The hot air leak of gases up to 420°C caused serious damage *inter alia* to control cables and pulleys, hydraulic pipeline fairleads, numerous fuel seals, and structural members in the vicinity in No. 7 Tank Dry Bay. It was, in fact, exactly the sort of serious zonal incident envisaged by Hazard H73: *"in an area closely packed with flight control cables and pulleys, hydraulic services, unprotected electrical cables and hot air ducting there exists potential for hot air ... leaks and possible fire".*[131] As the BOI observed, *"... the incident illustrates the extensive effects of heat damage concomitant on the spread of hot gases within this area."*[132] XV227 was fortunate not to have been lost entirely**.**

11.248 In these circumstances, there is no doubt in my mind that the XV227 incident should have been a *"wake up call"* (as one Nimrod line maintenance engineer called it) to those responsible for maintaining the NSC. Unfortunately, it was not.

11.249 The XV227 investigation and the compiling of the NSC were not completely concurrent exercises. As explained in **Chapter 10B**, the NSC was effectively 'signed-off' by the end of 2004, although a significant number of hazards remained to be 'managed' by the Nimrod IPT in early 2005, and the NSC itself was supposed to be a 'living' database. On 26 November 2004, the Nimrod IPT issued an Urgent Technical Instruction[133] that the SCP should be electrically isolated for "Nil use" across the fleet pending further advice from the IPT. Subsequently, between December 2005 and April 2006, BAE Systems was tasked to conduct a detailed investigation of the incident. Unfortunately, it would appear that neither the Nimrod IPT (nor BAE Systems), thought to revisit and fundamentally reconsider the risk categorisation of Hazard H73 in the light of this near-catastrophic incident, notwithstanding that the Fault Investigation report (MOD Form 761) into the incident noted ('for reference only') that *"a bleed air duct failure of this nature, in this aircraft zone, is recognised in the Nimrod Baseline Safety Case hazard ref. NM/H73".* Whilst Frank Walsh sent a copy of the *"Initial Report of Serious Occurrence or Fault"* (Annex A to BP 1301) in respect of the XV227 incident to Witness C [BAE Systems] on 14 December 2004, together with photographs of the damage, he requested merely that these be 'added' to CASSANDRA against Hazard H73.

[130] At point in the duct between the Pressure Regulating and Shut off Valve (PRSOV) and the Flow Limiting Venturi.

[131] See section 1 of Mech Systems Pro-Forma for Hazard H73.

[132] BOI Report, Exhibit E [E-2].

[133] UTI/NIM/026, dated 26 November 2004.

11.250 In my view, this statement itself is indicative of an approach which treated the NSC as a receptacle for data as opposed to a means of critical analysis. Rather than merely noting that the hazard was recognised in the NSC and 'adding' details of XV227 to CASSANDRA, those responsible for maintaining the NSC should have asked themselves 'What is the impact of this particular occurrence on the safety of the aircraft? Does it illustrate any other potential hazards? Does it in any way alter our previous assessment of the risks in this zone? However, the Review saw no evidence to suggest that anyone at the Nimrod IPT or BAE Systems ever considered the relevance of the XV227 incident to Hazard H73. On the contrary, the Hazard Log on CASSANDRA shows that the hazard probability for Hazard H73 (the No. 7 Tank Dry Bay) was reduced from *'Remote'* to *'Improbable'* by the Nimrod IPT on 17 Mar 2005, after the XV227 incident. The reason was that: *"a further review of past incidences (sic) indicates no major occurrences of these hazards."* However, if XV227 was not a major occurrence, then it is very unclear what would count as such. At any rate, the outcome was that yet another opportunity to capture BAE Systems' errors in its analysis of Hazard H73 was, tragically, lost.

11.251 It is highly unfortunate that more thought was not given to the implications of the XV227 incident and the earlier 1980s duct failure history at this stage.[134] It is even more unfortunate that this remained the case even after the second duct failure on XV229 in August 2005. As I explain in **Chapter 8**, following the duct failure on XV229, BAE Systems pointed out that the potential for this type of failure in the engine bay was recognised by way of Hazard H66 in the NSC, which had been ascribed a probability of *"Incredible"* by the Nimrod IPT by way of its letter to BAE Systems of 16 March 2005. Given that there had now been two duct failures on the Nimrod fleet, BAE Systems recommended that the probability of Hazard H66 should be reviewed by the Nimrod IPT and *"should be reassessed to IMPROBABLE or more likely REMOTE"*.

11.252 However, in his letter to BAE Systems of 3 March 2006 (see **Chapter 8**) regarding Hazard H66, George Baber instructed BAE Systems that *"the effect of the failure is to remain at Catastrophic but the probability is to be raised to Improbable (Remote likelihood of occurrence to just one or two aircraft during the operational life of a particular fleet. You are requested to amend hazard NM/H66 accordingly and set it to Managed."*

11.253 In my judgment, it was inappropriate for the Nimrod IPT to re-categorise the hazard risk for Hazard H66 in this manner. In circumstances where there had been two potentially serious incidents of duct failures, attributable to corrosion and fatigue, occurring within the space of only nine months, common sense would suggest that the likelihood of a similar event occurring in the future was higher than merely *"Improbable"* (as defined).

11.254 Moreover, no similar (or indeed any) reassessment of any other zones in the aircraft containing similar hot air ducts appears to have been made as a result of the second duct failure on XV229. In particular, the area most vulnerable to a similar duct failure was Hazard H73 itself (where the first failure on XV227 occurred). Common sense would again suggest that Hazard H73's probability should also have been increased following the incidents on XV227 and XV229, along with any other zone with a hot air duct. There was a lack of thought, once again.

(11) The Nimrod IPT failed to ensure that airworthiness and the safety of the Nimrod fleet was the first priority.

11.255 In my judgment, the Nimrod IPT failed to ensure that airworthiness and the safety of the Nimrod fleet was the first priority during the period 2002 to 2005.

11.256 The management of the preparation of the NSC was not given the attention and priority that it deserved. It was a major safety tool for ensuring the current safety and airworthiness of the Nimrod fleet but the project management of it was left in the hands of a relatively junior officer. This was symptomatic of a more general attitude that safety cases were not a priority. QinetiQ's representative, Witness L [QinetiQ], drew the Nimrod IPT's attention to the fact that the safety case for the mission systems (EWAD) of the Nimrod R1 was being drawn up in-house by a RAF line engineer who himself felt unqualified and uncomfortable being asked to carry out this task. Witness L [QinetiQ], acting as ISA, wrote *"Highly unsatisfactory (safety)"* on this report and raised his concerns at a Task Review meeting on 15 July 2003. It appears, however, from minutes of the Task Review meeting of 18 November 2003 (after Witness L [QinetiQ] had left) that the issue was subsequently deemed 'closed' following 'contact' by Frank Walsh with EWAD.

134 See **Chapter 7**.

11.257 In my view, the Nimrod IPT allowed operational pressures and workloads associated with implementing the Logistics Transformation process to detract or distract from safety tasks and, in particular: (a) the proper management of the production of the NSC; (b) proper adherence to relevant procedures under the Nimrod SMP; (c) ensuring that hazards were identified, assessed and classified carefully,; and (d) giving appropriate priority and personal attention to the NSC and hazard management as important features of safety and airworthiness of the Nimrod fleet. For these reasons, the airworthiness and the safety of the Nimrod fleet slipped down the agenda during the period 2002-2005.

Criticisms of individuals at Nimrod IPT

11.258 The key personnel at the Nimrod IPT during the period 2002 to 2005 who had duties in relation to the NSC were the Nimrod IPTL and PE, George Baber, the Head of Air Vehicle, Michael Eagles and the Safety Manager, Frank Walsh. These three individuals share responsibility for the failures of the Nimrod IPT in relation to the NSC.

Group Captain (now Air Commodore) George Baber

11.259 George Baber bears the lion's share of the blame for the failures of the Nimrod IPT regarding the NSC. He was the IPTL, PE and the senior LOD holder. His was a fundamental failure of leadership. He failed to ensure that the Nimrod IPT project managed the NSC properly. He failed to exercise proper supervision and management of Michael Eagles and Frank Walsh in relation to the NSC. He allowed Frank Walsh to be put in a position which he was unqualified and lacked the experience to fulfil. His was also a personal failure to take reasonable care when he was called upon to sign off the NSC project and sentence risks. He allowed himself to be distracted by other matters. He failed to check carefully and query what he was signing. He failed to follow processes which he himself had put in place. (The latter is surprising for someone who prided himself on creating elaborate processes and, indeed, became something of a High Priest of 'process'. This was, however, symptomatic of a wider malaise within the MOD, whereby having lots of process has become more important than actually following it.) He regarded the Nimrod IPT as 'trail-blazing' in producing the first, or one of the first, Safety Cases on legacy platforms. He appears, however, to have been more interested in trumpeting this fact than devoting appropriate time, trouble and resources to ensuring its contents were absolutely correct.

11.260 George Baber's culpability must be judged in context. First, the job of Nimrod IPTL in 2002-2006 was difficult and became, in many ways, over-complex and over-stretching. His portfolio was multi-faceted and required him to point in an increasing number of directions at the same time. He had to cope with what several witnesses described as an *"awesome"* workload. There were increasing and *"extremely challenging"* operational demands supporting aircraft in two medium-sized conflicts, Afghanistan and Iraq; this involved numerous unscheduled upgrades and Urgent Operational Requirements, which put immediate and substantial additional pressures on him and the Nimrod IPT. He was initially responsible for 200 people at RAF Waddington, 120-130 at RAF Wyton and a small team at RAF Kinloss. In 2005 (as part of the Defence Logistics Transformation Programme), he was required to take on Depth maintenance at RAF Kinloss. Depth Maintenance was acutually contracted to a BAE Systems subsidary company. The IPT's responsibility extended to monitoring the contract. He was responsible for large budgets: overseeing an annual budget of £200 million and a major acquisition programme costing £500 million. He travelled a great deal: spending a week a month at RAF Kinloss and two days a month at RAF Waddington, as well as making frequent visits to the USA. This all limited his time at RAF Wyton. He had the benefit of, but equally was responsible for, eight immediate subordinates at Wing Commander rank and for running the IPT machine. He was not only in overall charge as IPTL, but also had elected to be his own Project Engineer (PE) and, therefore, was ultimately responsible for sentencing all Class A and B risks. This was probably a step too far.

11.261 Second, this was against a backdrop of the Nimrod IPT being ordered to reduce its output costs by 20% in accordance with the 'Strategic Goal' (**Chapter 13**). There was undoubted pressure on budgets. As one senior IPT officer put it: *"Costs were King. All IPTLs were held to account very, very closely and to keep within resource totals. It was a heinous crime to go above"***.** A department which complained about the extra workload imposed by the NSC was told the IPT had *"no alternative but to bear the load with no associated resources."* The MOD agenda in 2000-2005 was dominated by 'transformation' and the need to deliver 'cuts and change'. This added to the burdens of IPTs. It also led to a weakening of the safety assurance and ensurance structure. Business became the prevailing culture rather than safety. I deal with this in detail in **Chapter 13**.

11.262 Third, there was a general dilution of oversight and guidance from above (see further **Chapter 13**). He said in interview that the eventual removal of the 2-Star oversight in relation his LOD made him feel *"abandoned".*

11.263 Despite all this, in my judgment, George Baber's performance nevertheless fell well below the standard that might reasonably have been expected of someone in his position at the time. As Nimrod IPTL, Nimrod PE and an LOD holder during the period 2002-2006, George Baber failed to give adequate priority, care and personal attention to the preparation of the NSC. He failed properly to utilise the resources available to him within the Nimrod IPT to ensure the airworthiness of the Nimrod fleet. He failed to give the NSC the priority it deserved. In doing so, he failed, in truth, to make safety his first priority.

Wing Commander Michael Eagles

11.264 Michael Eagles, as Head of Air Vehicle, bears a significant share of the blame for the failures of the Nimrod IPT in relation to the NSC. His was a complete failure to do his job in relation to the NSC. As Nimrod Head of Air Vehicle, Michael Eagles had a pivotal safety role in the Nimrod IPT. His responsibilities included 'ownership' of the production of the NSC. His was, however, an abrogation of responsibility. He failed to perform his role to manage the production of the NSC and failed to exercise proper supervision and management of the Safety Manager, Frank Walsh. He delegated the project wholesale to Frank Walsh, whilst he concentrated on other things. Frank Walsh was, however, too inexperienced and insufficiently competent to manage such a project, at least without very detailed supervision. Michael Eagles exercised little oversight or supervision in relation to Frank Walsh. Michael Eagles also failed to follow processes clearly laid down in the Nimrod SMP.

11.265 Michael Eagles' culpability must be judged in context. First, he was newly promoted to the rank of Wing Commander**.** This was a significant step up. He may have found the job demanding and even been out of his depth in some respects. Prior to joining the Nimrod IPT in August 2003, he had never worked on Nimrods. He had never even worked in an IPT. He had no experience of safety cases, hazard management or risk assessment. He received no specific training in these topics. Second, he had a very heavy workload which included: (1) line management responsibilities for individuals at Chadderton, RAF Kinloss and RAF Wyton; (2) BLSC and SMP for the Battle of Britain Memorial Flight; (3) preparation of a Life Extension paper on the Nimrod; (4) negotiating NISC 3 which was intended to produce savings on support contracts; (5) costs comparisons between the MR2 and MR4; (6) managing the switch to an 'equalised' maintenance policy, which was intended to produce savings of £8,000,000; (7) responsibility for aspects of maintenance at RAF Kinloss following the acquisition of responsibility for Depth by the Nimrod IPT; (8) dealing with maintenance backlogs due to the extension of the MR2 out of service date; and (9) dealing with changes to the operational use of the Nimrod following the addition of equipment for use in Afghanistan and Iraq. In addition, his workload was exacerbated by manpower and resources issues within the IPT, in particular posts being left 'gapped'. Third, there is little evidence of any oversight being exercised in relation to him, in turn, by George Baber who, on the contrary, appeared to assent to the arrangement.

11.266 Despite this, in my judgment, Michael Eagles' performance nevertheless fell well below the standard that might reasonably have been expected of someone in his position at the time. As Head of Air Vehicle and a LOD holder during the period 2003-2005, Mike Eagles had responsibility for managing the preparation of the NSC. He simply did not do so at all. Michael Eagles failed to give adequate priority, care and personal attention to the NSC task. He failed properly to utilise the resources available to him within the Nimrod IPT to ensure the airworthiness of the Nimrod fleet. He failed to give the NSC the priority it deserved. In doing so, like George Baber, he too failed to make safety his top priority.

Frank Walsh (Safety Manager)

11.267 Frank Walsh, the Safety Manager, bears a significant share of the blame for the failures of the Nimrod IPT in relation to the NSC.

11.268 It must be emphasised, however, that Frank Walsh was put in a position that he should never have been placed in. First, he was effectively left to manage the NSC project on his own with little or no supervision or guidance. Second, he was required, or left, to give advice to the IPTL on sentencing risks on his own with little or no guidance. This was singularly inappropriate and unfair. He was of a relatively junior rank. He was not an LOD holder. He did not begin to have the qualifications, knowledge, experience or skills to perform such roles. His training in safety management was minimal. Nor did he even have the authority to sentence risks. He had no prior knowledge of the Nimrod. It is not surprising that, most of the time, he was clearly out of his depth and did not really know what he was doing.

11.269 Despite this, in my judgment Frank Walsh's performance and conduct fell below the standard that might reasonably be expected of him in his position at the time. As Safety Manager at the Nimrod IPT during the period 2003-2005, Frank Walsh: (1) exceeded his responsibilities, authority and capability with regard to the NSC project and the sentencing of risks; (2) failed to recognise the limitations of his responsibilities, authority and capability with regard to the NSC project and the sentencing of risks and seek appropriate guidance from his superiors; (3) failed properly to manage the NSC project and check and monitor its outcomes with reasonable skill, care and attention, and in particular to read the NSC Reports carefully when received; (4) took it upon himself to assess hazards and did so in a slapdash manner, failing to consult relevant desk officers in the Nimrod IPT regarding technical matters in accordance with the SMP; and (5) failed to alert his superiors when he realised that he had overlooked important matters, in particular (a) in December 2004, when he realised the number of hazards left *"Open"* and *"Unclassified"* by BAES and (b) in February 2005, when he realised the need to sentence *"Remote"* risks down to *"Improbable"* .

11.270 Frank Walsh's failure to put his hand up and admit to his superiors that he had overlooked matters, and then effectively to cover over his mistakes, is his most serious failing. In doing so, he failed to act honourably. In matters of safety, there can be no compromise on openness and honesty. It is, therefore, my opinion that he failed to act safely.

CRITICISMS OF QINETIQ in relation to Nimrod Safety Case

Introduction

11.271 In my judgment, QinetiQ also bears a share of the responsibility for the poor outcome of the NSC and its failure to capture the catastrophic fire risk presented by the Cross-Feed/SCP duct. If QinetiQ had performed its duties as 'independent advisor' to the Nimrod IPT in relation to the NSC with appropriate vigour and assiduity, it is quite possible that the outcome would have been different and the NSC would have identified, assessed and addressed this fire risk and the loss of XV230 would have been avoided.

11.272 As explained in **Chapter 10A**, QinetiQ was never formally appointed or tasked to act as a full ISA in relation to the NSC in accordance with Def-Stan 00-56, but at all material times acted as 'independent advisor' to the Nimrod IPT regarding the NSC. The criticisms of QinetiQ arise in respect of this latter, ostensibly more limited, role.

QinetiQ's experience in Safety Cases

11.273 QinetiQ had some previous experience of considering and assessing Safety Cases. In September 2001, it produced a paper on the development of Safety Cases. In January 2002, it carried out an assessment of the Global Express Safety Case. In January 2003, it carried out an interim assessment on the Nimrod MRA4 PA1 Safety Case. In December 2003, it carried out an audit of the Hercules C-130K Safety Case. In early 2004, it issued guidelines for Safety Cases relating to modifications. Later on, in 2004 and 2005, it carried out Safety Case Assessment Reports for each of the Nimrod MRA4 development aircraft (PA1, PA2 and PA3).

QinetiQ's real role

11.274 In its written evidence to the Review, QinetiQ sought to contend that its role in relation to the NSC was limited *"to occasionally being called upon to provide advice in relation* [sic] *the process and methodology to be used, and used, for the purposes of the completion of the BLSC and Hazard Log"*. It is my view, however, that this does not reflect the full picture. Although never formally appointed as ISA, it is clear that QinetiQ was nevertheless tasked and retained by the Nimrod IPT to act as its 'independent advisor' throughout the development of the NSC, and QinetiQ accepted that role (see the Tasking Forms 2002-2006 for QinetiQ Task No. 10, pursuant to which QinetiQ was tasked to *"provide advice and assistance to the Nimrod IPT on matters concerning Safety Management Systems"*). During the period 2002 to 2006, QinetiQ was regarded as, and did in fact assume the role of, independent advisor in this regard and gave regular advice to the Nimrod IPT in relation to the development of the NSC. QinetiQ representatives attended all the relevant meetings at which the NSC was discussed during the period 2002-2005 (namely all the PSWG meetings, all the QinetiQ Task Review meetings, the Scoping meeting on 19 May 2003, the Progress Review meeting on 17 June 2004, and the Customer Acceptance Conference on 31 August – 1 September 2004). Moreover, and as indicated by the detailed account of those meetings in **Chapter 10A,** on most occasions (with the notable exceptions of the Customer Acceptance Conference and Sixth PSWG), QinetiQ actively participated in those meetings, engaging in substantive discussions as to the methodology and content of the NSC, and advising the Nimrod IPT in respect thereof (see especially the meetings of 19 May 2003 and 17 June 2004, discussed in **Chapter 10A**). During the period 2002 to 2006, QinetiQ charged £30,528.00 for its services as 'independent advisor' to the Nimrod IPT in relation to its Safety Management Systems including the NSC.

11.275 In the circumstances, I am in no doubt that QinetiQ's role was not merely *ad hoc* but QinetiQ was properly regarded as, and assumed the role of, the Nimrod IPT's 'independent advisor' in relation to the NSC project. Accordingly, in my view, during the gestation of the NSC, QinetiQ had three main duties to perform: (a) actively to consider, question and advise the Nimrod IPT whether it was *"satisfied with the work done so far and the approach taken"* by BAE Systems;[135] (b) to speak out and warn the Nimrod IPT whenever significant issues of concern regarding the NSC came to its attention; and (c) to satisfy itself that it was appropriate for the Nimrod IPT to sign off the final BLSC deliverable reports. I explain below how, in my judgment, QinetiQ failed properly to fulfil these duties.

Summary of criticisms of QinetiQ

11.276 In my judgement, the following criticisms of QinetiQ regarding its role as 'independent advisor' in relation to the NSC during the period 2002 to 2005 are borne out:

(1) **QinetiQ failed to take adequate steps to formalise its appointment as ISA or otherwise clarify the nature of its role.**

(2) **QinetiQ failed to check that BAE Systems sentenced risks in an appropriate manner, i.e. using appropriate data.**

(3) **QinetiQ failed to check that BAE Systems included risk mitigation evidence in the BLSC Reports.**

(4) **QinetiQ failed to advise the Nimrod IPT properly at the Customer Acceptance Conference, failed to ask intelligent questions, and succumbed to pressure to be party to a 'consensus' that BAE Systems had completed the NSC task.**

(5) **QinetiQ failed to read the NSC reports or otherwise check BAE Systems' work.**

(6) **QinetiQ failed to advise the Nimrod IPT properly at the Sixth Platform Safety Working Group meeting or ask any intelligent questions.**

(7) **QinetiQ subsequently supported the 'sign off' of BAE Systems' NSC reports in circumstances where it was manifestly inappropriate to do so: (a) without even having read any of them and (b) in the absence of an ISA audit report, contrary to Def-Stan 00-56.**

[135] This formulation is taken from Martyn Mahy's e-mail to Frank Walsh dated 21 May 2004 following a visit to BAE Systems Chadderton.

(8) QinetiQ was too compliant and eager to please the Nimrod IPT.

(9) QinetiQ fundamentally failed to perform its duty as independent advisor to the Nimrod IPT and was little more than a rubber stamp or cipher.

(10) QinetiQ failed to understand the meaning of ALARP.

Detailed analysis of the critisms of QinetiQ

11.277 I analyse and explain each of these criticisms in turn below.

(1) QinetiQ failed to take adequate steps to formalise its appointment as ISA or otherwise clarify the nature of its role.

11.278 In my judgment, QinetiQ shares some of the responsibility itself for the fact that its appointment as ISA was never formalised and its precise role never entirely clarified.

11.279 As explained in **Chapter 10A**, the suggestion that QinetiQ should formally be appointed as the ISA in relation to the NSC was made at an early stage. The minutes of the QinetiQ Task Review Meetings from October 2001 onwards show that there were several discussions about QinetiQ's role in the project and a clear expectation on the part of all those present that QinetiQ would be tasked to act as an ISA. This is confirmed by a draft version of an 'Interim Report – Independent Saftey Auditor assessment for Legacy Safety Case on Nimrod Aircraft (QIC)' dated August 2003 and very belatedly disclosed to the Review. The introduction to the draft report states as follows:

1 Introduction

1.1 *QinetiQ Safety & Software Assessment (S&SA) have been contracted by the Nimrod(ES) IPT, of the Defence Logistics Organisation (DLO), to undertake the role of Independent Safety Auditor (ISA) of the 'Legacy' Safety Case on the Nimrod R Mk1 and Nimrod MR2 aircraft fleet.*

1.2 *QinetiQ's responsibilities and duty of care are conducted in accordance with the provisions of Joint Services Publication 553 [1] and Defence Standard 00-56 [2]; to provide independent competent advice to the customer and transparency to the safety evaluation process. The evaluation process encompasses UK health and safety legilsation, EU Directives and Defence Standards as applicable.*

11.280 It is thus clear beyond a peradventure that QinetiQ was expecting to be formally tasked to act as ISA in relation to the NSC and conducted itself accordingly. In the event, however, this was never formalised. QinetiQ was never formally tasked as ISA and proper ISA terms of reference were never drawn up and agreed.

11.281 Whilst the responsibility for this must lie largely at the door of the Nimrod IPT, in my view, QinetiQ could, and should, have done more to ensure that the matter of its appointment as ISA was properly addressed, formalised and documented. It knew, that the formal appointment of an ISA was a requirement under Def-Stan 00-56. QinetiQ initially allowed the matter of its formal appointment to drift; and then, having settled into the *quasi*-role of 'independent advisor', it seemed content to do the minimum and 'ease the passing' of the NSC in conformity with the Nimrod IPT's wishes.

11.282 The importance of the appointment of an ISA and an ISA having a well defined role that is clearly understood by all parties was, or should have been, well understood at the time.[136] If QinetiQ had been properly appointed as ISA, it would have been required to carry out a full audit of the NSC produced by BAE Systems in accordance with Def-Stan 00-56 and it is likely that some of the errors in the NSC which have now been identified would have come to light, including, possibly, the errors relating to Hazard H73. As it was, however, in my view, QinetiQ's duties as 'independent advisor' (see above) gave QinetiQ sufficient scope and responsibility to ensure a proper NSC was produced. Nevertheless, this case is an object lesson in the dangers of ambiguity of role.

[136] See, for example, *"An Introduction to Safety System Management and Assurance"* (Issue 2, July 2005) known as the 'White Booklet' by Advantage Technical Consulting Ltd, at page 22.

(2) QinetiQ failed to check that BAE Systems sentenced risks in an appropriate manner using appropriate data.

11.283 In my judgment, QinetiQ failed to take adequate steps to ensure or check that BAE Systems sentenced risks in an appropriate manner using appropriate data.

11.284 As 'independent advisor' in relation to the NSC, QinetiQ should have taken steps to satisfy itself as to the following matters: (1) that BAE Systems only used appropriate mitigating evidence to sentence hazards; (2) that BAE Systems did not use MRA4 data to sentence MR2 and R1 hazards (which Chris Lowe had eschewed at the first 'Inaugural' PSWG Meeting on 18 March 2002); (3) that BAE Systems used quantitative and qualitative mitigation evidence appropriately to sentence hazards; (4) that the 'checklist' (which BAE Systems had referred to at the 'scoping' meeting at Chadderton on 19 May 2003) was appropriate and was in fact used to sentence hazards, (5) that the final BAE Systems' BLSC report(s) included a statement that 'past reliabilities data' would not demonstrate future reliability (which Witness L [QinetiQ] insisted on at the 'scoping' meeting on 19 May 2003); and (6) that mitigating evidence in fact used in the NSC reports reflected these points appropriately. As it was, QinetiQ failed to take any steps to ensure that such advice that it did give in relation to these matters was properly followed through.

(3) QinetiQ failed to check that BAE Systems included risk mitigation evidence in the BLSC Reports.

11.285 In my judgment, QinetiQ failed to take adequate steps to ensure or check that all risk mitigation evidence was, in fact, properly included by BAE Systems in the final NSC Reports.

11.286 As explained in **Chapter 10A**, Martyn Mahy had insisted in an e-mail to the Nimrod IPT dated 24 June 2004, as a pre-condition to supporting the sign-off of the BLSC Reports, that *"...all the risk mitigation evidence is included in the final safety case report"*. It appears, however, that QinetiQ failed to take any steps to satisfy itself that this was in fact the case before it supported the sign-off (see further below).

(4) QinetiQ failed to advise the Nimrod IPT properly at the Customer Acceptance Conference, failed to ask intelligent questions, and succumbed to pressure to be party to a 'consensus' that BAE Systems had completed the NSC task.

11.287 In my judgment, QinetiQ failed to advise the Nimrod IPT properly, or protect the Nimrod IPT's interests, at the Customer Acceptance Conference, failed to ask intelligent questions, and succumbed to pressure to be party to a 'consensus' that the BAE Systems had completed the NSC task. QinetiQ allowed the Nimrod IPT to agree that BAE Systems had properly completed the NSC task when QinetiQ did not have a proper basis for assuming this was the case.

QinetiQ sent an ill-prepared representative to Customer Acceptance Conference

11.288 The purpose of the Customer Acceptance Conference at Chadderton on 31 August and 1 September 2004 was for BAE Systems to present the results of Phase 2 of the NSC and to demonstrate to the satisfaction of the Nimrod IPT and QinetiQ that the contractual requirements of PDS Task 06-3409 had been satisfied. It was, therefore, an important meeting. QinetiQ sent Witness O [QinetiQ] to the meeting because Martyn Mahy was unfortunately unavailable at the last moment. Witness O [QinetiQ] had no familiarity with the NSC, had not been properly briefed, and had insufficient time to familiarise himself with the relevant issues. In my judgment, he was ill-prepared for the meeting and it was inappropriate for QinetiQ to have sent him.

BAE Systems Presentations

11.289 The nature of the presentations given by BAE Systems and what transpired at the meeting are set out in detail above and in **Chapter 10A**. For present purposes, it is important to remember that BAE Systems did not hand out copies of the six deliverable reports at the meeting, did not draw attention to the fact that it had left over 40% of the hazards *"Open"* and over 30% *"Unclassified"* (many with only vague recommendations) and represented that the NSC task had been completed.

Failure to ask intelligent questions

11.290 Witness O [QinetiQ] played an essentially passive role during the meeting. In the circumstances, this is understandable. But is it disappointing that he did not ask BAE Systems any of the intelligent questions which arguably should have been asked, *i.e.*: Why was there no review of how each of the hazards had been classified, mitigated and sentenced? How many hazards had BAE Systems actually left *"Unclassified"* and/or *"Open"*? How could PDS Task 06-3409 be considered completed when hazards remained *"Unclassified"*? How could the aircraft be considered ALARP when hazards remained *"Open"* and *"Unclassified"*?

QinetiQ's representative 'booed'

11.291 I also set out in detail in **Chapter 10A** Witness O [QinetiQ]'s description of what took place during the meeting. I accept his compelling evidence that when, at the end of the Customer Acceptance Conference on 1 September 2004 he initially refused to support the completion of the task by BAE Systems on the grounds that he was only standing in and had not seen any of the key deliverable documents, the other attendees *"booed me and muttered things along the lines 'bloody safety engineers always have to caveat their statements'"* (see **Chapter 10A**).

Witness O [QinetiQ] succumbed to the pressure

11.292 In interview with the Review, Witness O [QinetiQ] was questioned about the *"consensus"* that was apparently reached at the meeting, namely that the task had been successfully completed by BAE Systems and that *"the aims and objectives of the project had successfully been achieved"* whereupon Frank Walsh formally agreed on behalf of the Nimrod IPT that *"PDS Task -06-3409 could be considered closed by the issue of the minutes of this Conference".*[137] He was adamant that, despite being booed, he maintained his principled stance on behalf of QinetiQ and refused to be a party to the sign-off of the task. I have, however, concluded on all the evidence that, unfortunately, Witness O [QinetiQ] did, in fact, succumb to the pressure at the meeting; and in the end, did not wish to be seen to be standing in the way of what was clearly the strong 'mood of the meeting', namely that BAE Systems had completed the task. This is principally for two reasons.

11.293 First, it is clear that Witness O [QinetiQ] undoubtedly felt under considerable pressure to conform and go along with the 'consensus'. He was a new boy at the meeting. He explained how he felt like 'a fish out of water'. He was not familiar with the project and had not been privy to BAE Systems' work, although his colleague Martyn Mahy had. It was clear what the strong collective view around the table was. It was also clear what the attitude was to someone in his position having the temerity not to go along with it. He had been instructed by Martyn Mahy not to agree to anything at this 'customer acceptance conference' but merely to ask a number of questions. In these circumstances, it was perhaps unsurprising that he probably felt that he was not in a position to rock the boat.

11.294 Second, the contemporaneous documents tend to suggest that Witness O [QinetiQ] *was* compliant and, indeed, complimentary about the work that had been done and did not make a stand. A 'Situation Report' prepared by Martyn Mahy on 5 November 2004 for Witness M [QinetiQ] referred to Witness O [QinetiQ]'s attendance at the Customer Acceptance Conference on 31 August and 1 September 2004 'in his place' and continued: *"QQ were happy with the SC presentation and the examination of the CASSANDRA database <u>and supported the sign-off</u> of the Baseline Safety Case"*.[138] Martyn Mahy said that this document recorded what Witness O [QinetiQ] had said to him and Witness N [QinetiQ], the technical leader for the QinetiQ heavy aircraft section, after the meeting. Witness O [QinetiQ] admitted to the Review that he probably did say at the meeting that he was 'happy' with the presentation and the Hazard Log, but denied saying that he had supported the sign-off to anyone, including Martyn Mahy. In my view, his recollection is faulty on this point (the wish being the father of the thought). In any event, it is probably immaterial whether Witness O [QinetiQ] said, either at the meeting itself or subsequently to Martyn Mahy, in terms that he 'supported' the sign-off. Since the presentations, in particular Richard Oldfield's presentation, were to the effect that the task was 'complete', Witness O [QinetiQ]'s

[137] Paragraph 9 of the Minutes of the Customer Acceptance Conference.

[138] This situation report subsequently formed the basis of Martyn Mahy's report the QinetiQ Task Review Meeting which was to take place on 19 November 2004 - see further below.

statement that he was '*happy* with the presentation and the Hazard Log' was probably regarded as tantamount to an acceptance by him that the task was complete, at least in the absence of formal clarification by him to the contrary. This may explain the wording in the minutes *"The meeting... reached a consensus..."*. There is simply no evidence of Witness O [QinetiQ]'s having positively objected or demurred at any stage. Indeed, quite the opposite. Richard Oldfield's contemporaneous note records Witness O [QinetiQ] making a positive remark at the end of the meeting : *"Witness O [QinetiQ] – From what he's seen looks that we've done a good job!!"*. This expression of approval on behalf of QinetiQ was recorded and relayed by Chris Lowe when he reported to Witness A [BAE Systems].

Failure of duty to maintain independence and objectivity

11.295 In my judgment, Witness O [QinetiQ] was wrong to succumb to the pressure. His job as 'independent advisor' was to maintain independence and objectivity on behalf of his clients, *whatever* the pressure or blandishments. He should have maintained his stance, which was, in my view, both principled and correct. He simply should have refused to become party to the 'consensus'. However, I have considerable sympathy with his personal position and the difficulty and dilemma which he had been placed in. He said he felt like 'a fish out of water'. I am not surprised that he found it intimidating to be 'booed' and was surprised and embarrassed at being heckled in this manner. Given that he had been asked to step in at the last moment, that he knew little about the project, that he had been given only a vestigial briefing and had not been instructed *not* to agree to 'customer acceptance' unless various conditions were fulfilled, I do not think that it would be fair or proportionate to name him or specifically criticise him in his Report. The fault lies more with those who put him in this position and the ambient culture of the meeting itself.

(5) QinetiQ failed to read the NSC reports carefully or otherwise check BAE Systems' finished work.

11.296 In my judgment, QinetiQ can be criticised for failing to read the NSC reports carefully or otherwise check BAE Systems' finished work.

11.297 The minutes of the Customer Acceptance Conference, together with the six NSC 'deliverable' reports, were distributed by e-mail on or about 21 September 2004. The distribution list included all those who had been present at the meeting, including Witness O [QinetiQ] for QinetiQ. However, for reasons which are unclear, QinetiQ were not on the list of addressees on the relevant e-mail sent out by Richard Oldfield. It would appear, therefore, that QinetiQ did not at this stage receive e-copies of the six deliverable reports. Nevertheless, in my view, QinetiQ should have asked for copies and insisted on seeing copies since it was QinetiQ's duty as independent advisor to 'assess' the reports and advise the Nimrod IPT in respect thereof. QinetiQ never did, and were content to support the sign off without ever having seen copies (see further below).

(6) QinetiQ failed to advise the Nimrod IPT properly at the Sixth Platform Safety Working Group meeting or ask any intelligent questions.

11.298 In my judgment, QinetiQ can be criticised for failing to advise the Nimrod IPT properly at the Sixth PWSG meeting or ask any intelligent questions at that meeting. QinetiQ failed to advise the Nimrod IPT properly, or protect the Nimrod IPT's interests, at the Sixth PSWG meeting. In particular, QinetiQ allowed the Nimrod IPT and IPTL to confirm that BAE Systems had properly completed the NSC task when this was manifestly not the case.

11.299 The details of the presentations and what took place at the meeting are again set out above and in **Chapter 10A**.

Failure to ask intelligent questions

11.300 In my view, QinetiQ can be criticised for the fact that Martyn Mahy, who was the designated QinetiQ 'Task Manager' and was familiar with the project, did not raise any queries in relation to the BAE Systems presentations or ask BAE Systems any of the intelligent questions which arguably should have been asked, *i.e.*: How many hazards had BAE Systems actually left *"Unclassified"* and/or *"Open"*? How could PDS Task 06-3409 be considered completed when hazards remained *"Unclassified"*? How could the aircraft be considered ALARP when hazards remained *"Open"* and *"Unclassified"*? Instead, he appears to have been content simply to sit, essentially passively, throughout the Sixth PSWG meeting. He should not have allowed the Nimrod IPTL to accept the completion of BAE Systems' work at the meeting without taking proper steps to satisfy himself that this was, in fact, justified and appropriate.

(7) QinetiQ subsequently supported the 'sign off' of BAE Systems' NSC reports in circumstances where it was manifestly inappropriate to do so: (a) without even having read any of them and (b) in the absence of an ISA audit report in breach of Def Stan 00-56.

11.301 In my judgment, it is surprising and disturbing that QinetiQ was prepared to 'sign-off' on the BLSC Reports: (a) without having read or checked them; and (b) in the absence of an ISA Report in breach of Def-Stan 00-56. This was a fundamental abrogation of QinetiQ's duty as an 'independent advisor'.

11.302 Following the Customer Acceptance Conference, on 5 November 2004, Martyn Mahy produced a situation report on the BLSC for the QinetiQ TRM regarding Witness O [QinetiQ]'s attendance at the 'Customer Acceptance Conference' on 31 August and 1 September 2004. That situation report stated: *"QQ were happy with the SC presentation and the examination of the CASSANDRA database and supported the sign-off of the Baseline Safety Case."* The QinetiQ TRM took place on 19 November 2004. The minutes record in terms that Martyn Mahy reported that *"QQ were now ready to sign off the BLSC"*. There is a clear statement recorded in the minutes: *"QQ (Mr Mahy) reported that QQ were now ready to sign off the BLSC..."*. It does not appear, however, that anyone at QinetiQ had actually read any of the Nimrod BLSC Reports (see **Chapter 10B**).

Inappropriate for QinetiQ to have supported 'sign-off' of NSC

11.303 In my judgment, it was manifestly inappropriate for QinetiQ to have 'signed-off' or agreed to 'support the sign-off' of the NSC task and BLSC Reports in these circumstances, for the following reasons. First, it was well known and understood by everyone concerned, in particular the key participants at QinetiQ, that JSP553 and Def-Stan 00-56 mandated that an independent review (ISA) must be carried of the NSC before it could be finally 'signed-off' as completed. Second, QinetiQ had had early involvement in the process *"to ensure that the [Nimrod] Safety Case is independently assessed without any surprises"*.[139] Third, QinetiQ had not themselves prepared any ISA report verifying the NSC work as required by JSP553 Def-Stan 00-56, and were not aware of any third party having prepared such a report or being asked to do so. Fourth, QinetiQ had never even seen, let alone read, any of the deliverable reports comprising BAE Systems' work on the NSC, in particular the BLSC Reports themselves.

Previous Task Manager

11.304 Witness L [QinetiQ] said in evidence to the Review that it was *"bizarre"* for QinetiQ to have signed-off the NSC Reports, not least because QinetiQ had not done or seen an ISA review, nor even read the Reports. I agree. It is unfortunate that Witness L [QinetiQ] left QinetiQ in the summer of 2003. He was impressive and rigorous. I have no doubt that had Witness L [QinetiQ] stayed at QinetiQ for the remainder of Phase 2, he would have done two things. First, he would have pointed out to the Nimrod IPT that it was required to appoint an ISA under Def-Stan 00-56 because Class A and B risks were involved. Second, he would not have agreed to 'sign-off' the NSC as Martyn Mahy did and would have firmly pointed out to his superiors, including Witness N [QinetiQ], that there had been a non-compliance with Def-Stan 00-56 and that, therefore, QinetiQ should not sign-off and if it did, it would be doing so 'at risk'.

[139] Frank Walsh's e-mail leading to 17 June 2004 meeting (see **Chapter 10B**).

Martyn Mahy's arguments

11.305 In interview with the Review, Martyn Mahy raised a number of points which I have carefully considered but rejected. First, I reject Martyn Mahy's suggestion that he may have been influenced by being told by Witness O [QinetiQ] that BAE Systems had informed the Customer Acceptance Conference that it had carried out an 'independent review' of the NSC. There is no record of Witness O [QinetiQ] having relayed this to Martyn Mahy. Nor does it feature in his Situation Report. There is also no evidence that QinetiQ received the minutes of the meeting at this stage. Even so, it would in any event have been inappropriate for QinetiQ to have supported the sign-off without having satisfied itself that a proper ISA report had been prepared in accordance with Def-Stan 00-56. Second, I reject Martyn Mahy's evidence that at the Sixth PSWG meeting he raised with Frank Walsh the issue of why QinetiQ had still not received copies of the BLSC Reports or the CASSANDRA Hazard Log and was told that QinetiQ had already had the opportunity to inspect on 17 June and on 31 August/1 September 2004, and so he did not pursue the matter further. Third, I reject Martyn Mahy's suggestion that QinetiQ was purporting to support the sign-off of the NSC in a limited capacity which related to 'process' only because QinetiQ were not given access to the documents:

> *"**MR PARSONS QC:** So how can you have a final sign-off of a safety case, unless and until it has been independently assessed?*
>
> ***MR MAHY:** Yes, I agree. All we can do is give approval to, if we accept the processes and methodology used in producing it. But if we are not given an opportunity to review the documents or be involved in an independent safety assessment, our approval in terms of a sign-off is limited to the processes that they have employed in producing it."*

11.306 In my view, there was little excuse for the manner in which he, on behalf of QinetiQ, was prepared to 'sign-off' or 'support the sign-off' the BLSC Reports. Martyn Mahy had no answer to this in interview:

> *"**MR HADDON-CAVE QC:** How is it possible that you [QinetiQ] managed to find yourself in the situation where you approved the baseline safety case without ever having looked at it?*
>
> ***MR MAHY:** Because the meetings that we went to with the IPT, the goalposts continually moved. We were never sure from one meeting to the next what their expectation was. The wording differed between the minutes and what was agreed outside of the meetings. And at the end of the day, we were at the point where: we've done everything that we've been asked to do and we will support you on that basis. But, you know, we couldn't insist on them doing anything. We could only advise them.*
>
> ***MR HADDON-CAVE QC:** What you could have done was say, "I'm sorry, we haven't seen the baseline safety case report, we haven't examined it, we haven't read it and we certainly haven't had an opportunity to assess or audit it, for which of course we would need task money, therefore we cannot possibly sign off the baseline safety case report".*
>
> ***...***
>
> ***MR MAHY:** In hindsight, it would have been a better answer, yes.*
>
> ***MR PARSONS QC:** But that is the right answer.*
>
> ***MR MAHY:** Yes, we should have said that.*
>
> ***MR PARSONS QC:** And the whole purpose of any safety system is to have a series of checks and balances, and the last line of defence is the independent safety adviser, even putting it at its lowest, saying "This is not good enough. We cannot support this". Isn't that right?*
>
> ***MR MAHY:** Yes.*
>
> ***MR PARSONS QC:** And that is what should have happened here.*
>
> ***MR MAHY:** Yes, with hindsight."*

11.307 I am satisfied that this was a failure of foresight, not hindsight, by the individuals concerned (see further below).

Colin Blagrove

11.308 Colin Blagrove was the relevant Technical Assurance Manager responsible for the technical integrity of the NSC. He was also the Design Approved Organisations Scheme (DAOS) signatory. As he admitted when asked about his role in interview, it was his personal responsibility as DAOS signatory to ensure that QinetiQ did not sign-off on matters unless there was adequate evidence to justify it:

> *"**MR HADDON-CAVE QC:** Finally, [Mr Blagrove], I'm bound to ask this, I am afraid. Whose responsibility was it to ensure that Martin Mahy did not sign up QinetiQ to things which QinetiQ should not have been signed up to? Was it [the Technical Manager's] responsibility or your responsibility or both your responsibilities?*
>
> ***MR BLAGROVE:** Yes. I understand the question. I think my answer, though -- and I don't want to sound obtuse -- but it is that for a safety specialist to offer advice to a customer, they should get formal approval. I would probably want to see something written down with supporting evidence, and it would be signed off by a DAOS signatory. Somebody like myself.*
>
> *In the case of a statement about, "We support the sign-off", you can't stop people explaining things and expressing things to the customers. I think that's healthy. But to have them accept that as something formal that we have delivered is misconstruing it. So I think in the case of: whose responsibility was it for sign-off? The question is: well, we weren't being asked to sign anything off. So I think the question in my mind doesn't indeed arise.*
>
> ***MR PARSONS QC:** But you were being asked to sign off. Whose responsibility was it to ensure that you don't unless you had adequate evidence?*
>
> ***MR BLAGROVE:** The DAOS signatory. The technical information would be a DAOS -- we have used the term "technical assurance manager".*
>
> ***MR PARSONS QC:** So that would be you?*
>
> ***MR BLAGROVE:** Yes.*
>
> ***MR PARSONS:** What would [the Technical Manager's] responsibility be in those circumstances?*
>
> ***MR BLAGROVE:** To provide the specialist advice into that process."*

'Sign-off' means 'sign-off'

11.309 A number of the QinetiQ witnesses, including Colin Blagrove, equivocated about the meaning of 'sign-off'. This was not edifying. In my view, 'sign-off' means what it says: the actual or notional signature on a document or piece of work to signify approval by the signatory of that document or piece of work. It matters not that there was no actual physical signature placed on the BLSC Reports by Colin Blagrove as the relevant QinetiQ DAOS signatory present. The fact is that he was the senior 'assurance' person present at the Task Review Meeting on 19 November 2004 at which the Task Manger had said *"QQ were now ready to sign off the BLSC..."*; and despite *"mutterings"* by some of the other QinetiQ representatives present and the Project Manager, Witness M [QinetiQ] saying, *"Have we seen the reports yet?"*, to which the answer was *"No",* Colin Blagrove was prepared to let the matter to go through on the nod (see **Chapter 10B**). He should not have done so.

11.310 I am satisfied, that at the Task Review Meeting on 19 November 2009 (see **Chapter 10B**) by actions of Martyn Mahy and assent of Colin Blagrove, QinetiQ, in effect, put its name to the BLSC Reports in an unqualified manner and, therefore, gave its blessing to both the substance and form of the NSC. This allowed the ISA role, *de facto*, to be fulfilled regarding the sign off of the NSC.

Failure of management and leadership

11.311 The fact that QinetiQ found itself in the position whereby it was 'signing-off' on the BLSC without having seen the actual Reports was due in part to its failure to clarify its role at an early stage and its failure later on to insist on being given sight of relevant documentation at any stage. Matters were allowed to drift. This was a failure of management and leadership. QinetiQ's much vaunted 'Matrix Management System' allowed a situation to develop whereby QinetiQ slid into a position of being prepared to go along with an informal process and give assent without any proper formalities being followed. The fact that QinetiQ was prepared to support the sign-off of the NSC in these circumstances is symptomatic of the twin vices of: (a) a lax attitude to the proper proprieties; and (b) a desire to please the client.

If QinetiQ had read the BLSC Reports

11.312 If anyone at QinetiQ had carefully read either of the BLSC Reports for the MR2 and R1 the following matters would, or should, have been apparent to them that:

151.1 BAE Systems had left 43 hazards *"Open"*, many with no recommendation beyond *"Further analytical techniques are required..."*, i.e. over 40% of the total.

151.2 BAE Systems had failed to assess all the hazards and left 33 hazards *"Unclassified"*, with no recommendation beyond *"Further analytical techniques are required..."* i.e. over 30% of the total.

151.3 There was no indication as to what *"Further analytical techniques are required..."* meant, beyond simply 'further work' being required.

151.4 The following unqualified statement on page 2 of the Executive Summaries of the BLSC Reports was not justified:

> *"From the above, it is thus declared that all potential hazards have been identified, assessed and addressed and that all appropriate standards had been met. Accepting this the top level goal of the Nimrod MR Mk2 type Equipment Safety Case that*
>
> ***"The aircraft type is deemed acceptably safe to operate and maintain within specified contexts"***
>
> *has been demonstrated as having been achieved."*

151.5 The following (materially different) statement on page 46 in the Conclusion of the BLSC Reports required explanation:

> *"From the above, it is thus declared that all potential hazards have been identified, assessed and addressed* <u>*to ALARP (subject to consideration of the proferred recommendations)*</u> *and that all appropriate standards had been met. Accepting this the top level goal of the Nimrod MR Mk2 type Equipment Safety Case that*
>
> ***"The aircraft type is deemed acceptably safe to operate and maintain within specified contexts"***
>
> <u>*is considered as having*</u> *been demonstrated as having been achieved."*
>
> (underlined emphasis added)

151.6 There was no mitigation evidence of any sort included in either of the BLSC Reports (contrary to the requirement set out in Martyn Mahy's e-mail to the Nimrod IPT dated 24 June 2004 and repeated to the QinetiQ TRM on 16 July 2004).

151.7 There was no basis upon which QinetiQ could check and satisfy itself that BAE Systems had used appropriate mitigation evidence to sentence the hazards.

151.8 BAE Systems had failed to complete PDS Task 06-3409 and the sign-off was not appropriate.

(8) QinetiQ was too compliant and eager to please the Nimrod IPT.

11.313 In my judgement, at the root of the problem so far as QinetiQ is concerned lies a worrying truth: QinetiQ was too compliant and eager to please the customer and lost sight of its overriding duty, as independent advisor, to remain objective and rigorous. QinetiQ did not want to risk upsetting the Nimrod IPT in case this damaged their relationship and imperilled future business. It traded its duty for commercial expediency.

11.314 As Witness L [QinetiQ] explained to the Review:

> *"All work we did at QinetiQ was controlled by Internal Project Managers ("PMs"). They authorised work packages and interfaced with the customer, i.e. the relevant IPT, for task allocation and costing. In my view they were always stressed and on the back foot with the IPTs. This always seemed to stem from the fact that the IPTs had an inherent belief that QinetiQ were 'robbing them'. I felt that they went to extraordinary lengths to keep their IPT Leaders ("IPTLs") happy. I also felt that QinetiQ generally was on occasion prepared to modify its position for the same reason."*

11.315 This appears, unfortunately, to have been true in this case. It was the duty of QinetiQ in its role as *"independent advisor"* to protect the Nimrod IPT, and to give the IPT objective, unvarnished advice. The duty of a safety engineer is sometimes to point out difficulties and unpalatable truths.

QinetiQ culture – 'bending over backwards to please the IPTs'

11.316 In my view, there was a prevailing problem with the culture at QinetiQ and its potentially compliant attitude to the customer:

> "**MR PARSONS QC:** *If you were to use a word or phrase to sum up the attitude or the culture that you experienced, what would that be?*
>
> **WITNESS L [QinetiQ]:** *I wouldn't say it was a negative safety culture, but I would say that it was a culture that was "can do" for the IPTs. That was the problem with QinetiQ. Because QinetiQ were bending over backwards to please the IPTs, doing what they felt the customer wanted.*
>
> **MR PARSONS QC:** *What did the customer want?*
>
> **WITNESS L [QinetiQ]:** *The customer didn't want problems. That was quite clear, and that was made abundantly clear to me. "Take that out, the customer doesn't want to hear that."*
>
> **MR PARSONS QC:** *So of course, if the customer had wanted problems, if the customer had said "We need to understand safety issues, we need you to question them", that would drive a different attitude?*
>
> **WITNESS L [QinetiQ]:** *Certainly at QinetiQ that would have, yes, without a doubt."*

11.317 QinetiQ found itself in a slightly awkward situation of being given a 'cold shoulder' by the Nimrod IPT and BAE Systems and not being furnished with all the information and full ISA status that it should have been accorded. Nevertheless, it should have stood its ground and insisted on seeing and studying the BLSC Reports in full and not supported the sign-off until it had done so. It was too submissive and meek.

(9) QinetiQ fundamentally failed to perform its duty as independent advisor to the Nimrod IPT and was little more than a rubber stamp or cipher.

11.318 In my judgment, QinetiQ fundamentally failed to perform its duty as independent advisor to the Nimrod IPT and was little more than a rubber stamp or cipher.

11.319 For the reasons given above, it is particularly unfortunate that QinetiQ supported the sign-off of the NSC. Had it refused to do so, until a proper ISA review had been carried out in accordance with JSP553 and Def-Stan 00-56, it is possible that the many errors and defects contained it in would have been unearthed, including that in relation to Hazard H73.

(10) QinetiQ failed to understand the meaning of ALARP

11.320 In my view, it is also a matter of concern that leading experts such as QinetiQ do not seem to understand basic concepts such as the meaning of ALARP (As Low As Reasonably Practicable).

11.321 The Executive Summary to QinetiQ's Nimrod Fuel System Safety Review Report (QINETIQ/EMEA/IX/ SCR0702915, October 2007, Issue 1) stated:

> *"Having considered the evidence referred to within this safety case report, noting that there are outstanding recommendations and the level of risk present to the fuel system <u>is not ALARP</u>, the operation of the fuel system <u>is tolerably safe</u> given the mitigation currently in place."* (emphasis added)

11.322 This report sowed much confusion. There is no such thing as 'tolerably safe but not ALARP'. Risks are either 'tolerable and ALARP' or intolerable:

- This is clear from Def-Stan 0056 (Part1)/4 Annex A (Definitions):

Term	Definition
Tolerable	A level of risk between broadly acceptable and unacceptable that may be tolerated when it has been demonstrated to be ALARP.

- This is clear from BP1201 (Risk Classification Table):

Risk Classification	
'C'	Tolerable - The residual risk is tolerable only if further risk reduction is impracticable or requires action that is grossly disproportionate in time, trouble and effort to the reduction in risk achieved.

11.323 The 'R' in ALARP includes a temporal as well as a financial element (see **Chapter 9**). As made clear in *Edwards v National Coal Board* [1949] 1 KB 704: a computation must be made in which the quantum of risk is placed on one scale and the sacrifice, whether in time, money or trouble, involved in the measures necessary for averting the risk is placed in the other.

Criticisms of individuals at QinetiQ

11.324 I am satisfied that two individuals bear particular responsibility for the failures of QinetiQ in relation to its role in respect of the NSC.

Martyn Mahy

11.325 Martyn Mahy was the QinetiQ Task Manager for the NSC Project from about October 2003. It was his duty on behalf of QinetiQ to ensure that the Nimrod IPT was properly advised in respect of the NSC project. He failed to do so.

11.326 Martyn Mahy bears immediate responsibility on behalf of QinetiQ for: (1) failing to formalise QinetiQ's appointment as ISA or otherwise to clarify its role at any stage; (2) failing to check that BAE Systems sentenced risks in an appropriate manner, *i.e.* using appropriate data; (3) failing to check that BAE Systems included risk mitigation evidence in the BLSC Reports; (4) failing to brief and de-brief Witness O [QinetiQ] adequately before the Customer Acceptance Conference; (5) failing to read the NSC reports or otherwise check BAE Systems' work (and failing to ask for copies of the Reports when they were not initially supplied); (6) failing to advise the Nimrod IPT properly at the Sixth Platform Safety Working Group meeting or ask any intelligent questions; (7) subsequently 'signing off' or supporting the 'sign-off' of BAE Systems' NSC reports in circumstances where it was manifestly inappropriate to do so: (a) without even having read any of them; and (b) in the absence of an ISA audit report, contrary to JSP553 and Def-Stan 00-56.

11.327 It is right to point out that Martyn Mahy may have felt somewhat bruised by his earlier encounters with the Nimrod IPTL when QinetiQ had been accused of 'touting for business' and relations were not good. It is also right to point out that he might have expected to have had more management help and guidance from, *e.g.* his Technical Manger and Technical Assurance Manager. It is not clear that he particularly asked for any or was given it save in relation to the early breakdown of relations with the IPT. It was unfortunate that, for understandable reasons, he was unable to attend the crucial Customer Acceptance Conference and Witness O [QinetiQ] had to go in his stead. It is also right to point out, as he did in interview, that *"There were people at that [19 November 2004] meeting in a senior position to me, such as Colin Blagrove, Technical Assurance Manager, who could have raised that concern himself".*

11.328 Nevertheless, I am satisfied that Martyn Mahy failed to do his job as Task Manager properly in certain key respects, and failed to give any sort of real independent assurance, even in the limited role which he and QinetiQ had been assigned and adopted. For the reasons given above, his most blameworthy fault was agreeing on behalf of QinetiQ to 'sign-off' or support the sign off of the NSC and BLSC without seeing or reading the Reports.

Technical Leader

11.329 In my view, the Technical Leader for the Nimrod 010 Safety Management task also bears some share of the responsibility for QinetiQ's failures outlined above. He was Martyn Mahy's line manager and responsible for ensuring the technical input was correct. He possibly could, and should, have done more at the time to ensure he had proper oversight of Martyn Mahy's handling of the Nimrod 010 Safety Management task and thought more carefully about the direction in which QinetiQ's involvement was drifting. His involvement was, however, sporadic and intermittent and he was unsighted as to some of the details. QinetiQ's 'Matrix Management System' may not have particularly assisted in this regard. In all the circumstances, I have concluded that it would not be appropriate, fair or proportionate to name him in this report.

Colin Blagrove

11.330 Colin Blagrove was the Technical Assurance Manager for the Nimrod 010 Safety Management task and DAOS signatory. It was his ultimate responsibility to ensure that QinetiQ did not sign off anything unless it was appropriate to do so. He failed in this critical task.

11.331 The fact that QinetiQ found itself in the position whereby it 'signed-off' on the NSC and BLSC Reports in circumstances where it was manifestly inappropriate from an assurance point of view to do so, is due to a failure of management and leadership. Ultimately, it was for him, as the senior person responsible for assurance, to stop the drift and ensure that: (a) QinetiQ's role was clarified; and (b) QinetiQ insisted on being given proper sight of relevant documents, proper tasking and proper opportunity to carry out its role. It was for him, as the senior person responsible for assurance present at the critical Task Review Meeting on 19 November 2004. to make it clear that QinetiQ could not put its name to something which it had not read and which, in any event, required a full ISA report for which QinetiQ would have to be properly tasked. The fact that he did not do so, but instead showcased QinetiQ's new Safety Case process which should be more to the IPTs liking, was symptomatic of QinetiQ's unfortunately lax and compliant approach to the Nimrod IPT at the time. He candidly admitted *"... I think we let it drift over us at that meeting".*

11.332 It is fair to bear in mind the following points. First, this was only one of large number of tasks and areas in which Colin Blagrove was involved or responsible for at the time. Second, his involvement in the project was intermittent and only as required. Third, he did not get as much assistance from the Technical Leader as he might have expected.

11.333 I am satisfied, however, in all the circumstances, that Colin Blagrove fundamentally failed to perform his vital function of assurance leadership at critical times.

Conclusion

11.334 QinetiQ's approach was fundamentally lax and compliant. QinetiQ failed at any stage to act as the independent 'conscience' of the IPT. As a result, the 'third stool' in the safety process, namely independent assurance, was effectively missing from the NSC process.

PART IV:
ORGANISATIONAL CAUSES

PART IV: ORGANISATIONAL CAUSES

"The organizational causes of this accident are rooted in … history and culture, …years of resource constraints, fluctuating priorities, schedule pressures, …. Cultural traits and organizational practices detrimental to safety were allowed to develop, including: reliance on past success as a substitute for sound engineering practices …; organizational barriers that prevented effective communication of critical safety information and stifled professional differences of opinion; lack of integrated management across program elements; and the evolution of ... informal ... decision-making processes that operated outside the organization's rules.…" (Columbia Accident Investigation Board Report, Volume 1, Chapter 1, page 9)

Introduction to Part IV

1. The organisational causes of the loss of XV230 are rooted in the history and culture of the organisations in the MOD responsible for the in-service support and airworthiness of RAF aircraft.

2. Huge organisational changes took place in the In-Service support and airworthiness arrangements for Defence equipment and RAF aircraft in the years prior to the loss of XV230. There were three major themes at work: (a) a shift from organisation along purely 'functional' to project-oriented lines; (b) the 'rolling up' of organisations to create larger and larger 'purple'[1] and 'through-life' management structures; and (c) 'outsourcing' to industry (see **Chapter 12**).

3. A Nimrod Airworthiness Review Team Report in 1998 warned of *"the conflict between ever-reducing resources and ... increasing demands; whether they be operational, financial, legislative, or merely those symptomatic of keeping an old ac flying"*, and called for Nimrod management that was *"highly attentive"* and *"closely attuned to the incipient threat to safe standards"*, in order to safeguard the airworthiness of the fleet in the future.[2] These warnings were not sufficiently heeded in the following years (see **Chapter 13**).

4. In fact, the MOD suffered a sustained period of deep organisational trauma between 1998 and 2006 due to the imposition of unending ***cuts*** and ***change***, which led to a ***dilution*** of its safety and airworthiness regime and culture and ***distraction*** from airworthiness as the top priority (see **Chapter 13**).

5. These organisational causes adversely affected the ability of the Nimrod IPT to do its job and the oversight and culture in which it operated during the crucial years when the Nimrod Safety Case was being prepared, in particular 2001-2004.

6. The serial delays in the In-Service Date of the replacement Nimrod 2000/MRA4 programme have had a malignant effect on In-Service Support for the MR2 (**Chapter 14**).

7. The history of Procurement generally in the MOD has been one of years of major delays and cost over-runs. This has had a malignant effect on In-Service Support and safety and airworthiness generally. Poor Procurement practices have helped create 'bow waves' of deferred financial problems, the knock on effects of which have been visited on In-Service Support, with concomitant change, confusion, dilution and distraction, as occurred in the post-Strategic Defence Review period 1998 to 2006 (**Chapter 14**).

[1] Also called 'Jointery' *i.e.* in the merging of single service organisations into tri-service 'purple' organisations. See further **Chapters 12** and **13**.

[2] Nimrod Airworthiness Review Team Report, dated 24 July 1998, paragraphs 13 and 30.

CHAPTER 12 – HISTORY OF RAF IN-SERVICE SUPPORT (1990-2009)

Contents

Chapter 12 sets out a brief history of the RAF in-service support for aircraft during the period 1991 to 2008. In this Chapter, I answer the following questions:

- Which organisations have been responsible for providing in-service support and airworthiness arrangements for RAF aircraft?
- How have they evolved and changed over the past 18 years?
- With what effect?
- What is the current structure?
- What are the regulations relevant to airworthiness?

Summary

1. Huge organisational changes took place in the In-Service support and airworthiness arrangements for Defence equipment and RAF aircraft in the years prior to the loss of XV230.

2. It is necessary to understand the history, nature and scale of these changes in order better to understand the organisational causes which contributed to the loss of XV230.

3. In essence, there were three themes at work:

3.1 First, a shift from organisation along purely 'functional' to project-oriented lines, *i.e.* a move from having different organisations responsible for different aspects of support, to having individual multi-disciplinary bodies for each platform.[1]

3.2 Second, the 'rolling up' of organisations to create larger and larger structures[2] as a result of: (a) a drive to create more tri-service (*i.e.* 'purple')[3] organisations by the merger of single-Service Royal Navy, Army and RAF bodies; and (b) a move to 'whole-life' management of equipment by merging procurement and in-service organisations.

3.3 Third, the 'outsourcing' to industry of increasingly more of the functions traditionally carried out by those in uniform.

4. These features were at their most intense during the period 2000-2006 (see below).

5. Prior to 1991, procurement and In-Service support of aircraft were arranged on purely functional lines, *i.e.* Engineering (including airworthiness), Logistics, Finance and Commercial. Procurement was the responsibility of the MOD (Procurement Executive) (MOD(PE)) and In-Service support was arranged on single-Service lines (Royal Navy, Army, RAF).

6. Since 1991, there have been four periods of change:

6.1 <u>1991-1994: early MDG era:</u> when "Multi-Disciplinary Groups" (MDGs) were introduced, which combined the Engineering and Logistics functions of In-Service support for individual aircraft types.

[1] *i.e.* type of aircraft, tank, ship etc.

[2] Culminating in the single Defence Equipment & Support (DE&S) of today.

[3] Navy, Khaki and Light Blue = Purple.

6.2 1994-1999: RAF Logistics Command: when RAF Logistics Command was formed, which brought together and co-located all aircraft MDGs and Finance was added to each.

6.3 2000-2006: formation of DPA/DLO and IPTs: following McKinsey's recommendations and the Strategic Defence Review in 1998, the formation of the Defence Procurement Agency (DPA) and the Defence Logistics Organisation (DLO), which involved the merger of the three single-Service support organisations manned by the Chief of Fleet Support (Naval Support Command); the Army's Quartermaster General (Quartermaster General) and the RAF's Air Member for Logistics (RAF Logistics Command), the formation of the tri-Service Defence Aviation Repair Agency (DARA) and the introduction of "Integrated Project Teams" responsible for procurement and in-service support for each platform type.

6.4 2007: formation of DE&S: the merger of the DPA and the DLO to form Defence Equipment & Support (DE&S), responsible for the whole life of military equipment (Concept, Assessment, Demonstration, Manufacture, In-service and Disposal, *i.e.* CADMID cycle).

7. The significance and effect of some of these changes are considered in more detail in **Chapter 13**.

Introduction

12.1 This **Chapter 12** provides a brief overview of the history of RAF in-service support during the period 1991 to the present day. It is not intended in any way to be comprehensive.

Pre-1991: functional lines

12.2 Prior to 1991, both procurement and in-service support of aircraft were arranged on purely 'functional' lines, *i.e.* Engineering (including airworthiness), Logistics, Finance and Commercial. Procurement was the responsibility of the tri-service MOD (Procurement Executive)(MOD(PE)). In-service support, however, was arranged along individual service lines, *i.e.* Navy, Army and RAF. Responsibility for in-service support for aircraft lay, therefore, with the RAF. Both the MOD(PE) and the RAF were organised along 'functional' lines, *i.e.* with different organisations being responsible for different aspects of in-service support. There were four strands of in-service support: (1) Engineering, (2) Logistics, (3) Finance and (4) Commercial (see Figure 12.1 below).

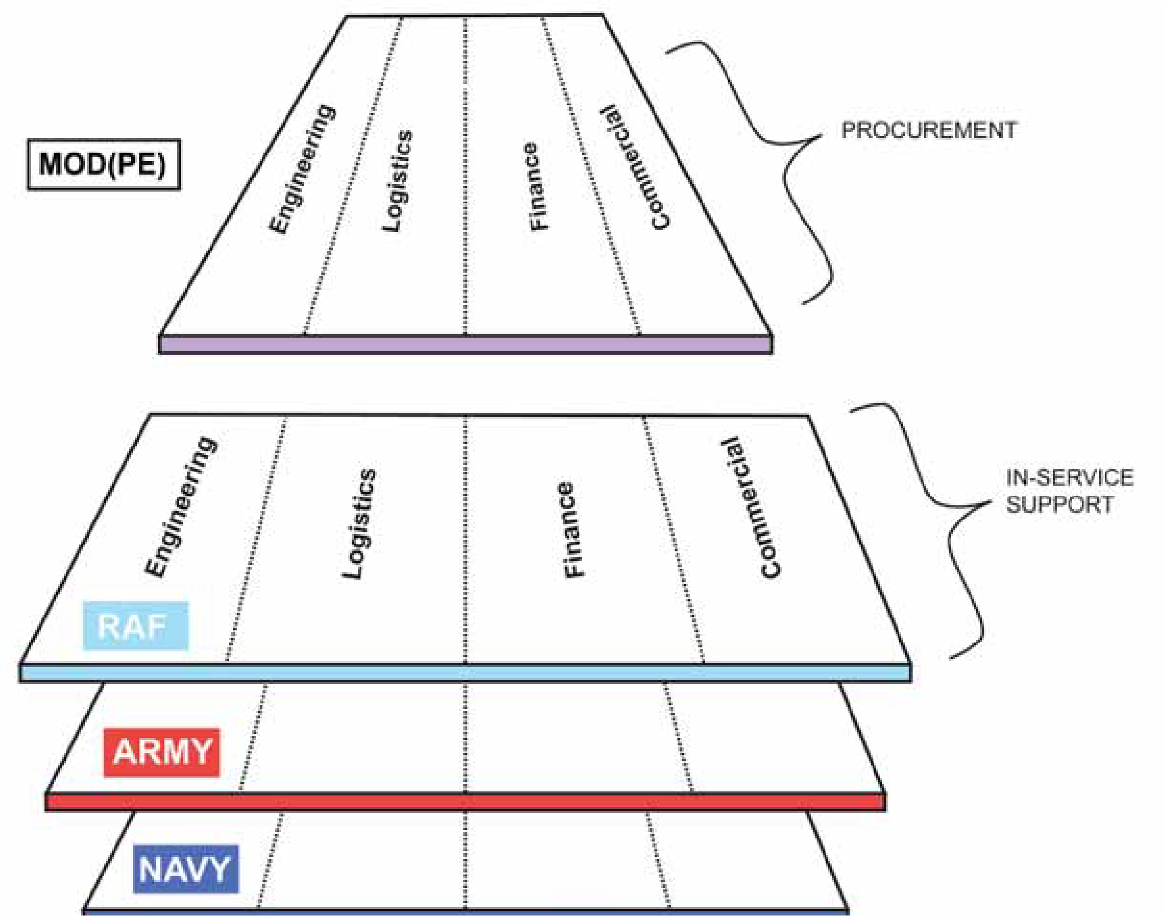

Figure 12.1 : Pre-1991 – MOD Procurement/ In-Service Support

1991-1994: early MDG era

12.3 In 1991, the RAF introduced "Multi-Disciplinary Groups" (MDG). MDGs combined in a single body two of the support disciplines required to support aircraft in-service, namely Engineering (including airworthiness) and Logistics. Each aircraft type was effectively 'project managed' by its own MDG, although Finance and Commercial support remained as 'shared' Services. The heads of MDGs were predominantly engineers. Even though the constituent parts of MDGs remained geographically spread out, MDGs yielded benefits in the form of reduced costs and better aircraft availability. The MOD(PE) retained responsibility for initial acquisition and major upgrades (see Figure 12.2 below).

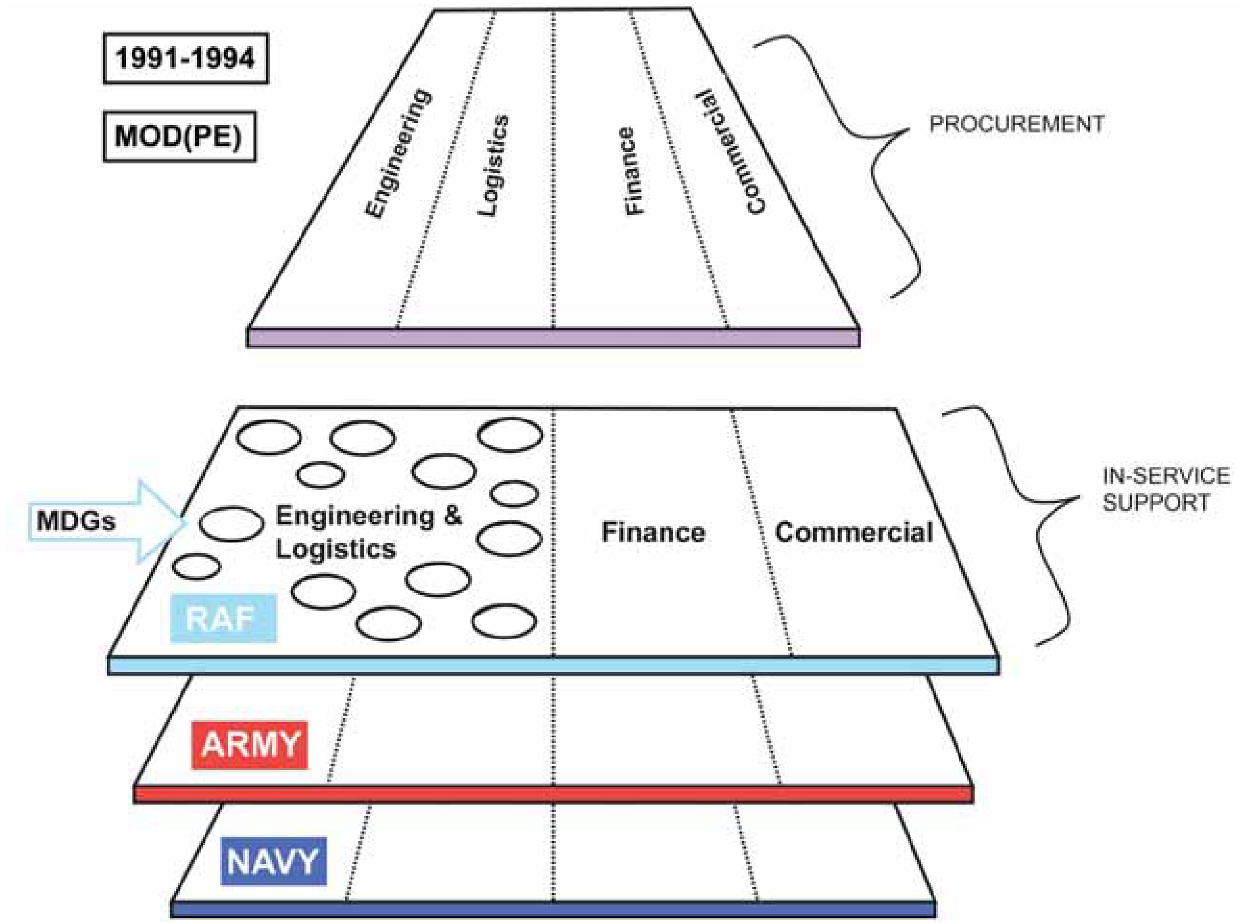

Figure 12.2: 1991-1994 – MOD (PE) and In-Service Support

Airworthiness responsibility – RAF Chief Engineer

12.4 During this period, primary airworthiness responsibility lay with the RAF's Chief Engineer (CE(RAF)), a military 3-Star officer based in London. CE(RAF) was responsible to the Chief of the Air Staff (CAS) for the formulation of engineering policy for the RAF as a whole. CE(RAF) was directly accountable to the Air Member for Supply and Organisation (Air Member (S&O)) who was a member of the Air Force Board (AFB). Responsibility for airworthiness was devolved down an 'airworthiness chain' by 'Letters of Delegation' (LOD) which were issued to Project Engineers, then called Engineering Authorities (EA), who were formally empowered to discharge defined airworthiness and safety duties. LOD were only issued to individuals who were deemed suitably qualified and experienced Engineer Officers, or Civil Service equivalents, to hold them. A similar LOD process remains in place today.

1994 – 1999: RAF Logistics Command

12.5 On 1 April 1994 RAF Logistics Command was formed. It brought together and co-located all RAF MDGs, added Finance staff to each MDG (although Commercial staff remained a centrally managed resource), and amalgamated most of the logistics functions of the former RAF Support Command, with the flying and ground training elements of that organisation's portfolio being re-brigaded elsewhere. RAF Logistics Command had its Headquarters at RAF Brampton with the support staff seven miles away at RAF Wyton. RAF Logistics Command provided in-service support and in-house deep repair and overhaul for 30 different aircraft types, 4,000 aero-engines and a large volume and range of avionics equipment for the RAF, Royal Navy and Army. Over 40% of the entire RAF annual expenditure was vested in RAF Logistics Command. (see Figure 12.3). RAF Logistics Command was disbanded on 31 October 1999 and the majority of its functions subsumed by the tri-service Defence Logistics Organisation (DLO) which came into existence on 1 April 2000.

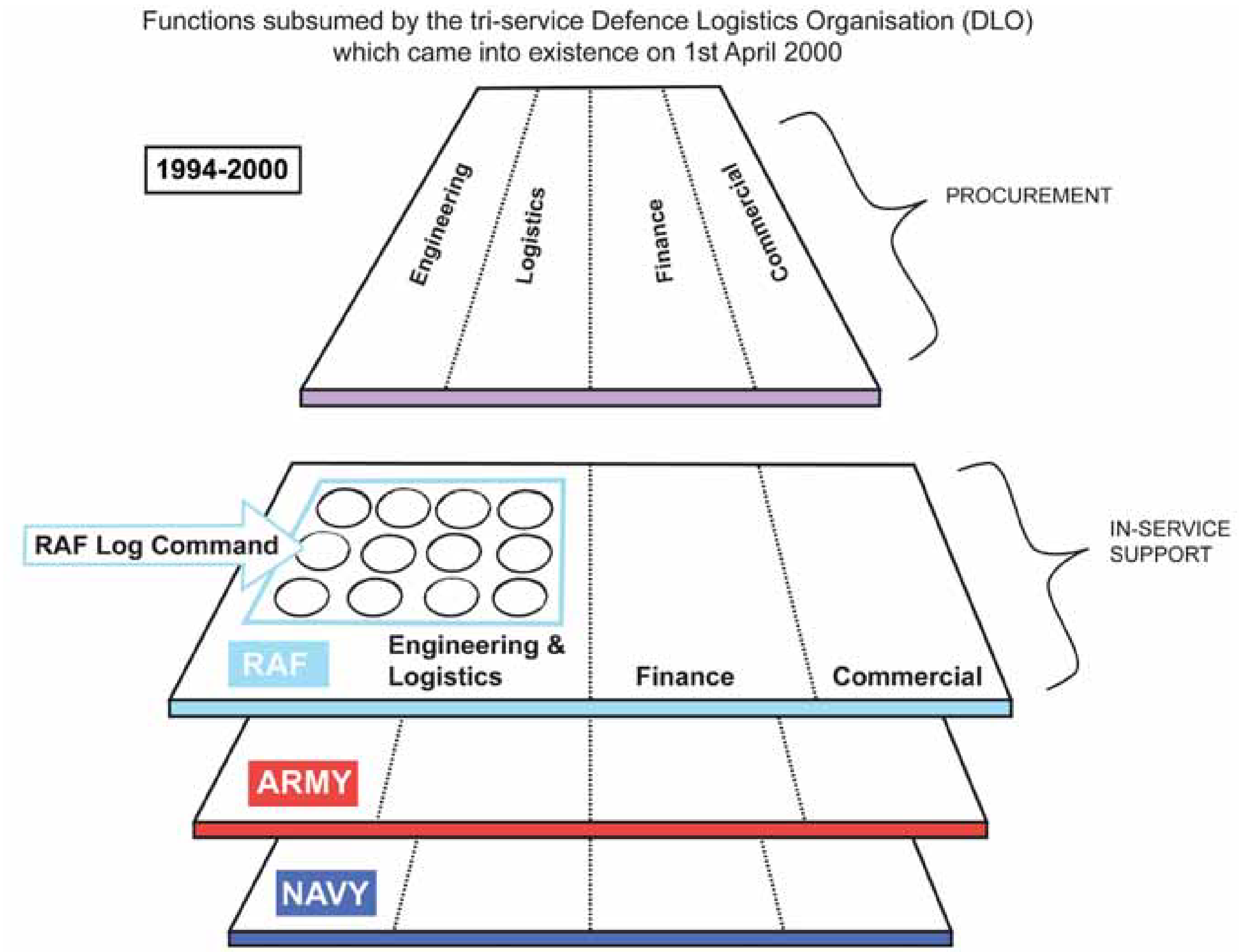

Figure 12.3: 1994-2000 – RAF Logistics Command

Airworthiness responsibility

12.6 In 1994, the CE(RAF) role was transferred to the Senior Engineer Officer at RAF Logistics Command. This was either the Commander-in-Chief (CinC) of Logistics Command (an RAF 4-Star or 3-Star officer) or, in the event of him being a non-engineering specialist, his Chief of Staff (CoS) (an RAF 2-Star office). The CinC Logistics Command was a member of the AFB and, through the CE(RAF) office, he had 'lead command' responsibility for RAF-wide airworthiness policy.

1998 – 'Downey' cycle replaced by 'CADMID' cycle

12.7 In 1998, the 'Downey' cycle was replaced by the 'CADMID' cycle. This reduced the various phases through which Defence equipment passes during its life from seven phases (Concept, Feasibility, Project Definition, Full development, Production, In-service and Disposal) to five phases (Concept, Assessment, Demonstration, Manufacture, In-service and Disposal, *i.e.* CADMID).

2000-2006: formation of DPA/DLO and IPTs

12.8 Major organisational changes to the MOD were brought about by the Strategic Defence Review (SDR) which was published in 1998. McKinsey & Co was engaged to review military acquisition, in the light of the MOD's continued *"serious failings"* in the process of developing and purchasing major military systems.[4] In its report dated February 1998 entitled *Transforming the UK's Procurement System*, McKinsey made a series of far-reaching recommendations for organisational change which were accepted. The major organisational changes launched by the 1998 SDR covered both acquisition and in-service support and included, in particular:

[4] *Transforming the UK's Procurement System*, McKinsey & Co., 20 February 1998, page 1.

- The creation of Integrated Project Teams (IPTs).
- The formation of the Defence Procurement Agency (DPA).
- The formation of the Defence Logistics Organisation (DLO).
- The formation of the Defence Aviation Repair Agency (DARA).

(see Figure 12.4 below).

12.9 The 1998 SDR changes were motivated by a belief in the increased efficiencies and savings that would come from: (i) greater 'project-orientated' organisations, *i.e.* as opposed to 'functionally-oriented' organisations; (ii) greater 'purple', *i.e.* a move from single-service to tri-service organisations; and (iii) greater 'through-life' management of platforms, *i.e.* throughout the whole CAMDID cycle. These organisational changes are discussed in more detail in **Chapter 13**, but are briefly summarised below.

IPTs

12.10 McKinsey recommended a transition *"from a functional to a project-based organisation based on Integrated Project Teams (IPTs)"*. Although this process had started with MDGs, the move towards IPTs represented a major sea-change for three reasons. First, because IPTs were to have far wider responsibilities than MDGs, encompassing complete management of the platform throughout the CADMID cycle. Second, IPTs were to contain under one roof *all* of the staffs necessary for individual projects and platforms for all four functions, *i.e.* Engineering, Logistics, Finance and Commercial. Third, IPT Leaders (IPTL) were to have delegated to them far greater levels of power and responsibility than had previously been delegated to the 'project' level. The IPT model was adopted by both the DPA for procurement (see below) and the DLO for in-service support.

DPA

12.11 The Procurement Executive (PE) was re-modelled to form the Defence Procurement Executive (DPE) as an Executive Agency of the MOD.

DLO

12.12 The three single-Service in-service support organisations (RAF Logistics Command, Naval Support Command and Quartermaster General) were merged into a tri-Service (*i.e.* purple) organisation called Defence Logistics Organisation (DLO) to achieve greater efficiencies by converging similar logistics processes, eliminating duplication and overlap, and increasing the MOD's ability to exert leverage on its suppliers. The DLO was formed in April 2000 and a new 4-star post, Chief of Defence Logistics (CDL), created to head the DLO. The IPT model was adopted in full by the DLO. Upon the disbanding of RAF Logistics Command, the equipment support IPTs were 'brigaded' into three groups broadly along environmental lines within the DLO (Sea, Land and Air) each headed by a 2-star military officer or Civil Service equivalent. For RAF aircraft, the 2-star was Director General Equipment Support (Air) (DG ES(Air)). Each service Board retained a 2-star officer from the DLO as a permanent member. In the case of the Air Force Board, this was DG ES(Air).

DARA

12.13 The three single-Service aircraft deep maintenance and repair organisations merged into the tri-Service Defence Aviation Repair Agency (DARA).

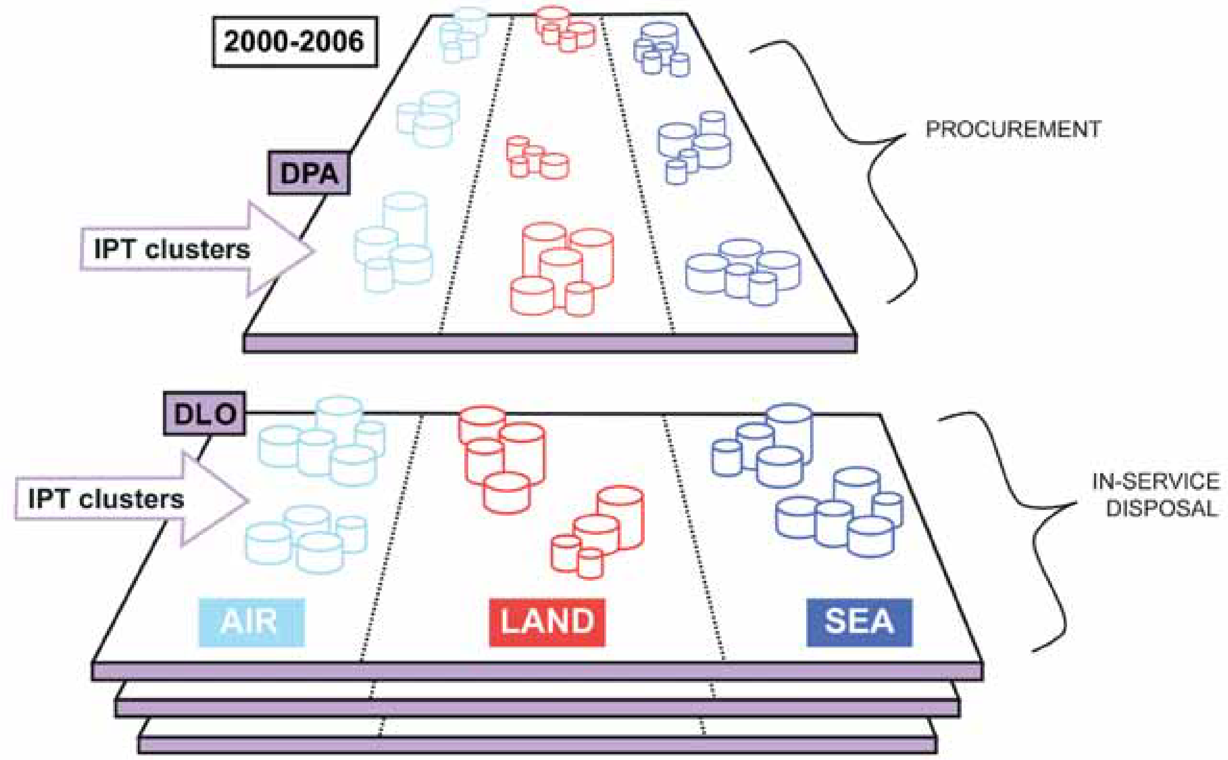

Fig. 12.4: 2000-2006 – DPA and DLO

Airworthiness

12.14 The role of Equipment Support (Air) (ES(Air)) was *"to provide safe, airworthy platforms, systems and supporting aerospace equipment to the front line aviation customers"*; and the management of safety risks to platforms was *"the responsibility of individual IPTs"*.[5] Overall responsibility for RAF airworthiness policy became vested in DG ES(Air) (a 2-star post who was a member of the AFB). The DG ES(Air) role expanded to include responsibility for co-ordinating the DLO's outputs to the RAF. The title was changed to Director General Logistics (Strike) (DG Log Strike).[6] The role and title CE(RAF) was dropped.

JSPs and JAPs – MARDS

12.15 In 1999, in recognition of the increasing number of 'Joint', *i.e.* multi-Service, units and operations, the Assistant Chief of the Air Staff (ACAS) directed the establishment of a single military aviation regulatory structure, with supporting regulations for all three Services. A major drafting exercise was undertaken to converge the single-Service aircraft regulations and maintenance policies into a series of Joint Service Publications (JSP) and Joint Air Publications (JAP) respectively. The terms of reference for the team responsible for drawing up the new regulations were to update current regulations and make them joint; *"empower"* commanders through *"few rules, firmly applied"*; take account of civil regulations and recent legislation; provide access to regulations primarily by electronic means; establish long term administration for the new structure.[7] This regulatory framework covers not only IPT activity, but also the operational maintenance activity carried out by single-service Front Line Commands (FLC). Collectively, the JSPs and supporting publications are known as the Military Aviation Regulatory Documents Set (MARDS).[8]

Late 1990s onwards – Increasing role of Industry

The traditional support model

12.16 Prior to the introduction of Partnering, the MOD purchased a variety of services from Industry to support its aircraft. These were:

[5] Report of AD Eng Pol in DLO Environment & Safety Report 2002.
[6] Although responsibility for in-service support of Helicopters was transferred to Director General Logistics (Land).
[7] MART brief to the Nimrod Review Team on Military Aviation Policies, Regulations and Directives dated 27 March 2008.
[8] The process is described in the forward to JSP550 (Military Aviation Policy, Regulations and Directives).

- *Upgrade/Update Services.* Periodically, aircraft require upgrades to introduce new capabilities, or updates to deal with the obsolescence of components and thus to maintain existing capability. The MOD normally contracted with Original Equipment Manufacturers (OEMs) for design activity to support these programmes, as well as for the manufacture of new equipment.
- *Spares.* The in-service support of an aircraft requires spare parts both for routine, scheduled maintenance and to rectify defects. Although simple parts might be sourced from approved 2nd or 3rd tier suppliers, complex items (which are generally the cost drivers) are either only produced by the OEMs or need to be qualified by them as being fit for purpose. Equally, the specialised repair of components is often beyond the capability of third parties without uneconomic investment in facilities and equipment.
- *Post-Design Services.* Post-Design Services (PDS) is a term that covers the technical support for repair schemes, the design of routine modifications and fault investigation. Although the MOD traditionally had a limited engineering design capability, and some third parties provided support in this area, the OEM is normally best placed to handle complex PDS tasks. This is by virtue of its facilities, expertise and experience in designing major air systems. As the volume of the aircraft support business has reduced, the overheads associated with maintaining multiple centres of expertise have become increasingly uneconomic.
- *Maintenance, Repair and Overhaul Services.* The MOD has always carried out a significant amount of Maintenance, Repair and Overhaul (MRO) in-house. However, some specialist tasks, such as fatigue life-extension programmes or major upgrades, require facilities and skills available to the OEMs, but which would be too costly to replicate elsewhere. Thus, Industry has always been contracted to undertake a proportion of the MOD's MRO.

'Partnering'

12.17 'Partnering' was the term coined by the MOD for its strategy of entering into long term arrangements with Industry for the support of equipment across the Sea, Land and Air domains. There were two primary *stimuli* for the Partnering initiative which began in the late 1990s. First, the cost of supporting MOD aircraft was regarded as increasingly expensive; this was partly because inflation in the aircraft support sector had for many years been running at a higher rate than the inflation escalator applied to MOD budgets. Second, with successive reductions in the size of the RAF, Army Air Corp and Fleet Air Arm, the number of orders for new air systems had been steadily falling and the UK Defence Industry and major OEMs began to look to offset the loss of new-build business by providing more in-support services to the military. The MOD believed that the UK Defence Industry should maintain a viable industrial base because otherwise its ability to support existing in-service platforms and equipment would be jeopardised.

12.18 'Partnering' was predicated on entering into long term agreements with OEMs for integrated support services encompassing most, if not all, of the traditional support sub-disciplines. The aim was to use the stability inherent in such arrangements to deliver long-term efficiencies and to incentivise Industry to reduce recurrent costs. By focusing on overall aircraft or equipment availability as the measure of Industry's success, OEMs were incentivised to deliver all aspects of a support solution to time, cost and performance. In addition, it is in Industry's interests to seek to improve reliability and availability as well as to tackle the root causes of obsolescence.

12.19 The MOD continues to hold airworthiness responsibility on behalf of the Secretary of State for Defence. Successful 'partnering' (and outsourcing generally) is crucially dependent on the MOD acting as an 'intelligent customer'. This in turn depends on (a) continued engagement of MOD personnel in the technical decision-making process and (b) maintaining the necessary in-house expertise in the relevant disciplines. I make Recommendations regarding this in **Chapter 24.**

End-to-End (E2E)

12.20 The 'End-to-End'[9] (E2E) initiative was conceived in roughly the same timeframe (the late 1990s) and for similar reasons. Again, the reduction in numbers of front line aircraft was the stimulus and it was recognised that there was excess capacity within the combined MOD/Industry facilities. The E2E programme began in parallel with Partnering and was conceived to address the inefficiencies associated with maintaining multiple centres of excellence for MRO activity, and the conflicting priorities of the various parties undertaking such work.

[9] The American idiom is 'Soup to nuts' (and Lat. '*ab ovo usque ad mala*').

Previously four levels of maintenance

12.21 Prior to the E2E rationalisation, MOD aircraft maintenance was categorised into four depths and delivered by four different types of organisation. The regime was essentially characterised as follows:

- Depth A, 1st line. Depth 'A' maintenance was the activity directly associated with the preparation for, and recovery from, aircraft sorties. It included limited rectification and preventative maintenance and was carried out by flight line personnel.
- Depth B, 2nd line. Depth 'B' maintenance was the majority of scheduled maintenance activity and rectification associated with continued airworthiness. It was carried out on each flying station, normally by uniformed personnel working exclusively for that station.
- Depth C, 3rd line. Depth 'C' maintenance was the very deep, or Major, servicing, carried out by the MOD's Maintenance Units (MU). Such activities occurred only a few times during an aircraft's life and they were often used to sweep up other, significant repair or upgrade/update programmes.
- Depth D, 4th line. Depth 'D' maintenance was activity beyond the normal capability of the MOD lines of maintenance and was carried out by Industry. It was normally associated with significant modification activity, such as mid-life updates.

12.22 Although the level of complexity and effort associated with Depths 'B'-'D' varied, much of the work, particularly disassembly and reassembly, was common. Also, unsurprisingly, many of the necessary skills and equipment were to be found in every organisation carrying out such work and the reduced overall volumes of activity associated with the post-Cold War draw-down of the Services made this uneconomic. In order to increase efficiency in the deeper lines of maintenance, relatively high numbers of aircraft were 'floor-loaded', particularly in fast-jet fleets and helicopters. Although this kept the workforce at 3rd and 4th line fully employed, it was at the expense of front line aircraft availability.

End-to-End Study in 2003

12.23 A joint MOD and McKinsey study on logistics also took place focusing on from 'foxhole to factory' including the then DPA, DLO and Front Line Commanders.[10] The *End to End Study* (E2E) reported in 2003, making 52 recommendations. Hard 'stretch' targets were introduced for cost savings. There were three objectives: (a) configuration of logistics support for the most likely operational scenarios; (b) concentrating support facilities at the logistic centre of gravity; and (c) 'streamlining' the supply chain, *i.e.* synchronising all logistics efforts with the final output and applying 'lean' techniques. E2E recommended streamlining the four depths and four lines of maintenance so that there were two levels of maintenance, 'Forward' and 'Depth'. 'Forward' support is the immediate logistics support required by the operational commander to enable him to complete the operational task. 'Forward' equates roughly to the previous 1st line and is most naturally located alongside flying activity, *i.e.* on base. 'Depth' support encompasses all static, non-deployable elements and some capabilities that may need to be deployed in support of Forward Support elements on specific operations. 'Depth' equates to the previous latter three maintenance lines, 2nd, 3rd and 4th lines, and is most commonly located on a flying station, but can be 'rolled back' to a former MU. 'Depth' maintenance began increasingly to be carried out by Industry under 'Partnered' arrangements. Most aviation 'Depth' organisations now consist of 'joint' civilian and military teams. I consider E2E in further detail in **Chapter 13**.

'Lean' and 'Leaning'

12.24 A key activity at this time, associated with, and complementary, to the implementation of the End-to-End programme, was the introduction of *'lean'* production techniques to the aircraft maintenance business. Lean is a well-accepted business improvement methodology which has been widely deployed in the manufacturing industry and which seeks to identify and remove wasteful activity, freeing up capacity and resources. The programme was initially very successful within the MOD but, unfortunately, subsequently became something of a perceived panacea for realising savings that had already been made in support budgets. The term *'leaning'* also became regarded as a euphemism for cuts and regardless of one's view of the early benefits of the programme, there is now widespread cynicism among the workforce concerning its true benefits. I consider Leaning in further detail in **Chapter 13**.

[10] See the letter of proposal dated 18 November 2002 from McKinsey on streamlining End to End Air and Land Logistics.

2007: formation of DE&S

12.25 On 1 April 2007, the DPA and DLO merged to form DE&S. Prior to this merger, IPTs within the DPA who were procuring equipment, either had to transfer their responsibility to the DLO once the equipment reached its In-Service Date (ISD), or move from one organisation to the other, *i.e.* from the DPA to the DLO. IPTs within the DLO engaged in major upgrade programmes had 'dual-accountability': they were responsible to the DLO for in-service support, but to the DPA for the upgrade element of their programmes, with split budgets to match. Under the DE&S, an IPT now remains with the same organisation throughout the life of an equipment and is responsible for every stage of the CADMID cycle.

12.26 DE&S employs approximately 25,500 people and has a budget of £13 billion. It acquires and supports through-life, equipment and services ranging from ships, aircraft, vehicles and weapons to information systems and satellite communications. It sustains current requirements for food, clothing, medical supplies and temporary accommodation. DE&S is also responsible for HM Naval Bases, the Joint Supply Chain and the British Forces Post Office (BFPO).

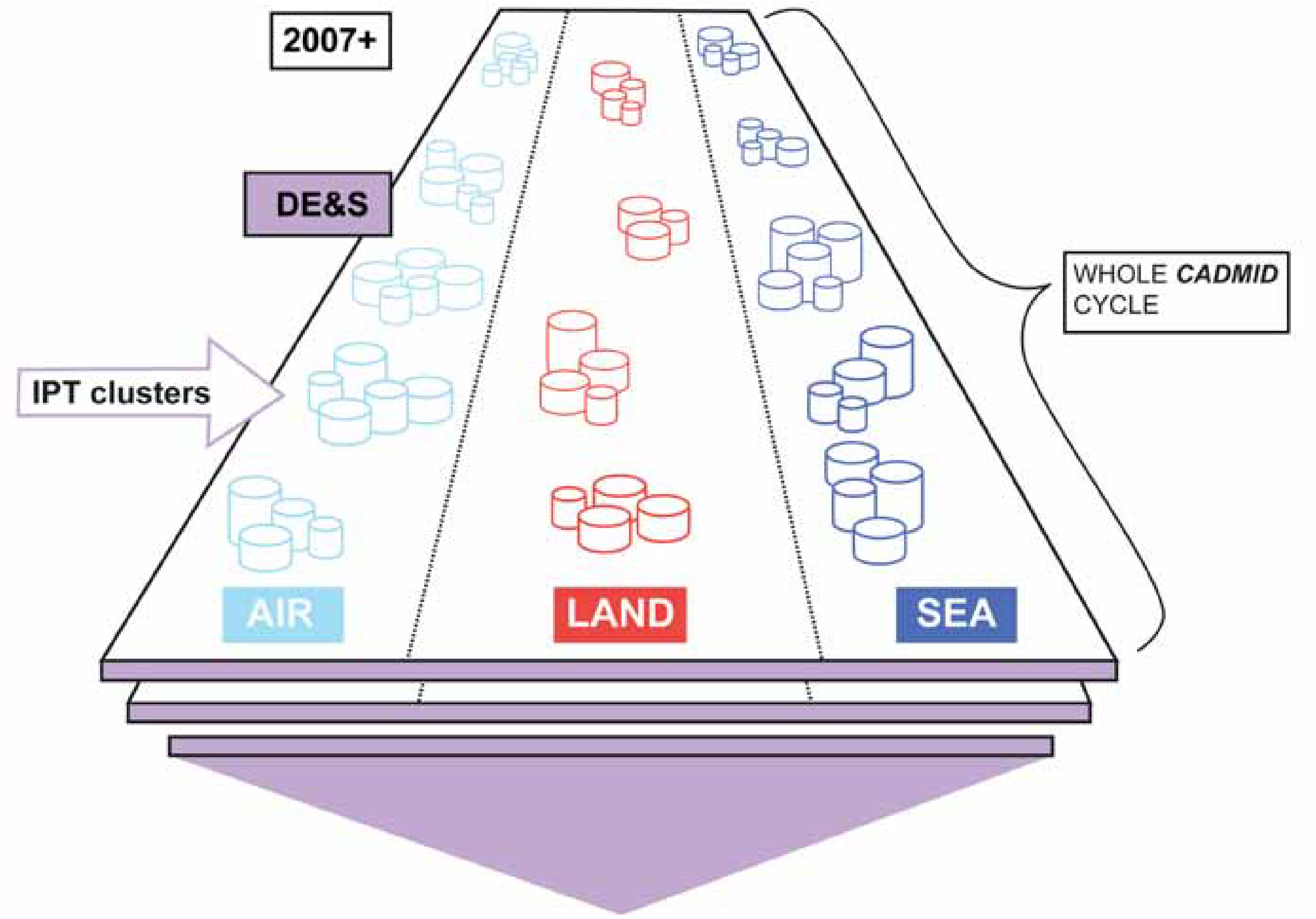

Figure 12.5: 2007+ Defence Equipment & Support

12.27 A Chief Operating Officer (COO), a 3-Star equivalent post, has overall responsibility for all IPTs. He faces Industry and is responsible to CDL. The IPTs are grouped under 2-Star Directors General (DG). There are three separate management groupings for aircraft:

- DG Combat Air has responsibility for Fast Jets, Training aircraft and Unmanned Air Vehicles (UAV).
- DG Air Support has responsibility for Transport, Tanker and ISTAR aircraft (including the Nimrod).
- DG Helicopters has responsibility for all rotary wings.

12.28 Today, there are three main organisations involved in Defence equipment:

- DE&S, which acquires and manages Defence equipment throughout its life, using Integrated Project Teams (IPT).
- Front Line Commands (FLC)[11], which operate the equipment, and maintain it in accordance with policies laid down by DE&S and the IPTs.
- Industry, which plays an ever-increasing support role in the provision of technical advice, spares, upgrades, and, increasingly, MRO services.

Airworthiness

12.29 Within the DE&S, Hd Air Systems, a 1-star aircraft engineering specialist within the "Corporate Services" organisation, provides a number of technical enabling services to aircraft IPTs, such as quality assurance support, specialist engineering advice and limited maintenance data analysis. In addition, he is dual-hatted as the technical airworthiness regulator, a role he discharges on behalf of the Chairman of the MOD Aviation and Regulatory Safety Board (MARSB)[12], separate from the DE&S organisation. As such, he is the senior technical specialist within the MOD's Airworthiness policy organisation.

Airworthiness regulatory structure 2000-2005

12.30 The authority to operate and regulate military aircraft was (and remains) vested in the Secretary of State for Defence (SoS). The SoS delegated his responsibility for regulation of the different aspects of airworthiness (design and production, through life maintenance of 'mature' systems, and flying operations) to the respective Service Chiefs of Staff (COS) (including CAS, CDP, CDL and the Chief Executive Defence Aviation Repair Agency) for the aircraft and aircraft systems for which they were responsible (JSP318B, paragraph 3.11ff). Responsibility for the in-service phase of the Nimrod was required to be exercised at 2-star level and sub-delegated to the IPTL, who was the 'airworthiness authority' for acquisition upgrades, sustainment, service designed changes, safety operation on the Military Aircraft Register and the approval of amendments thereto (JSP318B, paragraphs 3.12.21 to 312.2.5). DG ES(Air) received Letters of Delegation (LOD) from CAS (regarding aspects of safe operation) and from CDL (regarding technical airworthiness responsibility) (JSP318B para. 3.5). DG ES(Air) sub-delegated to the appropriate IPTLs (including the Nimrod IPTL). JSP318B, paragraph 3.6 summarised the IPTL's airworthiness responsibility as follows:

> *"The IPTL has specific duties and authority for recommendations regarding the airworthiness of the aircraft, systems and equipment for which he is responsible under the delegations described above. The IPTL is to ensure that the aircraft, systems and equipment meet the airworthiness standards and guidance...".*

Regulatory set

12.31 The Airworthiness system used by the MOD is governed by an extensive suite of Airworthiness regulations and standards and separate Safety Management regulations which cover: (i) the procurement and support of equipment; (ii) aircraft operation; (iii) training; and (iv) airspace management.

12.32 As indicated above, 'Airworthiness' in the MOD is governed through the Military Aviation Regulatory Documentation Set (MARDS). At the highest level, Safety & Environmental Management (including Health and Safety) is covered by **JSP815** and **JSP375** respectively. Operational Airworthiness is governed through the **JSP550** series – Military Aviation Policy, Regulations and Directives – which covers Flight Safety (**JSP551**), Air Traffic (**JSP552**), Military Airworthiness (**JSP553**), Aerodrome Criteria and Standards (**JSP554**) and Test Flying (**JSP556**), with Flying Orders for Contractors covered in the **AvP 67**.

11 Fleet, Land and Air Command.

12 Formerly the Defence Aviation Safety Board (DASB).

12.33 For the management of airworthiness in the acquisition environment, including Release to Service, in addition to **JSP553** (Military Airworthiness Regulations), there are a number of Defence Standards which are applied to the acquisition of new equipment and services covering Procurement, Design, Safety Management and Configuration Management of Military Aircraft. (e.g. **Def-Stans 05-123, 00-970, 00-56, 05-57**). Within the acquisition environment, there are also various local Business Procedures most of which are detailed within the DE&S Acquisition Management System.

12.34 General air platform regulations covering the practical maintenance of airworthiness are detailed within the **JAP 100A-01** (Military Maintenance Procedures) and **Def-Stan 05-130** (Maintenance Approved Organisation Scheme). For platform specific airworthiness management, there are various documents produced/owned by the IPTs such as Aircraft Maintenance Manuals, Illustrated Parts Catalogues and Master Maintenance Schedules which form part of the Aircraft Documentation Set. Finally, for the 'delivery' of airworthiness management on unit, there are a number of Unit Engineering Instructions & Maintenance Procedures applicable.

12.35 In summary, the main Airworthiness Regulations, Standards and Procedures comprise:

- Military Airworthiness Regulations – **JSP 553**
- Flying Orders for Contractors – **AvP 67**
- Certification of Defence Standards:
  - **Def-Stan 00-970** – Design of UK Military Aircraft
  - **Def-Stan 07-85** – Design of Weapon Systems
  - **Def-Stan 00-56** – Safety Management
- Procedures Defence Standards:
  - **Def-Stan 05-122** – Military Registration of Civil-Owned Aircraft
  - **Def-Stan 05-123** – Procurement of Aircraft, Weapon & Electronic Systems
  - **Def-Stan 05-130** – Maintenance Approved Organisation Scheme

12.36 The hierarchy of the MOD Regulatory set is illustrated in Figure 12.6 below.

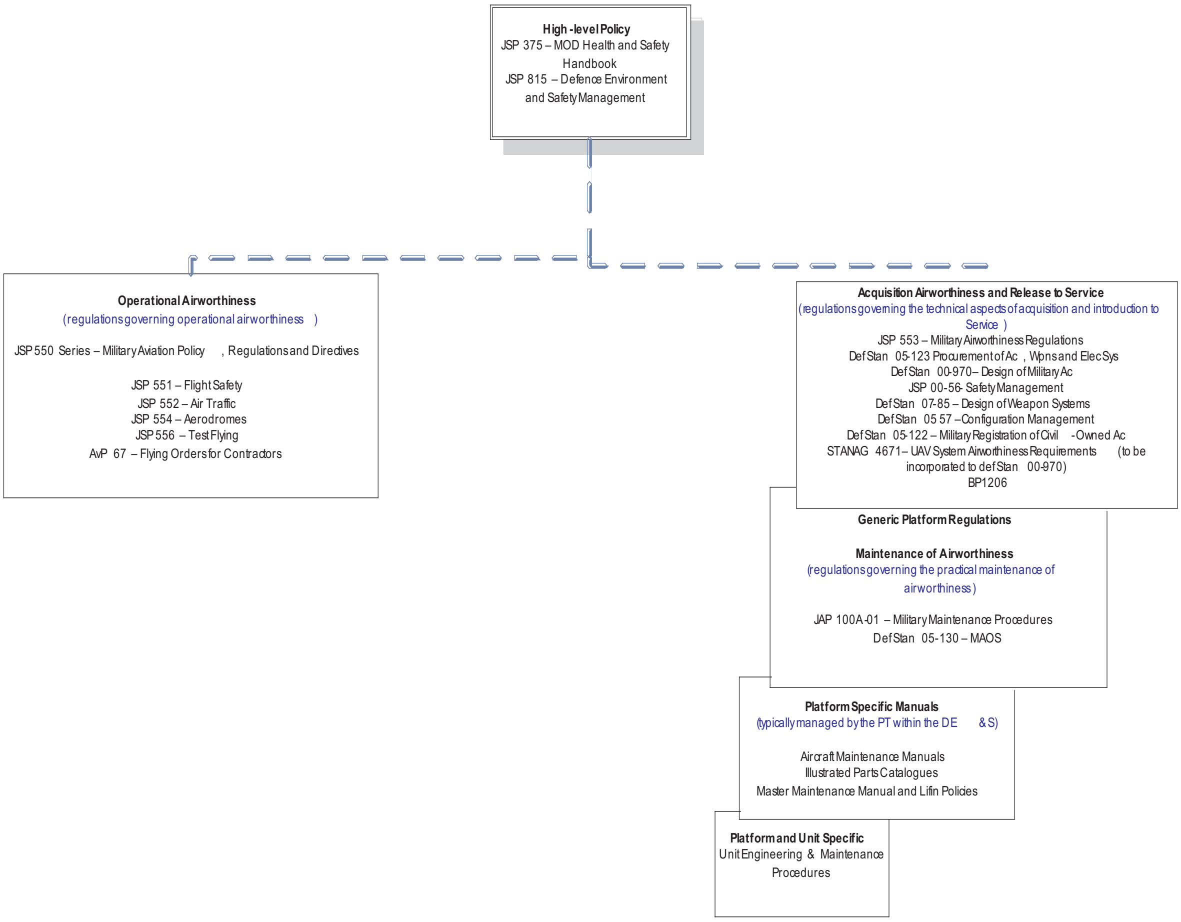

Figure 12.6: Joint Service Airworthiness Management Regulatory Documentation Set

12.37 I turn in **Chapter 13** to consider in detail the organisational changes that took place in In-Service Support during the period 1998-2006.

CHAPTER 13 – CUTS, CHANGE, DILUTION AND DISTRACTION (1998-2006)

"There was no doubt that the culture at the time had switched. In the days of Sir Colin Terry[1] you had to be on top of airworthiness. By 2004, you had to be on top of your budget, if you wanted to get ahead". (Former Senior RAF Officer, 2008)

"Your friend the British Soldier can stand up to anything except the British War Office." (George Bernard Shaw, 1856-1950, The Devil's Disciple (1901))

"We trained hard, but it seemed that every time we were beginning to form up into teams, we would be reorganized. I was to learn later in life that we tend to meet any new situation by reorganizing; and a wonderful method it can be for creating the illusion of progress while producing confusion, inefficiency, and demoralization." (Gaius Petronius Arbiter, 210 BC)[2]

Contents

Chapter 13 addresses the key organisational causes which contributed to the loss of XV230. It answers the following questions:

- What were the concerns in 1998 about maintaining the future airworthiness of the Nimrod fleet? Were they heeded?
- What organisational changes followed the 1998 Strategic Review? What was their cumulative effect?
- What were the financial pressures during this period? What effect did they have?
- What happened to the airworthiness regime in the MOD during this period?
- What effect did the organisational changes and financial pressures have on the Defence Logistics Organisation during this period?
- Did organisational failings contribute to the loss of XV230? If so, how?

Summary

1. The MOD suffered a sustained period of deep organisational trauma between 1998 and 2006 due to the imposition of unending *cuts* and *change*, which led to a *dilution* of its safety and airworthiness regime and culture and *distraction* from airworthiness as the top priority.

1998 Strategic Defence Review

2. This organisational trauma stemmed from the 1998 Strategic Defence Review which unleashed a veritable 'tsunami' of cuts and change within the MOD which was to last for years.

3. Financial pressures (in the shape of 'cuts', 'savings', 'efficiencies', 'strategic targets', 'reduction in output costs', 'leaning', *etc.*) drove a cascade of multifarious organisational changes (called variously 'change', 'initiatives', 'change initiatives', 'transformation', 're-energising', *etc.*) which led to a dilution of the airworthiness regime and culture within the MOD and distraction from safety and airworthiness issues. There was a shift in culture and priorities in the MOD towards 'business' and financial targets, at the expense of functional values such as safety and airworthiness. The Defence Logistics Organisation, in particular, came under huge pressure. Its primary focus became delivering

[1] Air Chief Marshal Sir Colin Terry, Chief Engineer RAF (1997-1999).

[2] But sometimes attributed to Charlton Ogburn, Jr. (1911-1998).

'change' and the 'change programme' and achieving the 'Strategic Goal' of a 20% reduction in output costs in five years and other financial savings.

Nimrod Airworthiness Team Report 1998

4. A Nimrod Airworthiness Review Team Report in 1998 drew attention to low manning levels, declining experience, failing moral and *"perceived overstretch generally"*, and the hazards of sustaining operations *"with far fewer personnel and a smaller proportion of serviceable [aircraft]"*. The Report warned of *"the conflict between ever-reducing resources and … increasing demands; whether they be operational, financial, legislative, or merely those symptomatic of keeping an old ac flying"*, and called for Nimrod management that was *"highly attentive"* and *"closely attuned to the incipient threat to safe standards"*, in order to safeguard the airworthiness of the fleet in the future.[3]

5. In my view, these warnings were not sufficiently heeded in the following years:

   5.1 Management was not *"highly attentive"* to safeguarding the airworthiness of the Nimrod fleet in all respects in the period 1998 to 2006, as we have seen, from the lack of leak trend monitoring (**Chapter 5**), the lack of historical duct failure analysis (**Chapter 7**) and the Nimrod Safety Case.

   5.2 Management was not *"closely attuned"* to the incipient threat to safe standards within the Nimrod fleet. On the contrary, the conflict identified *"between ever-reducing resources and … increasing demands"* became markedly worse in the period 1998 to 2006: overall resources continued to be reduced and *"operational, financial, legislative"* pressures substantially increased as a result of: (i) severe financial targets following the Strategic Defence Review and the setting of the 'Strategic Goal'; (ii) massive organisational change, particularly in the Defence Logistic Organisation; (iii) markedly increased operational demands due to Iraq and Afghanistan; and (iv) the fact that 30-year old Nimrod MR2s were required to be kept flying longer than planned due to delays in the MRA4 programme.

   5.3 Meanwhile, the overall integrity of the airworthiness regime and culture within the MOD weakened during this period as a result of organisational change and the 'strategic' emphasis given to delivering 'change' and savings targets. Safety and airworthiness slipped off the top of the agenda.

6. The Nimrod fleet of aircraft was going to require more (not less) care, resources and vigilance and a strengthening (not weakening) of the airworthiness regime and culture if these 'legacy' aircraft were going to continue to operate safely until their extended Out-of-Service date. Unfortunately, this proved not to be the case.

Three major organisational themes

7. As explained in **Chapter 12**, the Strategic Defence Review intensified three organisational themes during the period 2000-2006:

   7.1 First, a shift from organisation along purely 'functional' to project-oriented lines.

   7.2 Second, the 'rolling up' of organisations to create larger and larger structures as a result of (a) the drive to create more tri-service 'purple' organisations, and (b) a move to 'whole-life' management of equipment.

   7.3 Third, the 'outsourcing' to industry of increasingly more of the functions traditionally carried out by those in uniform.

[3] Nimrod Airworthiness Review Team Report, dated 24 July 1998, paragraphs 13 and 30.

Cuts, Change, Dilution and Distraction

'Cuts'

8. Severe financial and resource pressures were placed on the MOD in the period 1998 to 2006. These included: (i) a 3% cut in the budget over the period 2000 to 2003; (ii) a 3% annual assumed efficiency saving in the period 2000 to 2004; and (iii) in the case of the Defence Logistics Organisation, a *'Strategic Goal'* of a 20% saving in output costs in the period 2000 to 2005/06.

'Change'

9. A major programme of organisational 'change-upon-change' was initiated by the Strategic Defence Review driven, in large part, by financial imperatives. This included the following initiatives:

(1) 'Smart' Procurement;

(2) Equipment Capability Customer;

(3) Defence Procurement Agency;.

(4) Defence Logistics Organisation;

(5) Integrated Project Teams;

(6) Defence Aviation Repair Agency;

(7) Joint Service and Air Publications;

(8) 'Partnership' with Industry;

(9) 'End-to-End'; and

(10) 'Leaning'.

10. There followed further waves of change, including:

(1) 'Re-energising' the DLO Change Programme in 2002;

(2) New DLO 'Change' Programme in 2002;

(3) 20-40% Manpower reduction programme commenced in 2002;

(4) Defence Logistics Transformation Programme in 2004;

(5) 'Streamlining End to End' Review in 2004;

(6) Expansion of 'Leaning' programme in 2004 onwards;

(7) Further savings required by the Gerson Report in 2004;

(8) Phase 2 of DLO re-structuring programme in 2005;

(9) Further MOD manpower reductions required in 2006; and

(10) Planning for eventual formation of DE&S (in 2007).

'Dilution'

11. The continuous organisational change during the period 2000 to 2006 led to a marked dilution of the safety and airworthiness regime and culture in the MOD, for three reasons. First, during this period there was an inexorable shift in the MOD from a 'safety and airworthiness culture' to a 'business culture'. Second, the organisational changes in the MOD led to a safety and airworthiness regime which was organisationally complex, convoluted, confused and *"seemingly dysfunctional"*. Third, meanwhile, there was also a steady dismantling of some of the important features of the safety and airworthiness regime which had previously existed:

(1) Abolition of the "Chief Engineer RAF";

(2) Demise of full Airworthiness Audits and Support Authority Reviews;

(3) Downgrading of level at which FWAMG was chaired;

(4) Dilution of air technical support services;

(5) Dilution of aircraft engineering skills;

(6) Demise of the Inspectorate of Flight Safety;

(7) Demise of the Role Office;

(8) Removal of 2-Star tier from the Letters of Delegation chain;

(9) 'Rationalisation' of AD Eng Pol with ADRP; and

(10) Dilution of 'airworthiness' as part of Safety, Health Environment and Fire Risk Management (SHEF).

'Distraction'

12. These financial pressures and organisational changes distracted attention from vital functional values such as safety and airworthiness, as people and organisations within the MOD, in particular the Defence Logistics Organisation, became increasingly focussed on delivering the 'change' and the savings required.

Increasing operational demands

13. This was against a backdrop of dramatically increased operational demands as a result of commitment to the conflicts in Afghanistan and Iraq (Operations 'HERRICK and 'TELIC').

Causation and the Nimrod IPTL and IPT

14. These organisational pressures, weaknesses and failures were a significant causal factor in the loss of XV230. They significantly contributed to the failures of the Nimrod Integrated Project Team (IPT) to ensure the airworthiness of the Nimrod fleet.

15. As set out in **Chapters 10** and **11**, there were significant failures by certain individuals within the Nimrod IPT in relation to the Nimrod Safety Case which contributed to its poor quality and failure to capture the risks which led to the loss of XV230. The evidence suggests that the Nimrod IPT was under increasing pressure during the period 2000-2005 as a result, in particular, of: (i) the demands of delivering the cuts and savings required by the Strategic Defence Review and 'Strategic Goal'; (ii) the demands of delivering the 'Transformation' required by the Defence Logistics 'Change' programme; (iii) the demands of supporting the growing operational roles of the Nimrod MR2 and R1 in the conflicts in Afghanistan and Iraq; (iv) the demands of extending the Out-of-Service Date of the MR2 as a result of delays in the In-Service Date of the MRA4; and (v) the wide role and remit of the Nimrod IPT Leader (IPTL). The job of the Nimrod IPTL during this period was described as *"awesome"*. The Nimrod IPTL, Group Captain (now Air Commodore) George Baber, said in interview that, at times, there was a *"lack of supervision"* by his superiors and he felt *"abandoned"* when the 2-Star tier of airworthiness delegation above him was removed.

16. These organisational factors, *i.e.* the cuts, change, dilution and distraction, go some way to explaining (whilst not excusing) the personal failures of George Baber and Wing Commander Michael Eagles. They were, to a significant extent, distracted by and preoccupied with delivering the cuts and change required by the 'Strategic Goal' and Strategic Defence Review and subsequent initiatives, and consequently gave materially less priority and personal attention to the Nimrod Safety Case and airworthiness issues during this period than was appropriate. The weakening of the airworthiness culture meant that 'business' goals and achieving savings and efficiency targets

became the paramount focus of their time and attention, at the expense of safety and airworthiness matters such as the Nimrod Safety Case. The weakening of the airworthiness regime meant that there were insufficient checks and balances and less oversight of the Nimrod IPT than was required in all the circumstances during this period.

Responsibility

17. Two very senior figures bear particular responsibility for the episode of cuts, change, dilution and distraction and its consequences outlined above, and are the subject of significant criticism in their roles as Chief of Defence Logistics (CDL) during the key periods:

- General Sir Sam Cowan (CDL from 1 April 1999 to 31 August 2002)
- Air Chief Marshal Sir Malcolm Pledger (CDL from 2 September 2002 to 31 December 2004)

Conclusion

18. Airworthiness in the MOD became a casualty of the process of cuts, change, dilution and distraction commenced by the 1998 Strategic Defence Review.

Introduction

NART Concerns about Nimrod fleet in 1998

13.1 By 1998, the Nimrods were nearly 30 years old and getting closer to their Out-of-Service Dates (OSD). The planned OSD for the MR2 was 2006, by which time it was to be replaced by the MRA4. The planned OSD for the R1 was 2009.

NART Report 24 July 1998

13.2 In 1997, as part of an ongoing Airworthiness Review programme, the Assistant Chief of the Air Staff (ACAS) and Air Member for Logistics (AML) tasked the Inspectorate of Flight Safety to carry out a review of the Nimrod fleet. The review was duly conducted by the Nimrod Airworthiness Review Team (NART) which was instructed *"to conduct a wide ranging independent review of all in-service marks of the Nimrod aircraft to assess the integrity of the airworthiness management and maintenance practices in place or proposed; the currently planned out-of service date for the MR-Mk2 is 2006 and 2009 for the R-Mk 1"*.

13.3 NART delivered its report on 24 July 1998. It expressed real concerns about ensuring the future airworthiness of the Nimrod fleet:

13.3.1 Page 13 of the Executive Summary stated:

"The Review's findings endorse those of various [Flight Safety] surveys and visits to RAF Kinloss over the past 2 years and highlight <u>low manning levels, declining experience, failing moral and perceived overstretch generally</u> as the driving concerns that impact directly on the MR Mk2 force's ability to meet its operational task safely. Overall, the MPA Force is attempting to sustain historical levels of activity with far fewer personnel and a smaller proportion of serviceable ac, i.e. <u>there is a large element of continuously trying to get 'a quart out of a pint pot', with all the attendant hazards that such a scenario presents to safe ac operations</u>." (emphasis added)

13.3.2 Page 30 of the Executive Summary stated:

"The majority of the [Nimrod Airworthiness Review Team]'s other airworthiness concerns and observations… tended to be linked to one central theme, i.e., <u>the conflict between ever-reducing resources and stable, or in some cases, increasing demands; whether they be operational,</u>

financial, legislative, or merely those symptomatic of keeping an old ac flying. The pressures that ensue from reducing resources place additional burdens on a 'can do' organisation such as the Nimrod Force and call for highly attentive management, closely attuned to the incipient threat to safe standards, if airworthiness is to be safeguarded." (emphasis added)

13.4 These concerns and warnings in the NART report were dismissed at the time as 'uninformed, crew-room level, emotive comment lacking substantive evidence and focus'.[4] They should not have been dismissed so easily in 1998. They proved to be very prescient. (It should be noted that many of the same concerns were echoed to me by rank-and-file during my visits to RAF Kinloss ten years later in 2008.)

13.5 In my view, the NART concerns and warnings were not sufficiently heeded in the following years leading up to the XV230 accident, 1998 to 2006:

13.5.1 Management was not *"highly attentive"* to safeguarding the airworthiness of the Nimrod fleet in all respects in the period 1998 to 2006, as we have seen from the Nimrod Safety Case (**Chapters 10** and **11**), the lack of leak trend monitoring (**Chapter 5**) and the lack of historical duct failure analysis (**Chapter 7**).

13.5.2 Management was not *"closely attuned"* to the incipient threat to safe standards within the Nimrod fleet. On the contrary, the conflict identified *"between ever-reducing resources and ... increasing demands"* became markedly worse in the period 1998 to 2006: overall resources continued to be reduced and *"operational, financial, legislative"* pressures substantially increased as a result of: (i) severe financial targets following the Strategic Defence Review and the setting of the 'Strategic Goal'; (ii) massive organisational change particularly in the Defence Logistics Organisation; (iii) markedly increased operational demands due to Iraq and Afghanistan; and (iv) the fact that 30-year old Nimrod MR2s were required to be kept flying longer than planned due to delays in the MRA4 programme.

13.5.3 Meanwhile, the overall integrity of the airworthiness regime and culture within the MOD weakened during this period as a result of organisational change and the 'strategic' emphasis given to delivering 'change' and savings targets. Safety and airworthiness slipped off the top of the agenda.

13.6 The Nimrod fleet of aircraft was going to require more (not less) care, resources and vigilance and a strengthening (not weakening) of the airworthiness regime and culture if these 'legacy' aircraft were going to continue to operate safely until their extended Out-of-Service date.

13.7 Unfortunately, this proved not to be the case because of the 'cuts, change, dilution and distraction' that took place in the MOD between 1998 and 2006.

'CHANGE'

Organisational change and trauma (1998-2006)

"There was so much successive change-upon-change and not enough support to people like the IPTLs in understanding exactly what the environment looked like, what their responsibilities were and what help they needed to undertake those responsibilities." (RAF Officer, 2008).

The 1998 Strategic Defence Review

13.8 The starting point of any analysis of the effect of organisational change in the past decade is the Strategic Defence Review (SDR) of 1998.[5] No single event introduced as deep or broad a change in defence acquisition as the SDR. It started a process of continuous 'change' which lasted for years, and the benefits and dis-benefits of which continue to be felt today.

[4] Notes of a meeting to discuss the report dated 24 September 1998. See also the Brief for ADI dated October 1998 D/DAO/14/3/5 which refers to: *"regret that some of the content* [of the NART report] *does tend to reflect crewroom gossip/whinges rather than factual data"*.

[5] *Modern Forces for a Modern World,* Strategic Defence Review, 1998 White Paper (Cm 3999).

McKinsey Report on Procurement

13.9 As set out in **Chapter 12**, McKinsey & Co (McKinsey) was engaged by the MOD in December 1997 to review military acquisition in the light of the *"serious failings"* in the process of developing and purchasing major military systems in the United Kingdom.[6] McKinsey was asked to undertake a review of the Procurement Executive with two objectives: to diagnose the underlying weaknesses in the present Procurement process and organisation; and to develop and cost alternative 'models' which would, if fully implemented, lead to a significant improvement in performance of the overall system as measured by though life programme costs, in-service dates and performance requirements.[7] In its report dated February 1998 entitled *Transforming the UK's Procurement System*, McKinsey made seven main recommendations for the organisational change of Procurement, including a revised 'front-end' process, the establishment of Integrated Project Teams (IPTs) and powerful industry incentives. McKinsey estimated the benefits of its recommendations to amount to: (a) a reduction in procurement time of 30-45%; (b) a saving of 30% on through life costs; (c) £150-290 million in annual savings through improved purchasing of parts and services; (d) £33-51 million annual savings from specific improvements in the purchase of non-operational common-use items; and (e) £35-50 million annual savings from a 20% reduction in the operating costs of the Procurement function. It is little wonder that McKinsey's Report was greeted with enthusiasm in certain quarters, and its recommendations accepted and made a central part of the SDR programme. Some of the recommendations and tenets migrated across to Logistics and In-Service Support.

Change driven by cost considerations

13.10 The desire to achieve cost reductions across Defence was a major driver behind the 1998 SDR:

> *"We are determined to make every pound spend on defence count. We instituted a fundamental review of activities and assets as part of the Defence Review. This has proved so successful that we have been able not only to provide for the enhancements necessary to modernise the Armed Forces, but also to make a contribution towards wider Government priorities. The Defence settlement will mean a reduction, in real terms, of £500M in the first year, rising to nearly £700M in the third year, as the efficiencies begin to take greater effect."*[8]

13.11 As explained in **Chapter 12**, there was a belief that increased efficiencies and savings would come from: (i) greater 'project-orientated' organisations, *i.e.* as opposed to 'functionally-oriented' organisations; (ii) greater 'purple', *i.e.* a move from single-service to tri-service organisations; and (iii) greater 'through-life' management of platforms, *i.e.* throughout the whole CADMID cycle.[9]

Organisational trauma

13.12 There were many valuable aspects to the 1998 SDR. Reform and rationalisation of Defence Procurement, in particular, was long overdue. This Report is not intended to detract from the many achievements of the SDR and its contribution to the improvement of Defence Procurement and In-Service Support.

13.13 In this Chapter, however, I wish to concentrate on and explain how the 1998 SDR was the start of a prolonged period of deep organisational trauma in the MOD. This organisational trauma was brought about by a combination of numerous sustained financial pressures (in the shape of 'cuts', 'savings', 'efficiencies', 'strategic targets', 'reduction in output costs', 'leaning', *etc.*) which drove a cascade of multifarious organisational changes (called variously 'change', 'initiatives', 'change initiatives', 'transformation', 're-energising', *etc.*) and which led to increasing organisational confusion, complexity, distraction and dilution. The Defence Logistics Organisation (DLO) within the MOD, in particular, came under huge pressure. There was a shift in culture and priorities towards 'business' and savings and efficiency targets, at the expense of functional values such as safety and airworthiness. The primary focus of the DLO became delivering 'change' and the 'change programme'. There was a dilution of the safety and airworthiness regime and culture within the MOD.

[6] *Transforming the UK's Procurement System*, McKinsey & Co., 20 February 1998, page 1.

[7] *Transforming the UK's Procurement System*, McKinsey & Co., 20 February 1998, paragraph 2.2.

[8] *Making Every Penny Count*, Appendix of supporting essays to SDR White Paper 1998.

[9] (Concept, Assessment, Demonstration, Manufacture, In-service and Disposal, *i.e.* CADMID cycle)

13.14 In my view, airworthiness was an unintended, but undoubted, casualty of the seemingly unending process of 'cuts and change' launched by the 1998 SDR.

Summary of organisational changes

13.15 I now turn to summarise the main organisational changes resulting from the 1998 SDR and their consequences so far as is relevant to this Report. The 1998 SDR covered both Acquisition and In-Service Support. The organisational changes introduced by, or consequent upon, the 1998 SDR were numerous and wide-ranging and included 10 major changes:[10]

(1) *Smart Procurement Initiative*: The launch of the *Smart Procurement Initiative*, a change programme based on McKinsey's recommendations aimed at transforming Procurement processes and organisation structures to make the procurement of defence equipment 'faster, cheaper and better'. The *Smart Procurement Initiative* was renamed *Smart Acquisition* in October 2000 to stress the point that the MOD was concerned not only with buying equipment, but with acquiring the means to support it throughout its in-service life. This programme had an associated target of reducing acquisition costs by £2 billion over the period 1998 to 2008.

(2) *Equipment Capability Customer*:_The creation of an *Equipment Capability Customer* (EC) organisation responsible for determining future equipment capability requirements and priorities for procurement.

(3) *Defence Procurement Agency*: The remodelling of the Procurement Executive as the *Defence Procurement Agency* (DPA), an Executive Agency of the MOD.

(4) *Defence Logistics Organisation*: The amalgamation of the three single Service Logistics Commands to form the *Defence Logistics Organisation* (DLO).

(5) *Integrated Project Teams*: The creation of *Integrated Project Teams* (IPT) which would have responsibility for project management of military platforms throughout the CADMID cycle. This involved a shift from an organisation based on 'functional' lines to one organised along 'project-oriented' lines. The IPT model was adopted across the DPA and DLO.

(6) *Defence Aircraft Repair Agency* : The merger of the three single-Service aircraft deep maintenance and repair organisations into the tri-Service *Defence Aviation Repair Agency* (DARA).

(7) *Joint Publications*: The convergence of the single-Service aircraft maintenance policies into a series of *Joint Service Publications* (JSPs) and *Joint Air Publications* (JAPs).

(8) *Partnership with Industry*: The increasing role of Industry in all of aspects of delivery of 'platform capability' and in-service maintenance and support, and the development of *'Partnership with Industry'* in a range of new areas.

(9) *End-to-End*: The re-organising of all maintenance activities into 'Forward' and 'Depth' and the greater involvement of industry, known as the *End-to-End* (E2E) initiative.

(10) *Leaning*: The introduction of efficiency business techniques and practices called *'Lean'* and '*Leaning'* developed by Japanese car manufacturers into all aspects of in-service logistics support.

13.16 I have touched on some of these principal organisational changes in **Chapter 12**. There are also many published documents regarding them. I therefore confine myself to expanding on certain particularly relevant aspects below.

Formation of DLO in 2000 and the 'Strategic Goal'

13.17 For present purposes, the principal organisational development was the formation of the DLO from the merged logistics organisations of the three Services. The new unified structure of the DLO 'stood up' on 1 April 2000. A new 4-Star level post of Chief of Defence Logistics (CDL) was created to lead the DLO. The CDL set the DLO a target of a 20% reduction in total output costs by the Financial Year 2005/2006 (£1.863 billion). This was referred to as the *"Strategic Goal".* I examine this in further detail below (under *Financial Pressures*).

13.18 The SDR rationale for the formation of the DLO was as follows:

[10] See generally the *Defence Logistics Transformation Programme Handbook*, April 2001.

"The Strategic Defence Review (Cm 3999) recognised that the three single Service logistics organisations that existed at the time provided the necessary close relationship between the logistics area and the Front Line forces it supported, but that it was less well suited to maximising the scope for rationalisation and convergence on a functional, defence wide basis. It also took into account that operations were increasingly conducted on a joint basis with units of two or three Services working closely alongside each other, and the need to realise the benefits of the smart procurement initiative. As a result, it was decided to bring together the single-Service organisations into a unified Defence Logistics Organisation (DLO) to provide logistic support to all three Services. The organisation would be commanded by the Chief of Defence Logistics (CDL) charged with re-configuring them, after an appropriate transition period, into one integrated organisation whilst retaining the necessary close relationship with Front Line forces."[11]

13.19 Some steps were taken to manage the risks inherent in the creation of the DLO. In particular, the Principal Administrative Officers (PAO) remained in place during the foundation year (April 1999 to April 2000), each Service retained a 2-Star officer as a permanent member of the DLO (in the case of the RAF it was DG ES(Air)) and governance arrangements were put in place from a newly formed DLO Headquarters in Bath.

Shift from 'functional' to 'project-oriented' organisation

13.20 The major management change at this time was the shift from an organisation based on 'functional' lines to one organised along 'project-oriented' lines, as recommended by McKinsey. This shift had the potential, however, to undermine key functional principles such as safety and airworthiness, unless carefully managed. This was for two reasons in particular. First, management organised on project lines would necessarily be focused upon, and driven by, the immediate needs of the project itself, *i.e.* the imperatives of delivery, time and cost, and ensuring a successful output, *i.e.* completion of the project on time and on budget. Second, the task of maintaining standards and principles and injecting 'orthogonal' (functional) values of Good Governance, Best Practice, Safety and Quality Assurance is more difficult when dealing with a series of semi-autonomous self-standing project-driven bodies.

13.21 When changing from a 'functional' to a 'project-based' organisation, it is vital to set up rigorous structures, procedures, audits and reviews which will inculcate and regularly monitor the maintenance of standards, principles and orthogonal values in the project-based bodies. The safety regime and culture needs strengthening to deal with the new structure, not weakening. Greater checks and balances are required in the system not less. It is not clear that sufficient thought was given to these issues at the time of the formation of the DLO.

13.22 The theory is as shown in Figure 13.1 below.

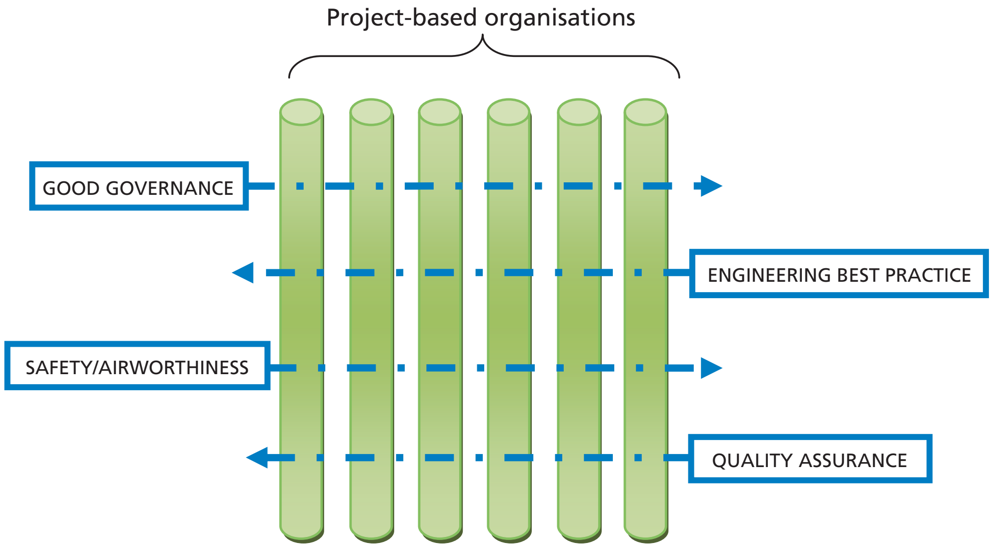

Figure 13.1: Orthogonal values in theory

[11] *A Stocktake of Defence Logistics Transformation*, November 2004.

13.23 The reality can look like Figure 13.2 (below).

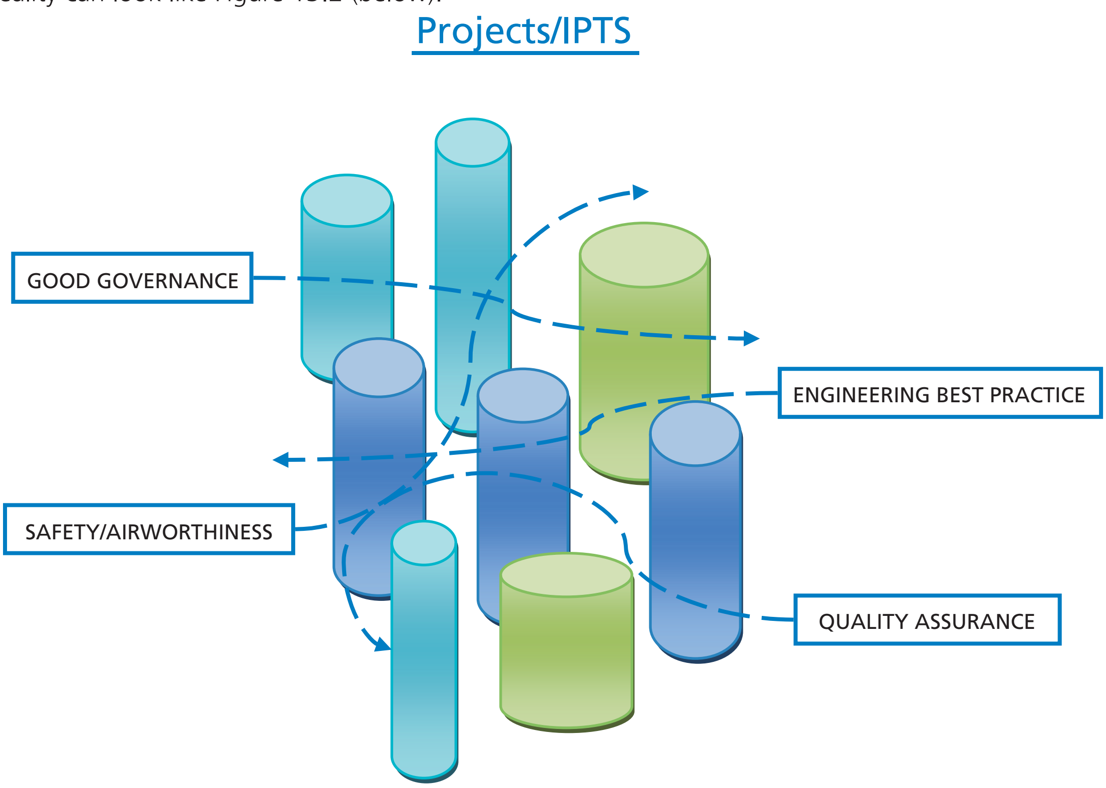

Figure 13.2: Orthogonal values in practice

De-layering

13.24 The process of devolution or 'federation' of responsibility to IPTs and IPTLs also involved 'de-layering', *i.e.* the removal of intermediate layers of management and oversight which had hitherto been provided by, *e.g.*, DG Technical Services, which had provided assurance and auditing functions, checks and balances. This was to 'empower' IPTLs and make IPTs fully 'self-standing'. Some 100 IPTs were created which, therefore, had great freedom and independence to manage their platforms 'end-to-end', *i.e.* throughout the CADMID[12] cycle, as they saw fit. But, IPTs were, to some extent, cast adrift by this process. The IPT model was heavily dependent on the right calibre of people, capable of managing complex organisations and operating with sufficient time, resources, guidance and oversight. As the Nimrod IPT proved, however, it was not always easy to manage priorities correctly or balance functional values with project outputs. *"Project Engineers were lonely"*, as one senior official put it to me.

Change was difficult

13.25 In my view, changing Defence Procurement and Logistics in the way envisaged by the SDR was always going to be very difficult. There were a number of obvious reasons why. First, there are obvious and significant differences between procuring for Industry and procuring for Defence. The former involves commercial firms driven by profits and bonus schemes, with everyone normally coming from homogenous organisations with similar aims and measures of success. The latter involves a variety of competing Service Personnel, Civil Servants, and Industry, often with widely differing agendas, budgets, and motivation (public service or profit). The former often involves incremental procurement. The latter involves long-term decisions and risks concerning cutting-edge technology years hence. Second, the turnover of civil servants and military personnel in post is often rapid, since the most able are moved around to broaden their experience leading to a loss of continuity. Indeed, promotion in the military depends upon achieving a rapid succession and breadth of two-year postings (McKinsey recommended that Directors and IPTLs should remain five years in post but this did not always happen). Third, brokering smooth 'civil partnerships' between the two different cultures of military and industry is often easier in the saying than the doing. Fourth, the military are rightly, and naturally, trained, focused and busy dealing with the day job, being part of a fighting force and meeting the day-to-day challenges of military exigencies and demands.

[12] Concept, Assessment, Demonstration, Management, In-Service and Disposal.

13.26 The extent to which all these considerations may not have been fully understood in some quarters from the outset is not clear.

SDR said 'One major or two minor conflicts'

13.27 The SDR was also predicated on the assumption that UK Defence forces should be able to: (1) respond to one major international crisis which might require a military effort and combat operations of a similar scale and duration to the Gulf War; or (2) undertake a more extended overseas deployment on a lesser scale (as in Bosnia), while retaining the ability to mount a second substantial deployment, which might involve a combat brigade and appropriate naval and air forces, if this were made necessary by a second crisis. The SDR stated, however, that "*We would not, however, expect both deployments to involve warfighting or to maintain them simultaneously for longer than six months*".[13] This proved to be a false assumption. UK Armed Forces were subsequently required to play a major role in two major conflicts: Iraq and Afghanistan. The DPA and DLO had to procure and support Service personnel, platforms, materiel and Urgent Operational Requirements (UORs) for two major conflicts. As we shall see, this came at the same time as coping with major change and re-structuring and delivering major financial savings.

Subsequent change to DLO 'Change' programme

13.28 I turn first to set out some of the further organisational changes which took place following the initial launch and 'stalling' of the DLO 'Change Programme'.

'Re-energising' the DLO Change Programme in 2002

13.29 By May 2002, the DLO 'Change Programme' was in trouble. This was due to a variety of implementation and other problems including 'IT' problems. McKinsey was again brought in to advise and asked to identify the causes of the problems and review and adjust the 'Change' programme. McKinsey was specifically tasked by the MOD to *"carry out a review of the DLO change programme to revitalise current improvement efforts and identify further scope for improvement, leading to a robust implementation plan for delivery of the full 20 percent output cost savings within the original timeframe."*

13.30 On 6 September 2002, McKinsey published its paper, *Re-energising the DLO Change Programme.* McKinsey said that the DLO's 'Business Change' programme had *"stalled"* due to questions about affordability, delivery, prioritisation and focus on 'core business drivers'. McKinsey said that the Strategic Goal set by CDL was *"a major challenge"* since it was equivalent to fully 5% of the MOD's then cash budget but said that the *"current shortfall"* had to be addressed and made recommendations for a more *"radical programme"* of change. McKinsey pointed out that every day that it took to implement the 'change' equated to £1.7 million lost. The overall 'Strategic' Objective of 20% savings in output costs by 2005-06 remained; but because, by 2002, the DLO had fallen behind where it should have been, savings greater than pro-rata 20% were required in the remaining years 2002-2005 to achieve the target.

13.31 It should be noted that the DPA was not immune. When giving evidence to the House of Commons Defence Committee (HCDC) in February 2003, the then Chief of Defence Procurement (CDP) stated that the DPA had adopted only one of the principles of *Smart Procurement.*

New DLO 'Change' Programme – September 2002

13.32 On 26 September 2002, the *DLO Change Programme* was launched which was said to replace *"the previous incoherent"* Business Change Programme. The DLO change programme comprised three elements: (a) existing initiatives; (b) McKinsey 'workstreams'; and (c) transformational activity from the Strategic plan. There were nine McKinsey 'workstreams': Strategy; Programme Management; Engineering & Asset management; Materiel Flow; Procurement; Finance & Performance Management; Information & Knowledge Management; and Organisation & Management. The aim was to move from *"a predominantly Provider role to one of an intelligent Decider".*

[13] *Modern Forces for a Modern World,* Strategic Defence Review, 1998 White Paper (Cm 3999), page 32.

McKinsey recommendation of 20-40% reduction in manpower

13.33 As part of the solution to 're-energising' the DLO change programme, McKinsey recommended that a major 'personnel reduction' exercise be commenced within the DLO which would achieve manpower reductions of 20-40 % from the levels of 1 April 2002. McKinsey observed that successfully 're-energising' the DLO change programme would represent *"a massive multi year challenge"* and changing the DLO's 'core' processes would be *"extremely difficult in its own right"*, as well as changing DLO working practices. The McKinsey manpower reduction recommendation was accepted and implemented, leading to further change and re-organisation within the DLO in the ensuing years.

Defence Logistics Transformation Programme in 2004

13.34 On 1 April 2004, the logistics elements of the DLO Change Programme and the E2E Review were brought together under the *Defence Logistics Transformation Programme* (DLTP) to form a single programme of logistics change initiatives across Defence. To achieve the three key DLTP 'deliverables' of 'effectiveness, efficiency and flexibility' seven 'key principles' were adopted: *"configure for the most likely operational scenario (medium scale); concentrate resource and material; rely on an effective supply chain; apply lean principles and techniques; minimize the deployed footprint; apply the forward depth concept; optimize MOD/industry contractual relationships"*. A number of new bodies were set up including the Defence Logistics Board (DLB), the Defence Logistics Transformation Board (DLTB) and the Logistics Programme Board (LPB).

'Streamlining End to End' Review 2004

13.35 The *End-to-End* programme was said to be on target to achieve the full target saving of £342 million in the next three to five years, but success depended particularly on ensuring *"supply, cost consciousness of the Front Line Commanders"*. A joint MOD/McKinsey Report said: *"There is a real danger of underestimating the sheer scale and intensity of the effort required for delivery over the next 5 years."*[14] The *End-to-End Review* made 51 recommendations. The principles and techniques of the 'Leaning' process were to be applied to the E2E supply chain.

'Leaning'

13.36 The *'Leaning'* programme gathered pace in 2003 and was rolled out across the board together with the E2E initiative over the next two years. Few areas were immune. 'Leaning' was applied to RAF Kinloss by both the Nimrod IPT and Strike Command. The scope for 'leaning' at RAF Kinloss was not obvious since, unlike *e.g.* the Tornado fleet which was spread out over several bases, the Nimrod fleet: (a) already had all its maintenance, Forward and Depth, on one base (RAF Kinloss); and (b) Flight Refuelling Services (FRS) were already contracted to carry out a high proportion of RAF Kinloss Nimrod maintenance.

13.37 Despite its valuable aspects in terms of eliminating waste and increasing efficiency, *'leaning'* became increasingly synonymous in many people's minds with 'cuts' and regarded as just another 'euphemism' for the inexorable rounds of reductions in manpower and resources. There was some justification for this view. *'Leaning'* proved something of a Trojan Horse for many.

Further savings required by Gershon Report in 2004

13.38 In 2004, a Spending Review (called SR04) took place in the course of which further savings were required by the *Gershon Report*. An 'efficiency' target of £2.82 billion by 2007/2008 was accepted. The report explained accounting changes from Long Term Costing and Cash accounting to Resource Accounting and Budgeting (RAB).[15]

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[14] *Streamlining End to End Air and Land Logistics, End of Wave 1 Report: From Demonstration to Delivery,* 8 April 2004.

[15] RAB included the full cost associated with the activity, platform or spares, including depreciation and interest on capital employed.

Phase 2 of DLO re-structuring programme: 2005

13.39 The MOD Annual Report and Accounts 2004-05 stated:

> *"The DLO completed Phase 1 of its Restructuring programme in 2004-05. This established the DLO's new corporate structure, realising around 700 post savings and reducing the cost of corporate support substantially. It has transformed the delivery of corporate support by dismantling the previous structure of 5 individual High Level Budget areas, including the headquarters, and establishing a single corporate approach. At the same time the Integrated Project Teams and other units delivering output to the DLO's customers were organised into clusters to provide effective and coherent management of a technology supplier or customer base. A radically different organisational structure has now been created based upon three Layers – a Delivery Layer, supported by an Enabling Layer of corporate support services and directed by a very small Strategic Layer. A new performance management regime has been created to drive performance across the organisation. For the first time the performance of the Enabling Services will be measured against standards set out in internal business agreements. These changes provide the basis for Phase 2 of the Restructuring programme, aimed at delivering significant effectiveness and efficiency benefits over the next two years."*

Further MOD manpower reductions required: 2006

13.40 In June 2006, *Enabling Acquisition Change*[16] contained a DLO plan to reduce MOD manpower numbers from 27,000 in October 2004 to 21,600 by March 2008. The Report observed:

> *"The Department has a record of being sound on analysis but less strong on implementation. The changes we have recommended should be incorporated into a single coherent DIS acquisition reform programme led at Departmental Level and managed in accordance with Office of Government Commerce best practice including a risk mitigation strategy. This programme should form part of the Defence Change Programme, but the governance arrangements will need to engage both the Acquisition Policy Board and the Defence Management Board. At the same time a major effort will be needed, involving Ministers and all members of the Defence Management Board to present the changes in a way that will bring them to life, and encourage the changes in behaviour and culture needed."*[17]

Formation of DE&S in 2007

13.41 As explained in **Chapter 12**, there was no further bedding down time because plans were developed in 2006 which led to the eventual merger on 1 April 2007 of the DPA and DLO to form the Defence Equipment & Support (DE&S).

Conclusion on Change

13.42 The scale, pace and variety of 'change' which the MOD in general, and the DLO in particular, underwent during the period 1998 to 2006 has been without precedent in recent times. Indeed, there existed a state of almost continual revolution, such that the MOD has almost became addicted to 'change' and a 'change culture'. 'Change' has been seen as a good thing *per se*. In some quarters, this attitude is still prevalent today.

13.43 It is reassuring to see an article by an RAF officer in *De*sider (the DE&S' own magazine) in February 2008 on the RAF *diaspora* in Main Building referring to the subject of the Air Force Board's (AFB) approach to leadership and, specifically, what is required from squadron and station commanders: "[The AFB] *want people in command who are confident enough not to succumb to changing things for the sake of change"*.

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[16] MOD Report, *Enabling Aquisition Change,* June 2006.

[17] Ibid, page 43.

13.44 'Change' in any organisation is a necessary and good thing. Change is required to improve quality and productivity, to address changed circumstances, and to meet future challenges. Change for change's sake, however, should be avoided. Further, great care must be taken to ensure that change is not at the expense of core functional values. Change can be seriously inimical to safety and airworthiness unless properly planned, resourced and managed. It can lead to the organisational dilution of safety structures. It can lead to a diversion of resources from safety matters. It can distract attention from safety issues. It can lead to a shift in priorities. It can change the culture. In this case, it did.

'CUTS'

Financial pressures on DLO (2000-2006)

> *"More for less is a perfectly tolerable position provided it is linked to genuine, achievable efficiencies. But the feeling we have is that the organisation is expecting more and more, in a way that takes little or no account of the level of resources, which are being cut as a matter of policy."* (Minute by Air Vice-Marshal, 1998-2000).

Cuts drove Change

13.45 It is clear that the SDR 'Change Programme', the formation of the DLO, and many of the subsequent initiatives outlined above were driven in large measure by a desire to achieve reductions in Defence costs.

General Sir Sam Cowan (CDL April 1999-August 2002)

13.46 General Sir Sam Cowan was chosen to be Chief of Defence Logistics (CDL) and charged with implementing the decision of the then Secretary of State for Defence to create the DLO. Sir Sam Cowan was promoted to 4-Star in September 1998 and held the post of CDL from 1 April 1999 until 31 August 2002. He was *"overseeing one of the biggest corporate change programmes under way in Britain"*.[18] As set out above, the concept of the DLO was the merger of the three single-service logistic support organisations into one tri-Service (*i.e.* purple) organisation. In the 1998 SDR White Paper, the Secretary of State stated that the CDL would be *"responsible for delivering best business practice throughout our support services"*.[19]

13.47 Sir Sam Cowan told the Review that the setting up of the DLO was *"strongly opposed by the Service Chiefs of Staff"*, but the Secretary of State insisted that it was both necessary and appropriate. He said he continued to encounter some opposition to the change throughout the implementation period and beyond. He said *"I was not helped by the fact that the Secretary of State, who made the decision, moved on at an early stage"*.[20]

Inherited financial risk – 'bow wave'

13.48 The MOD budget was already under great pressure at the time of the 1998 SDR because of financial problems inherited from the previous single-Service PAO budgets. By the late 1990s, a considerable amount of inherited financial risk had built up, *i.e.* commitments for which no ostensible financial provision existed or gaps between the cost of delivering programmes and the funding allocated. This was in the shape of a large 'bow wave' of deferred acquisition and other expenditure which had built up in the 1990s. This stemmed mainly from year-on-year 'Peace Dividend' financial cuts following the end of the Cold War. There were two 'Peace Dividend' reviews: *Options for Change* in 1990 (which led to major cuts in Defence manpower and resources); and *Defence Cost Study "Front Line First"* in 1990 (which led to 'purple'[21] and further reductions in manpower). There was, however, a reluctance to take hard decisions to cut future military equipment programmes to balance the budget, and the financial cuts were temporarily absorbed by the practice of

[18] *Financial Times* of Monday 3 April 2000.
[19] 1998 White Paper *Modern Forces for a Modern World*, paragraph 16.
[20] General Cowan's Written Statement to the Review dated 22 May 2000.
[21] Also called 'jointery', *i.e.* the merging of single Service organisations into tri-Service 'purple' organisations.

deferred expenditure or savings 'wedges'. There was a 'conspiracy of optimism' in 1990s. This had the knock-on effect of a growing gap between the PAO budgets and the actual cost of delivering logistics support two or three years down the line. A cash-based accounting system made the under-estimation of future resource costs possible. This was going to be less easy with RAB.

13.49 Sir Sam Cowan summarised his time as CDL:

> *"[M]y time as CDL was marked by a constant struggle with the central MOD financial authorities to get a greater allocation of cash to maintain logistics outputs, while we introduced the change in business practice mandated in the SDR to reduce the cost of delivering the outputs demanded."*

1 April 1999 brochure

13.50 On 1 April 1999, Sir Sam Cowan sent a brochure to every person in the DLO in which he spelt out how he saw the future financial position:

> *"We must acknowledge that in a world of shrinking Defence budgets, we will have to meet increased diverse operational commitments with the same or less money. The reality is that we simply cannot afford to maintain the front line agreed in the SDR unless the Defence Logistics Organisation finds better, cheaper ways to provide the support necessary within the money available."*

The brochure also said: *"There will be no sudden uprooting of large numbers of people. Change will come, but it will come at a suitable pace and where it is needed."* He told the Review that he stuck by that principle throughout his time as CDL.

'Strategic Goal' of 20% reduction in output costs by 2005

13.51 On 1 April 2000, a six-page Corporate Plan was distributed to each of the 43,000 people working in the DLO which announced the (so-called) 'Strategic Goal' of a 20% reduction in output costs by 2005:

> *"We are committing ourselves to a bold target. We will reduce our output costs by 20% by 2005 whilst ensuring that we continue to deliver and, indeed where appropriate, improve the quality of our outputs."*

13.52 Sir Sam Cowan's Corporate Plan was expressed in trenchant terms:

13.52.1 A 'transformation' was required: *"Quite simply, we have to achieve a transformation in how we deliver effective logistics support to the front line at a sustainable cost. This means that we must reduce the cost of our outputs, not by crude cuts but by changing the way we work".*

13.52.2 There was to be an urgent 'step change': *"We are committing to this strategic goal for a clear and vital purpose... the future effectiveness of the UK's Armed Forces. The consequence of us failing to deliver will be inadequate funding for investment to modernise our Armed Forces. To make these savings we need a step change in our performance which we must pursue with a sense of urgency".*

13.52.3 There was an exhortation on all to strive to achieve the goal: *"We must all be obsessive about performance. Where it is good we must strive to do even better and where it is barely adequate we must commit to radical new ways of working".*

Treasury synopsis 2000

13.53 A Treasury synopsis dated 3 April 2000[22] re-enforced the commitment to the 20% 'Strategic Goal':

[22] Public Services Productivity Panel Report, Targeting improved performance: *Performance Management in the Defence Logistics Organisation:* http://hm-treasury.gov.uk/pspp_press03.htm

13.53.1 The Minister for the Armed Forces was quoted as follows: *"The creation of the Defence Logistics Organisation was an essential element in delivering the Front Line improvements heralded in the Strategic Defence Review. It is committed to achieving major reductions in output costs within 5 years and improving the availability of equipment, and views a robust performance management regime as an essential tool in achieving this aspiration."* (emphasis added)

13.53.2 McKinsey was quoted as follows:[23] *"The newly-formed DLO has made commendable progress in improving performance, not least by committing itself to cutting output costs by 20% by 2005, while maintaining the standard of its service to its customer."* (emphasis added)

13.54 In the accompanying letter to the Prime Minister dated 4 April 2000, the Chief Secretary to the Treasury highlighted the following points:

- *"Responsibility for £2.75 billion of spend has been delegated to the leaders of 50 cross-functional Integrated Project Teams."*
- *"... the DLO has set itself a target of reducing output costs by 20% by 2005, whilst maintaining both the quantity and quality of the outputs required by its customers."*
- *"Particular challenges facing the organisation are to refine its agreements with customers to include robust and granular costings, to institutionalise its performance review processes, and to continue to refine its scorecard of measures. ..."*

Implementation of the 'Strategic Goal'

13.55 In its Performance Report to Parliament 2001-2002, the MOD reported that the DLO *"continued to work towards its Strategic Goal"* of realising a 20% reduction in output costs by 2005 while maintaining or improving delivery. It reported that the DLO had made a 5.6% reduction in output costs since March 2000 as a result of a number of 'efficiency' initiatives. These included the establishment of *"a single supply chain organisation"* for key commodities, the implementation of *"cost management and 'lean support' initiatives"*, the achievement of *"inventory reductions"*, the reduction of *"almost 1,000 posts"* in HQ, and the establishment of *"partnership arrangements"* with key industry suppliers. As explained above, however, the DLO 'Change programme' subsequently required 're-energising' in 2002 and 20-40% cuts in manpower were recommended by McKinsey.

13.56 In its Performance Report to Parliament 2002-2003, the MOD reported 3.5% savings in the year 2002/03 against an in-year target of 2%, leaving *"a balance of 10.5% to be achieved by March 2006"*.

Single supply chain in DLO

13.57 It is clear that, in 1998, the MOD's materiel and logistics base was inefficient and involved much duplication of effort, inventory and resources. Instead of having three storage organisations and three supply chains, it made sense for there to be some rationalisation, particularly given that there were more joint deployed operations. The SDR mandated that the DLO should hold ready *"only that manpower, equipment, materiel, weapons and ammunition that cannot otherwise be provided within readiness and preparation times without unacceptable operational risk or at greater cost."*[24]

13.58 The SDR principle set in train a huge process of stock reduction. The SDR set a target of a 20% or £2.2 billion reduction in the book value of inventory over the next three years.[25] In order to implement this directive, the DLO set an overall 5% target for 'stock reductions' in 2001-2002 and 2002-2003 and *"more stretching targets"* in some individual areas, including the Air domain, which had a target of 10% stock reduction in 2001-2002.[26] This involved the disposal of stock deemed to be 'surplus'. It is not clear whether sufficient thought was given, however, to the implications of some of the stock disposals, in particular getting rid of items which, whilst not in demand at the time, would be required further downstream. Analysis by the

[23] The McKinsey member of the Public Services Productivity Panel.

[24] National Audit Office (NAO) Report, dated 20 June 2002.

[25] Paragraph 186 of the SDR White Paper.

[26] National Audit Office (NAO) Report, dated 20 June 2002.

RAF's Logistics Analysis and Research Organisation indicated that while some 50% of stock items might be 'inactive' at any one time (due to a lag in the manufacturing/purchasing process), somewhat less than 10% of stock items were inactive in the long term. It appears, however, that a somewhat draconian approach to disposals may have resulted in valuable and necessary spares held in stores being thrown away, only to have been subsequently re-purchased at a later date.

13.59 The formation of a single supply chain organisation brought considerable financial benefits. It is not clear, however, whether sufficient risk analysis was done in relation to the central sourcing of spares. As I discuss in **Chapter 5**, the fact that a non-conforming Avimo seal part found its way into the Nimrod fleet raises concerns about the MOD procurement chain for such parts and whether it is wise for specialist aviation parts to be sourced by the centralised non-specialist 'Medical and General Stores IPT'. And as Sir Sam Cowan himself pointed out, the SDR principle that the armed services should not hold above what their immediate readiness needs were, soon *"broke down"* during the Afghanistan and Iraq deployments.

Further financial pressures on DLO: (a) 3% cut over three years and (b) 3% annual efficiency savings for four years

13.60 As Sir Sam Cowan would have been well aware at the time,[27] the 'Strategic Goal' came on top of two further financial pressures imposed on the DLO by the SDR. In the financial year 1999/2000, the DLO was given an allocation from the total MOD budget of £22.295 billion based on the aggregate of the three PAO budgets in the previous financial year. The DLO's allocation was some 20%, or approximately £4.6 billion, of the total MOD budget. The subsequent years' allocations were, however, subject to two further financial reductions imposed by the SDR: (a) a 3% cut in the total budget; and (b) 3% assumed annual efficiency savings, as explained below.

(a) Defence settlement: 3% cut over three years

13.61 The first financial reduction amounted to a *"3% over three years"* cut in the Defence Budget imposed by the SDR. The Government's SDR White Paper provided: *"The Defence settlement will mean a reduction, in real terms, of £500M in the first year, rising to nearly £700M in the third year, as the efficiencies begin to take greater effect. In sum, a fall of 3% in real terms in the Defence budget by the end of this Parliament".*[28]

(b) Annual efficiency savings of 3% over four years

13.62 The second financial reduction arose from the attribution of the assumption of future efficiency gains made in the SDR White Paper, namely *"a 3% annual efficiency saving in operating costs over each of the next four years".*[29]

Move from cash-based to RAB accounting

13.63 In 2000, the MOD began to move from cash-based financial management to RAB. The burden of implementing this change *"fell particularly heavily on all staff across the DLO".* During Sir Sam Cowan's time as CDL, however, financial accounting in-year continued to be run on a cash basis, *i.e.* at the start of each year he was given a cash allocation which he could not exceed.

Deductions at source – Iron rule

13.64 Thus, all budget reductions were be made at source, *i.e.* it was assumed at the beginning of the financial year that the targets for reductions in output costs and annual efficiency savings would be met and funds were deducted from the budget funds allocated for each financial year accordingly. It followed that each service

[27] And as Sir Sam Cowan explained in his Written Statement to the Review dated 22 May 2000.

[28] SDR White Paper, page 386, taken from the *"Press Notice and Key Points of the Strategic Defence Review".*

[29] SDR White Paper, paragraph 194.

or organisation faced a shortfall at the end of the financial year if the targeted savings were not made. The iron rule was the services had to live within the cash provided. The cash was being taken before the savings were in fact delivered.

Sir Sam Cowan's evidence about the 20% 'Strategic Goal' figure

13.65 Sir Sam Cowan was asked by Counsel to the Review about the figure of 20% 'Strategic Goal' figure for reduction in output costs:

> *"**MR PARSONS QC**: ...[Where does the] figure of 20 per cent.... come from?*
>
> ***GENERAL COWAN**: It comes entirely from me.*
>
> ***MR PARSONS QC**: It was your figure?*
>
> ***GENERAL COWAN**: It was my aspirational target. … It was appropriate at that stage to make certain that everybody in the organisation had a stretch target; had an imaginative aspirational target that we could achieve."*

13.66 Sir Sam Cowan was asked why he had chosen the figure of 20%. He explained that 'it could have been 15% or 25%' but came from his experience as Quartermaster General and work done as part of the SDR:

> *"**GENERAL COWAN**: ... — I had been the Quartermaster General for two and a half years before I took this job on. I had been immersed in this area. I knew about the inefficiencies on stocks. It had been, of course, spelt out for me in the separate piece of work done as part of this Strategic Defence Review.*
>
> *So I thought it was, having discussed with — internally, it could have been 15 per cent; it could have been 25 per cent. I thought that based on the work that we got underway — ... — so I inherited a lot of ideas which had been the product of nearly two years' work; of different work strands as part of the Strategic Defence Review."*

13.67 Sir Sam Cowan was asked whether he 'stress tested' the figure to see how realistic it was and what the risks associated with implementing it would be:

> *"**MR PARSONS QC**: During your six months with the implementation team, I assume that you stress tested the 20 per cent to see how realistic it was and what the risks associated with it would be?*
>
> ***GENERAL COWAN**: Well... this was not something that was stress tested and — I was not making a 20 per cent reduction in people's budgets. … I was not taking … a 20 per cent cut … and [passing] this on immediately arbitrarily in a very stupid way to the Nimrod IPT. Nothing like that took place.*
>
> ***MR PARSONS QC**: No, but what you were doing was setting a target of a strategic goal of reducing output costs by 20 per cent —*
>
> ***GENERAL COWAN**: Over five years.*
>
> ***MR PARSONS QC**: — in resource terms by 2005/2006 which is a major challenge equivalent to 5 per cent of the MOD's cash budget.*
>
> ***GENERAL COWAN**: Yes. We did it.*
>
> ***MR PARSONS QC**: That must drive cost-cutting actions.*
>
> ***GENERAL COWAN**: No.*
>
> ***MR PARSONS QC**: It must do. You must make a saving somehow.*
>
> ***GENERAL COWAN**: Yes, but they were not cost-cutting as under cash. They were reducing output costs by introducing specific measures; specific changes."*

13.68 Sir Sam Cowan subsequently added:

> *"**GENERAL COWAN**: I think I did carry out a self-examination, in discussion with my — my management board, about whether 20 per cent over five years was the right sort of area, given that there were no immediate consequential cuts in budgets that — dependent on this 20 per cent. These were going to be real savings achieved by implementing real changes and progressively reducing the costs of these outputs."*

13.69 Sir Sam Cowan was asked specifically whether, and if so, what, risk assessment he had carried out at the time as to the implementation of the 20% reduction in output costs programme:

> *"**MR HADDON-CAVE QC**: [The question is] whether and if so what risk assessment you did at the time with your board as to the implementation of this programme which you outlined.*
>
> ***GENERAL COWAN**: I think the simple answer to your question is that: this was an aspirational target. It would be decided year-on-year as we progressed and brought together the storage organisations, brought together the supply chain organisations. ...*
>
> *…[W]e decided that we would pitch this at 20 per cent and work our way progressively towards it, knowing that every single measure … would be properly assessed in terms of risk as an individual measure within the overall process."*

20% figure

13.70 In my view, the 20% Strategic Goal figure was more a product of expedience than analysis. It seems no co-incidence that the figure was precisely the same as the 20% aggregate of the total Defence funding year-on-year cuts over the previous seven years and the total shortfalls built up in some of the PAO's previous budgets, namely the 20% bow wave of risk which had built up in the AML. Sir Sam Cowan's choice of a figure of 20% must have met with warm approval in certain quarters.

No overall risk assessment carried out

'Aspirational' target

13.71 I reject Sir Sam Cowan's repeated emphasis on the notion that the 20% figure was merely an 'aspirational' target and a 'strategic' goal.[30] In my view, this was somewhat naive, if not disingenuous. His so-called 'Strategic Goal' was, in reality, an order down the line that the 20% reduction had to be achieved. This is how it was intended, and certainly how it came to be viewed. I doubt whether the 20% target felt particularly 'aspirational' to any of those who were subsequently charged with implementing or delivering it. The reality was that CDL, having personally committed the DLO to making these savings, expected everyone below him to deliver them. The strong impression one gets from the witnesses and the evidence is that the 'Strategic Goal' of 20% and other required financial savings were implemented across the board with a ruthless, if not 'Stalinistic', efficiency. As one former IPTL put it: *"It was a heinous crime to go above your resource totals."*

'Can do, will do' culture

13.72 The 'Strategic Goal' played straight into to the hierarchical, process-driven, but otherwise wholly admirable, *'Can do, will do'* culture of the Armed Forces. Unfortunately, *'Can do, will do'* became *'Make Do'*.

13.73 Every platform and department was expected to deliver its share, irrespective of special pleading. Ambitious officers on short two year tours saw delivering, and being seen to deliver, whatever 'change', savings and efficiency targets that were demanded as the route to preferment.[31] The zealots were on the fast track to promotion.

[30] Sir Sam Cowan drew parallels with General Slim's 'motivational' speech to his troops before taking Rangoon in 1945. But history relates that Rangoon was a critical supply and communications hub and had to be taken if the Japanese occupation of Burma was to be ended. Lieutenant-General Sir William Slim KCB, CB, DSO, MC said: *"I tell you this simply that you shall realize I know what I am talking about. I understand the British soldier because I have been one, and I have learned about the Japanese soldier because I have been beaten by him. I have been kicked by this enemy in the place where it hurts, and all the way from Rangoon to India where I had to dust-off my pants. Now, gentlemen, we are kicking our Japanese neighbours back to Rangoon."*

[31] 'Change' initiatives left behind by officers on short tours who have moved on are known as 'pet pigs'.

'Reduction in output costs'

13.74 Sir Sam Cowan denied that there were any allocated cuts (let alone any what he termed 'slash and burn') to any DLO budget as a result of the 20% target. He said that he recognised that budget holders *"were already challenged enough dealing with inherited risk, the SDR cut and the MOD's assumed efficiencies".* He sought to draw a distinction between a goal pitched in 'output' terms as opposed to 'cash' terms. In my view, however, this is a distinction without a difference. As Counsel to the Review put it, the Strategic Goal must have driven cost-cutting measures throughout the organisation. In practice, the Strategic Goal must have felt like cuts to those at the coalface. I do not accept his assertion that *"no cuts, either in manpower or in budgets, were made as a direct result of setting up the DLO".* It is clear from the evidence that, during the period 2000 to 2005, large amounts of time, energy and the resources of many people within the DLO were devoted to finding ways of making 'savings', 'efficiencies', 'reductions in costs', 'cuts' *etc*. This inevitably diverted and distracted people from their other duties and led to a shift in priorities.

No risk assessment

13.75 Sir Sam Cowan admitted that he did not carry out any initial 'change risk assessment' at the time of setting his 20% Strategic Goal. He suggested, however: (a) it was not necessary to do so because *"each proposal that came up in terms of a programme or work to rationalise a structure, to establish a function, would be properly assessed by risk"*; and (b) it was not appropriate to do so because *"all the changes were not specified ... at the outset".* I disagree with both arguments. The mere fact that it might be expected that specific safety assessments would be carried out whenever individual changes were made does not obviate the need for careful thought to be given at the outset to the overall impact of the launch of such a major programme of output. In my view, the effect of setting a substantial and defined 'Strategic Goal' of 20% savings in output costs in the DLO over five years inevitably had potential safety implications which ought to have been considered from the outset for a number of reasons. First, the 'Strategic Goal' was inevitably going to drive a series of cost-cutting measures and lead to a substantial amount of pressure, disruption, diversion and distraction on, of or for those charged with delivering the goal. Second, this was a brand new organisation that was only just bedding down and which already had the *raison d'être* of achieving 'transformation' in every area of the DLO, its structures, processes and resources, indeed, a revolution in the whole way in which the DLO 'did business' was called for. Third, there was a major challenge in maintaining the values and principles of safety and airworthiness during the organisational shift from 'functional lines' to 'project lines'.

Regulations for impact assessment – JSP815

13.76 A formal requirement to assess and control the impact of changes to organisational structure or resources which might affect safety was introduced in the civil nuclear arena in April 2000 following incidents at Dounreay in 1999 (Nuclear Site License Condition 36 *"Control of Organizational Change"*). A similar requirement was not introduced in the military arena, however, until 2006, by an amendment to JSP815 which provided (in **Chapter 3**):

"Management of Organisational Change

42. *Without adequate planning and analysis, change may result in the inadvertent erosion of the emphasis on high standards of environment and safety performance. This may manifest itself in the loss of established formal and informal environment and safety processes, loss of critical safety culture, knowledge and expertise, or lack of sufficient personnel to safely operate and maintain a process with consequent increased likelihood of accidents and incidents.*

43. *Duty holder organizations shall, prior to any significant changes, conduct an environmental and safety assessment to baseline the existing arrangements for critical environment and safety activities; analyse the impact and justify the proposed changes. The rigour of the assessment shall be proportionate to the significance of the change. Where appropriate and proportionate, the organization should seek the views of the relevant FSBs* [Functional Safety Board] *or discipline leads.*

44. *It shall be the responsibility of the individual or team proposing the initiative to implement and*

complete the assessment prior to making any changes. Outcomes of assessment shall be included in any submissions seeking endorsement to continue with the implementation phase. Once implemented the impact of the changes shall be reviewed after an appropriate period."

13.77 In my view, however, the absence of a formal regulatory requirement prior to 2006 did not mean that senior officers and managers had no duty to carry out impact assessments in relation to changes initiated by them in preceding years whenever appropriate. Common sense, good practice and responsible leadership have always required that careful thought to be given to the impact of decisions potentially affecting safety, including decisions giving rise to changes in organisational structures or resources which might affect safety.

LOD

13.78 As CDL, Sir Sam Cowan was ultimately responsible for safety and airworthiness in the DLO. Sir Sam Cowan received an LOD direct from the Secretary of State. His LOD dated 27 April 1999 stated:

> *"As Chief of Defence Logistics you are granted delegated authority for ensuring the safety and airworthiness of military aircraft, military aircraft materiel and services.... In executing this delegated authority you are to ensure that all staff comply as appropriate with formally promulgated procedures and regulations.*
>
> *You may make further sub-delegations of this airworthiness to other MOD staffs who are responsible for procurement of military aircraft, military aircraft materiel or services. If you of those to whom you have delegated authority become aware of any practice or procedure being followed in the procurement, support, or operation of military aircraft materiel which may compromise airworthiness or safety standards, then you are to take immediate steps to control the situation or, if outside your control, to draw the matter to my attention and to the attention of the CDP and the Service Chief of the Staff concerned."*

13.79 Sir Sam Cowan delegated airworthiness authority to his 2-Star Director General of Operations & Business Development (DG Ops & B Dev, including all Safety, Health, Environment and Fire Risk Management (SHEF).[32] But under his LOD, as CDL, he retained lead responsibility for safety and airworthiness.

Criticism of Sir Sam Cowan

13.80 In my judgment, in all the circumstances, it was incumbent on Sir Sam Cowan as CDL to carry out an overall impact assessment before launching his 'Strategic Goal'. The welter of 'change' which would inevitably flow from implementation of his 'Strategic Goal' had obvious safety and airworthiness implications, both directly and indirectly: directly, because a reduction in output costs of 20% over five years was plainly going to drive cost-cutting measures which might affect safety and airworthiness; and indirectly, because the major organisational changes envisaged and/or the sheer scale of activity in delivering change and 'savings' would inevitably divert time, attention and resources away from routine tasks such as to affect safety and airworthiness.

13.81 Sir Sam Cowan did not carry out any initial impact assessment before picking his 20% figure or launching his 'Strategic Goal'. In my judgment, Sir Sam Cowan is open to criticism for not having done so. Good and responsible leadership required it.

13.82 I am satisfied that, if he had given careful thought to the implications of imposing the 'Strategic Goal' on the DLO at this time and some sort of impact assessment had been carried out, it would have been apparent, at the very least, that the imposition of the blanket 20% 'Strategic Goal' gave rise to potentially significant risks and great caution, sensitivity and vigilance would be called for to safeguard safety and airworthiness. The following points, in particular, were foreseeable: (a) the difficulties that a large and complex organisation such as the newly-formed DLO was bound to have at all levels in coping with such a major programme of 'change' and 'transformation'; (b) the 'Strategic Goal' would drive a culture of cost-cutting which might be at the expense of, and impact on, safety and airworthiness; (c) the difficulties of maintaining functional safety and airworthiness oversight and standards when shifting from 'functional' to 'project-based' organisational

[32] MOD Health & Safety Handbook, JSP375 Volume 1, October 2001.

lines (see further below); (d) the widely differing needs and ages of military platforms and the particular challenges faced by 'legacy' platforms; (e) the exigencies and imperatives of future operational demands; and (f) the huge organisational burden and distraction of delivering three layers of year-on-year savings, namely the 20% 'Strategic Goal', the 3% cut and the 3% annual 'efficiency saving' required by the SDR.

13.83 It is unclear as to what, if any, impact assessment had been carried out at the commencement of the SDR itself.

Delays in MRA4 programme led to Nimrod MR2 out-of-service date being put back

13.84 As regards (d) above, between 1999 and 2003 the In-Service date (ISD) of the MR2's replacement, the Nimrod MRA4, was March 2005. In February 2003, however, further delays in the MRA4 programme led to the MRA4's ISD being pushed back to March 2009. This date was subsequently pushed back further to 2010 (see further **Chapter 14**). Sir Sam Cowan commented in his evidence to the Review: *"I assume that at the appropriate point work was initiated to assess how the Nimrod MR2 fleet was to be maintained in service for the extra years envisaged"*. He pointed to the Ageing Aircraft Audit (AAA) first conducted on Nimrods in 1993 and its review in 2003. During this period, however, AAA only related to structures. It was expanded in September 2006 to include systems as well as structures; but this was too late to benefit XV230.

Increased operational demands due to Afghanistan and Iraq conflicts

13.85 As regards (e) above, operational demands on all three Armed Services did subsequently increase dramatically. As Sir Sam Cowan accepted (albeit only with the benefit of hindsight) the *"very high operational demands"* on Nimrods following the deployment of British troops to Afghanistan[33] and then Iraq[34] was in stark contrast to the *"low tempo"* prior to September 2002. There was, however, no amelioration of the scale or tempo of the implementation of the Strategic Goal of 20% savings in output costs or other savings targets. Indeed, when the DLO 'Change' Programme was found to have *"stalled"* in September 2002, savings greater than pro-rata 20% were required in the remaining years 2002-05 to make up for the *"shortfall"*; and a raft of McKinsey recommendations to *"re-energise"* the DLO 'Change' Programme were accepted, including a major programme of 20-40% manpower reductions within the DLO.

Over 900 'cost reduction' initiatives

13.86 As regards (f) above, by mid-2002, the DLO had launched over 900 initiatives aimed at delivering 'cost reductions' within the STP 02 timeframe.[35] This shows how the Strategic Goal, together with other downward financial pressures, did unleash a *tsunami* of cost-cutting initiatives within the DLO during this period. The three-fold consequences of this were hardly surprising, in my view, and would or should have been apparent from an impact assessment. First, many within the DLO and on the Front Line found themselves increasingly diverted and distracted from their core duties by the imperative to formulate, create, implement, monitor and report on a plethora of 'cost reduction' measures. Second, priorities inexorably shifted so that the focus was increasingly on 'cost reduction' as the 'Strategic Goal'. Third, the eye was increasingly off the airworthiness and safety ball.

13.87 There was, in my view, a real and appreciable risk that the adoption of cost reduction as the central 'Strategic Goal' might or would relegate safety risk management to a secondary position. This is, in fact, what transpired.

[33] Afghanistan operation commenced 7 October 2001.

[34] Iraq operation commenced 20 March 2003.

[35] In 2003, the incoming DG(ES)Air sought to rationalise some of these 'disparate' initiatives across IPTs.

Formidable quadruple challenge faced by IPTs

13.88 Thus, platform IPTs within the DLO, including the Nimrod IPT, were being expected to face the formidable, quadruple challenge of: (i) coping with major organisational change; (ii) seeking to maintain or improve the availability of equipment to the three Armed Services; (iii) dealing with increasing operational demands and UORs; whilst at the same time (iv) dealing with the imperative of delivering three layers of substantial year-on-year financial cuts, reductions in output costs and efficiencies.

Safety regime

13.89 This was accompanied by a loosening rather than a tightening of the safety and airworthiness regime (see *Dilution of Airworthiness Regime* below). It is noteworthy that, in his Foreward to the DLO Environment & Safety Report 2002, Sir Sam Cowan had to report a *"challenging"* year for the DLO safety community *"with resources under considerable pressure"* in some business units. The Director Safety, Estates & Security reported that *"a recurrent theme is the challenge posed by an ever decreasing pool of suitably qualified and experienced personnel and, of course, the constraints imposed by limited resources"*.

13.90 In all the circumstances, it is not surprising that something subsequently gave way.

Air Chief Marshal Sir Malcolm Pledger (CDL 2002- 2004).

13.91 Air Chief Marshal Pledger replaced Sir Sam Cowan as CDL on 2 September 2002, a post which he held until 31 December 2004. His tenure as CDL, therefore, coincided with the key period of the drawing up of the Nimrod Safety Case (see **Chapters 10A** and **10B**).

Task

13.92 Sir Malcolm Pledger said in his evidence to the Review about his appointment: *"I was tasked with transforming the acquisition and through-life logistics support for the Armed Forces and delivering efficiencies equivalent to 20% of the £10 billion top level budget"*. When questioned, he explained that he had not been specifically tasked in so many words, but this was his interpretation of his role following his introductory meetings with the then Secretary of State and Ministers and others (see also further below).

Poisoned chalice

13.93 It is fair to say that that Sir Malcolm Pledger inherited a situation which was not of his making and, to some extent, was handed a poisoned chalice.

(1) Change programme 'stalled'

13.94 First, the DLO's 'Business Change' programme had *"stalled"* due to what McKinsey said were *"fundamental questions about affordability, delivery, prioritisation and focus on core business drivers"*.[36] It was clearly proving difficult to deliver the 20% reduction in output costs in the timescales required by the Strategic Goal as well as coping with the 900 'Change' initiatives. When Sir Malcolm Pledger took over as CDL in September 2003, the DLO had delivered only 5.6% of the 20% Strategic Goal and 14.4% remained to be achieved by 2005/06, *i.e.* only about a quarter of the Goal had been met with nearly half the time gone. As he said, *"the programme that I inherited had significant financial risk embedded within it"*. He would have to accelerate the programme and catch up if he was to achieve the Goal. He said that the 20% Strategic Goal figure gave him a 'concern' when he took over because *"I had no idea personally at the time whether or not what we held was sufficient to perform the operation that we were due to be embarked upon* [namely, Iraq]*"* and this kind of financial risk meant his ability to 'mend' aspects would be very restricted.

[36] McKinsey's its paper, *Re-energising the DLO Change Programme,* paragraph 2.1.

(2) Increased operational tempo: Afghanistan and Iraq

13.95 Second, at the same time, Sir Malcolm Pledger had inherited one major operation, namely the conflict in Afghanistan (Operation 'HERRICK') which had been running for nearly a year since coalition operations were launched on 7 October 2001. To add to this, within six months of his appointment, UK forces were committed to a second major conflict, the invasion of Iraq (Operation 'TELIC') which took place on 20 March 2003, and the subsequent aftermath.

(3) Did not believe he was fully qualified for the job

13.96 He told the Review, candidly, that he did not believe that he was fully qualified for the job of CDL. He said this was one of the reasons why he attended a two-week course at the IMD Business School in Switzerland. He was not a logistician or an engineer; he was a career helicopter pilot who had only brief hands-on logistics experience and no business experience.

(4) No clear plan

13.97 He told the Review that he was not aware of there being any *"clear plan"* drawn up of how the Strategic Goal and other targets were going to be achieved. He insisted that said there should have been such a plan *"from day one"*:

> *"**MR HADDON-CAVE QC:** You said earlier, Sir Malcolm, that you didn't think [a clear] plan existed as to how to deliver all this. Should there have been a plan —*
>
> ***SIR MALCOLM PLEDGER:** To my mind —*
>
> ***MR HADDON-CAVE QC:** — from day one?*
>
> ***SIR MALCOLM PLEDGER:** Absolutely. I think there was what I would call a top level piece from Sam, that described the strategic arrangements and the expectations. But I don't — I never saw a translation of those high level ideals into what I will call the "project activities" that would have then been visible and could have accumulated an answer to that top level strategic aim."*

(5) No idea whether targets deliverable

13.98 It is perhaps unsurprising, in these circumstances, that he admitted to the Review that he had *"no idea"* whether the targets were deliverable.

Tension between delivering '20% efficiencies' and supporting the conflicts

13.99 When questioned by the Review as to whether he felt there was an inherent tension between being required to deliver the 20% Strategic Goal and the need to support the Afghanistan and Iraq conflicts, Sir Malcolm Pledger initially said 'no'. His initial explanation ('delivering more with less') contained an element of *ex post facto* rationalisation. When questioned further, however, he gave a more candid and compelling explanation: he said he was a 'realist' and explained that, because the 20% Goal was already in place and was part of the Government's published agenda, he felt he could not ignore it and as CDL he was 'accountable':

> *"**MR PARSONS QC: ...** What I am trying to explore from your perspective is whether you considered it was appropriate for you to still be under the pressure of all this tasking to achieve a 20 per cent or bust, when the priority is to improve efficiency to support the front line.*
>
> ***SIR MALCOLM PLEDGER:** I just think I'm a realist, I am afraid. It existed. And yes, it was another pressure. But I tried to turn a requirement into a virtue.*
>
> ***MR PARSONS QC:** But they are different pressures, aren't they?*

SIR MALCOLM PLEDGER: *Oh, they are different pressures. I am not disagreeing with you. They are different pressures. But it is realistic. It was there, it was in place. That didn't mean to say we rushed headlong and without due consideration into anything associated with it. But you couldn't ignore it.*

MR HADDON-CAVE QC: *Sir Malcolm, you said it was there and it was in place. Can you help us with how much it was there and how much it was in place?*

SIR MALCOLM PLEDGER: *It depended on which authority you had that debate with. You know, not surprisingly, the Permanent Undersecretary had one view which may have been different from the Chief of Defence Staff, in terms of importance and in terms of response, but it had been published, it was part of the government's agenda, and it was something to which the CDL was accountable to the different aspects of the defence case."*

'Salute smartly and get on with it'

13.100 Sir Malcolm Pledger said that, on appointment, he was left in no doubt by Ministers as to what was expected of him and he felt he should *"Salute smartly and get on with it"*:

*"**MR HADDON-CAVE:** In a sense, some might say it was a bit of a hospital pass, and you were given a situation which was not of your making.*

SIR MALCOLM PLEDGER: *Yes.*

MR HADDON-CAVE: *Would it have been better if the first CDL, instead of remaining two years, had —*

SIR MALCOLM PLEDGER: *I think that's what I am saying. If the first target had been identified, if it had been in negotiation between Sam and the Ministry of Defence... if it had been to achieve a strategic goal of X, if he was willing to accept that and would agree with them it would take five years or six years, I think he should be appointed for six years. Classic example. But I think he should play a part in setting that target, because if he wasn't able to accept that as a reasonable target, I think he should be able to say no.*

MR HADDON-CAVE QC: *Assuming that he did have a role in setting that target, which he may well have, you, in a sense, were in the unfortunate position of not having a role in setting the target. You had to eat the meal... that was served to you.*

SIR MALCOLM PLEDGER: *Yes. I was summoned within — another nice, "Welcome. How are you?" — I was summoned by the House of Commons Defence Committee within a week of taking over the CDL and the first question was: well, now look what you have done. What do you think about your ability to achieve this 20 per cent cut? And, you know, why did you accept this appointment on that basis?*

MR HADDON-CAVE QC: *And why did you accept the appointment on that basis?*

SIR MALCOLM PLEDGER: *To which the answer was: I don't think you understand the military organisation. I was posted on a due date. I was not consulted in the parameters of this appointment. I was simply given the task to be the Chief of Defence Logistics. And that process is wrong.*

MR HADDON-CAVE QC: *And it's wrong, because?*

SIR MALCOLM PLEDGER: *Because it is imposed. I don't believe I was qualified to do the job, for want of a better word, fully. That was one of the reasons I went to IMD [IMD Business School in Switzerland]. But you are appointed. You are given the job and it says, "Report to such and such, on such and such a date", and away you go.*

So, you know, it was pointless asking me whether or not I agreed with a 20 per cent strategic goal or anything like that. So it was my arrival present, sitting there ticking. Whether or not I then tried to deliver it, I think is a completely different question, but that was the mechanism.

> ***MR HADDON-CAVE QC:*** *But you could have said, "I've now examined the background documents, I've seen that it has been going off track in the last two years, because it's proving to be very difficult to deliver and I've read McKinsey and these other documents that have come onto my deck. I see looming Iraq and other challenges. It's clearly time to take stock and move much more cautiously, because this is proving to be very, very difficult and I'm not going to commit to delivering this in the timescale that's been handed to me."*
>
> ***SIR MALCOLM PLEDGER:*** *I don't think I could have done that to the House of Commons Defence Committee, having been appointed as the new CDL, could I? I mean, surely I would have had to go to the PUS and say, "Thank you very much for this great honour, sir, but I am not taking the job", and "under these conditions. Can we negotiate"? And if the answer to that was "No", you know, "Which employment are you going to look actively for your next few years, Pledger?"*
>
> *Because I couldn't — if you have been appointed to a job, you have got to do it. Salute smartly and get on with it.*
>
> ***MR HADDON-CAVE QC:*** *But I thought you told us earlier that there wasn't a defined condition imposed.*
>
> ***SIR MALCOLM PLEDGER:*** *No, not in writing. No.*
>
> ***MR HADDON-CAVE QC:*** *In your paragraph 4. If it wasn't in writing, where was it, then?*
>
> ***SIR MALCOLM PLEDGER:*** *Well, as I also said to you, I was invited to a very senior meeting in the Ministry of Defence, a couple of months before I took over, to sit on the side and watch the Ministers debate the current arrangement progress within the organisation. Clearly the purpose of that was to leave me in no doubt as to what was expected.*
>
> ***…***
>
> ***MR HADDON-CAVE QC:*** *But even after two weeks of IMD, you, with the best will in the world, couldn't be sure, particularly given the background and the fact it had stalled, that this was deliverable.*
>
> ***SIR MALCOLM PLEDGER:*** *I had no idea. I am not sure that impacts on anything there, other than I had been posted to complete the job, to be CDL."*

Realpolitik

13.101 I am satisfied this latter explanation reflects more closely the reality at the time: Sir Malcolm Pledger took the path of *Realpolitik.* Faced with what he may have seen as the *fait accompli* of the 20% Strategic Goal already in place, he chose not to rock the boat but to get on with the delivering the 'Strategic Goal' and other rolling 'efficiency' measures. He admitted to the Review that achieving a one-fifth reduction in output costs meant that costs would have to be 'cut' and that redundancies and re-organising the business would be 'one outcome'. Unfortunately, he does not appear at any stage to have questioned the wisdom of seeking to enforce the Goal within the timescale envisaged, or at the pace required, notwithstanding: (a) the situation which he found when he arrived in post at the DLO in September 2002, namely, that the DLO 'Business Change' programme was already coming off the rails and great difficulties were being encountered in achieving the scale and pace of 'Cuts' and 'Change' required; and (b) the new operational situation which was rapidly developing, namely, preparations for the invasion of Iraq (see above).

Criticisms of Sir Malcolm Pledger

13.102 In my view, however, Sir Malcolm Pledger, did have a number of options and duties on taking up his appointment as the new CDL which he did not avail himself of or fulfil.

13.103 The first option, and duty, was to assess the situation and challenges which he had inherited very carefully and to question whether it was feasible, realistic and sensible to enforce the remainder of the 20% Strategic Goal at the pace and within the timescale envisaged, given the marked difficulties already encountered and the challenges ahead of supporting the greater operational tempo (see above). If he took the view that, in all the circumstances, it was necessary, sensible or desirable to act more cautiously and incrementally in enforcing the goals, he should have raised this and argued the case vociferously. There should, at least, have been pause for thought.

13.104 The second option, and duty, was to consider what special measures needed to be taken in the meanwhile, in any event, to ensure that fundamental values such as safety and airworthiness were preserved in the face of the serious challenges potentially posed by: (a) the size of the 'economies' required (a 14-15% reduction in output costs in two to three years plus the 3% efficiencies *etc*); (b) the huge amount of change that this would involve; (c) the substantial organisational changes already in train in the DLO; (d) the lack of a clear or coherent 'plan' as to how the Strategic Goal was to be achieved in the first place; (e) the evidence that the organisation was already finding it difficult to cope and deliver the cuts and change required; and (f) the growing operational challenges to be faced in the near future.

Option chosen – to acceleration pace of cuts and change

13.105 There is no evidence that Sir Malcolm Pledger considered either of the above options. He chose instead to *accelerate* the pace of cuts and change in order, in appears, to carry out his 'task' as he saw it and catch up with the Strategic Goal. In my view, these are matters which are open to criticism. Good and responsible leadership required a more measured and reflective approach in all the circumstances.

13.106 His attitude was 'Can do, will do' and he applied himself to the task with vigour as he quickly fashioned and implemented what was, in effect, a second phase of the DLO Change programme which he called the DLO 'Transformation' programme. He told the Review that selected the word *"Transforming"* in order *"to show the enormity of the task we faced".*

13.107 His *DLO Strategic Plan,* which was widely disseminated amongst the IPTs, set out the following uncompromising *"Key Targets"*:

- *"Reduce net Total Operating Costs £1225M[6] (14%) against the STP-2 baseline by Mar 06.*

  ...

- *All IPTs and logistic service providers to baseline their total Cost of Ownership by Mar 03; and subsequently to <u>reduce it by 10%</u> by Mar 04; a <u>further 10%</u> by Mar 05; and identify means of reducing it by <u>a total of 30%</u> before Mar 07."* (emphasis added)

13.108 As set out above, during the period 2002-2004, Sir Malcolm Pledger presided over the implementation of: (1) McKinsey's paper 'Re-energising' the DLO Change Programme which recommended a more *"radical programme"* of change; (2) the New DLO 'Change' Programme comprising existing initiatives, McKinsey 'workstreams', and transformational activity from the Strategic plan and the move from *"a predominantly Provider role to one of an intelligent Decider"*; (3) McKinsey's recommendation for a 20-40% reduction in manpower; (4) the Defence Logistics 'Transformation' Programme; (5) the 'Streamlining End to End' Review; (6) the 'Leaning' programme. McKinsey described its recommendations in its July 2003 paper[37] in the following terms: *"Our recommendations cut across the whole of Defence and are likely to require the most complex restructuring of MOD activities since the Strategic Defence Review."*

13.109 It is small wonder that IPTs and IPTLs felt increasingly pre-occupied with delivering costs reductions and 'efficiencies' during the period 2002 to 2004 and with coping with 'change'.

[37] *Streamlining End to End Air and Land Logistics,* 1 July 2003, McKinsey.

DLO Business Plan 2003

13.110 Sir Malcolm Pledger said that the Office of Government Commerce (OGC)'s principles and practices and risk management techniques were applied. [38] The DLO Business Plan for 2003 listed 12 'top-level' risks but they were all 'business' and implementation risks. It is noteworthy that none related to safety or airworthiness.

DLO Environment & Safety Report 2003

13.111 Sir Malcolm Pledger's Foreward to the DLO Environment & Safety Report 2003 echoed closely the wording of the previous year's edition in which Sir Sam Cowan had reported a *"challenging"* year for the DLO safety community" *with resources under considerable pressure"* in some business units. The Executive Summary stated: *"The most significant risk affecting E&S performance within the DLO.... relates to the lack of resources".* The report on Air Equipment Safety by ES AD EngPol stated:

"Issues & Risks

*4. <u>Funding Constraints.</u> <u>IPTLs consider that continued pressure on funding, without the provision of 'catch up' funds, could affect safety in the medium-to-longer term</u>**.** Moreover, whilst the new emphasis on hazard management allows much better targeting of safety issues, <u>all areas involved in support are under pressure to do more with the same, or reducing, resources</u>**.** Although the airworthiness of aircraft has not been compromised, there are examples where modifications to enhance airworthiness have not been taken due to lack of funding; all such instances are being report to the DASB via the Aviation Safety Steering Group (ASSG)."* (emphasis added)

Summary

13.112 For the above reasons, I am satisfied that both Sir Sam Cowan and Sir Malcolm Pledger each bear a significant share of the responsibility for the episode of cuts, change, dilution and distraction described in this Chapter.

13.113 These organisational causes adversely affected the ability of the Nimrod IPT to do its job and the oversight and culture in which it operated during the crucial years when the Nimrod Safety Case was being prepared, in particular 2001-2004 (see further below).

13.114 By the beginning of 2005, the effects of the episode of cuts, change, dilution and distraction of the previous years were entrenched, the Safety Case had been completed (unsatisfactorily) and the damage was done. There was little that a new incumbent to the job of CDL could reasonably have done thereafter to reverse or rectify matters that would have made any realistic difference.

[38] The OGC is a Treasury body.

'DILUTION'

"When a 3-Star is interested in safety, everyone is interested in safety."
(Junior RAF officer, 2009)

Dilution of airworthiness regime and culture (2000-2006)

Summary

13.115 In my view, a marked dilution of the airworthiness regime and culture took place in the MOD during the period 2000 to 2006. There was a steady erosion of focus on safety and airworthiness. The implementation of the SDR and the 20% 'Strategic Goal' held centre stage.

13.116 It is clear that *"continuous organisational change over an extended period"*[39] had a deleterious effect on the management of airworthiness. The period 2000 to 2006 was marked by three features so far as safety and airworthiness in the MOD was concerned:-

(a) First, there was an inexorable shift from a 'safety and airworthiness culture' to a 'business culture' during this period in the MOD.

(b) Second, the organisational changes in the MOD led to a safety and airworthiness regime which was organisationally complex, convoluted, confused and seemingly dysfunctional.

(c) Third, meanwhile, there was also a steady dismantling of some of the important features of the safety and airworthiness regime which had previously existed.

(a) Shift from 'safety and airworthiness' to 'business' culture

13.117 In my view, there can be no doubt that the implementation of the 1998 SDR and 'Strategic Goal' brought about a major shift in culture within the MOD from 'safety and airworthiness' to 'business'. All the evidence points to this being the case. Whereas in the 1990s there had been a strong focus on safety and airworthiness issues, in the period 2000 to 2006, 'business' was increasingly paramount. I agree with George Baber's summary of the position in his evidence to the Review:

> *"I believe that as major organisational change occurred, with the formation of the DLO and then subsequently as the DLO re-organised internally, then the balance between safety and business-related decision-making shifted, with airworthiness becoming less prominent. The consequence was to reduce the organisational oversight of IPT airworthiness systems, processes and outcomes and to make it more difficult for the IPTLs to balance their business responsibilities with those associated with safety."*[40]

(b) Airworthiness structure became complex, convoluted, confused and seemingly dysfunctional

13.118 As a result of the successive organisational changes, by 2005, the MOD's airworthiness structure had become, by its own admission, complex, convoluted and confused and seemingly dysfunctional.

MOD airworthiness regime was simpler and more coherent in 1990s

13.119 The airworthiness regime within the MOD used to be relatively simple, coherent and effective in the days of the Chief Engineer RAF and RAF Logistics Command in the 1990s. The airworthiness regime established during this period represents a high-water mark in my view.

[39] George Baber's written statement to the Review of 11 June 2009.

[40] Ibid.

Chief Engineer RAF

13.120 The *"Chief Engineer RAF"* CE(RAF) was a 3-Star who had overall responsibility for assuring the airworthiness of all fleets. He reported to the Air Force Board (AFB) on fleet airworthiness. He discharged his airworthiness responsibilities in a number of ways: setting airworthiness policy, drafting airworthiness regulations, conducting the airworthiness review process (the RAF Logistics Command Airworthiness Review was chaired by the CE(RAF)), and maintaining an airworthiness audit of Multi-Disciplinary Groups (MDGs).[41] MDGs were responsible to him regarding airworthiness (see below). Strike Command were required to assure him that they were correctly following maintenance procedures, standards and practices. The airworthiness regime operated by the CE(RAF) included a calendar-based self-check list of requirements, an effective audit regime, and *"Support Authority Reviews",* all within an ISO 9000-based quality management system.

13.121 The structure and lines of authority were clear, as shown in Figure 13.3 below.

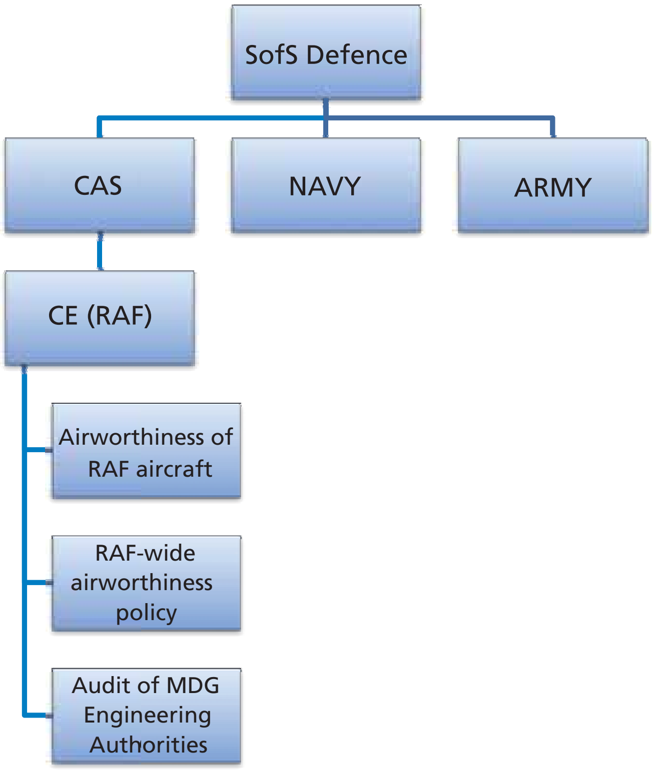

Figure 13.3: Airworthiness structure and lines of authority in 1990s

13.122 The chain of delegation for airworthiness was similarly clear. The CE (RAF) delegated responsibility directly to the 2-Star officer who commanded the MDGs (DGSM), who in turn delegated authority to "Heads of Engineering Authority", 1-Star officers who commanded groups of MDGs, each of which managed the airworthiness of aircraft or airborne equipment. This is depicted in Figure 13.4 (below). Strict protocols were in place to ensure that there were never successive gaps in the engineering management chain; i.e. if a non-engineering specialist filled a management post, the posts above and below his had to be filled by qualified engineers.

[41] Forerunners of the current Integrated Project Teams.

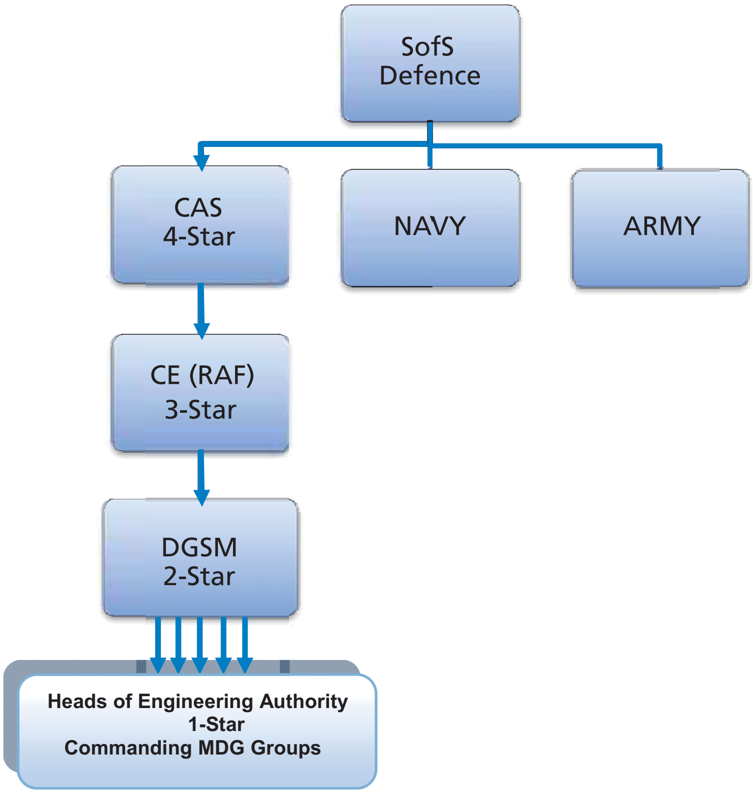

Figure 13.4: Chain of delegation for airworthiness in 1990s

13.123 The CE(RAF), therefore, had a powerful voice as regards airworthiness which resonated through the organisation.

Air Chief Marshals Sir Michael Alcock and Air Marshal Sir Colin Terry

13.124 In my view, the post CE(RAF) was a key feature of the strong airworthiness regime and culture which existed in 1990s. This was due in no small measure to the high calibre and leadership of those who held that post in the heydays of RAF Logistics Command, in particular Air Chief Marshal Sir Michael Alcock (1994-1996) and Air Marshal Sir Colin Terry (1997-1999). They commanded great respect and esteem: (a) because of their knowledge of the subject (they were both distinguished aviation engineers); (b) because they insisted on high standards and brought great rigour to bear; and (c) because they took a keen, personal interest in all airworthiness issues (and used the *"long screwdriver"* with great effect). They inculcated a strong airworthiness and 'questioning' culture at RAF Logistics Command which probably represents the 'golden period' for airworthiness in recent years. Many witnesses attested to this view.

CE(RAF)'s Audit team

13.125 The CE(RAF) and DGSM had an airworthiness audit team comprising a Wing Commander and four Squadron Leaders who were permanently engaged in visiting MDGs and auditing their airworthiness processes. This was achieved by both following a structured examination of internal MDG processes and activity, and sampling actual activity and decision-making. This system of regular auditing was very effective for two reasons. First, as one witness put it, the allocation of significant manpower resources directly to auditing *"allowed you to do a lot of digging"* and kept people on their toes. Second, there was no doubt about the airworthiness chain of responsibility: the delegation of airworthiness authority flowed down from DGSM to the MDGs. It was the DGSM himself who owned the audit team. The audit team reported back direct to him about what they found at the MDGs. It was, therefore, *"a very tight closed loop"* between the man who was delegating authority and the audit team who were responsible to him.

13.126 Following publication of the Turnbull Report in 1999, which focused on governance and internal controls, this airworthiness audit and assurance function was broadened to embrace also a 'corporate governance' approach, leading to some dilution.

AD(Eng)Pol

13.127 Group Captain Eng Pol/AD(Eng)Pol had a variety of roles in relation to developing engineering policy and supporting IPTs in particular in relation to airworthiness. AD(Eng)Pol's main responsibilities were: (a) developing and publishing RAF-wide engineering policy; (b) the subsequent migration of single-Service policy and documentation into a common standard for use across Defence (i.e. JAP); (c) liaising with ADRP regarding the development of JSP553; and (d) reviewing IPTLs for airworthiness standards. On the policy side, AD(Eng) Pol had seven or eight staff. On the airworthiness side, AD(Eng)Pol was assisted by three staff: a Wing Commander, a Major and a Flight Lieutenant. The Major advised IPTs about the GARP[42] process and Safety Cases, although IPTs were expected to recruit and train their own Safety Case specialists.

Inspectorate of Flight Safety (RAF)

13.128 The Inspectorate of Flight Safety RAF (IFS(RAF)) was an independent Directorate headed by a 1-Star officer (the Inspector) with a remit to inspect, study and survey throughout the RAF. The Inspector was expected to keep in current flying practice as an aircraft captain on at least one Front Line aircraft type, and he routinely visited RAF stations to fly as a member of the crew on other types of aircraft. During these visits, he would take time to talk to personnel of all ranks. Through his visits, the inspections carried out by his staff, and by monitoring all RAF occurrence reports, he was able to provide expert and well-informed advice to commanders. The IFS also conducted Airworthiness Reviews of RAF aircraft; in this context, the IFS took a broad view of its remit and included 'fitness-for-purpose' in addition to the technical airworthiness of the platform. The Fleet Air Arm (FAA), and the Army Air Corps (AAC) had their own in-house airworthiness review arrangements.

Defence Aviation Safety Centre (2002)

13.129 In 2002, the Defence Aviation Safety Centre (DASC) was formed and the IFS was folded into it. The change was brought about because of the perceived need for a pan-Defence Flight Safety (FS) organisation to reflect the growing proliferation of 'purple' or joint organisations in the MOD: *e.g*. Defence Logistics Organisation, Joint Force Harrier, Joint Helicopter Command etc. The DASC was led by a 1-Star officer with a staff comprised of officers from all three Services. It was considered to be a MOD level organisation, whose roles included the formulation, regulation and validation of Defence aviation safety policy, providing FS advice upwards and downwards throughout the Department and providing a single Departmental focus for FS issues. However, the Director was not an 'inspector' and the DASC's authority to audit and validate was limited to 'one level down', *i.e.* not below Strike & Support Command HQs, Fleet HQ and HQ Directorate of Army Aviation (DAAvn). This limitation appears to have stemmed from sensitivity in the Navy and Army that the DASC was just a re-badged IFS(RAF) with, most likely, a light blue 1-Star.[43] Ironically, whilst the FAA and DAAvn managed to retained their existing FS structures, the RAF, in a series of HQ rationalisations, ran-down its Command and Group FS staffs, presumably in the mistaken view that the DASC would continue to fulfil the IFS(RAF) roles (which it did not).[44]

Advantage Report in December 2002 was critical

13.130 In December 2002, a report by Advantage Technical Consulting identified and emphasised a series of trenchant and perceptive criticisms of the safety and airworthiness regime across the acquisition cycle in the MOD[45] and concluded: *"There is a pressing need to bring greater harmony and consistency to the assurance*

[42] Generic Aircraft Release Process.

[43] Director DASC, and Director DARS, are competed posts; the incumbent should be the best man for the job, irrespective of his Service. However, the size of the RAF in comparison to the FAA and Army Air Corps make it most likely that the Director would be 'light blue'.

[44] I understand that the resurrection of the IFS is currently being re-examined.

[45] Advantage Technical Consulting, *"Safety Process Review"* Report dated 23 December 2002.

of equipment safety. This will best be prosecuted by the appointment of a 2 champion empowered by the DESB".*[46] Commenting on the creation of DASC, Advantage said: *"This initiative brings much closer together the various components of air safety but does little, if anything, to move air safety closer in process, procedure or organisation to the rest of the MoD safety world"*.[47] The following criticisms and observations by Advantage of the MOD airworthiness regime at the time are particularly relevant and noteworthy:

13.130.1 *"IPTs do not believe that they get a sufficiently authoritative or sufficiently early view of who needs to do what, and when it needs to be done, with regard to safety management."* (Major Findings, page 4)

13.130.2 *The IPTs, Operators and Maintainers of equipments and platforms in many cases have separate Safety Management Systems which are sometimes disconnected and inconsistent."* (Major Findings, page 4)

13.130.3 *"Responsibilities for Safety Management are not clear through-life."* (Major Findings, page 4)

13.130.4 Section 2.2 of the report referred to the importance of separating the assurance functions from the ensurance functions in order to maintain the impartiality and credibility of the assurance provided. It was noted that *"there is an inconsistent approach to this separation of assurance and ensurance, and that this is further muddied by an unclear separation between advice and assurance in some areas. These inconsistencies appear to be largely resource driven – by both lack of and availability of resource – and this leads to different approaches being taken to, for example, the use of Independent Safety Assurance (ISA). These differences are manifested in different degrees of independence and also various interpretations of the "A" as meaning advisors, assessors, assurers, auditors and also in different degrees of mandation of an ISA. Taken together, these inconsistencies reduce the value of the assurance given to FSBs and the DESB."* (paragraph 2.2.2)

13.130.5 Advantage thus recommended that a clear policy on the role and use of ISAs should be identified. (paragraph 2.2.3)

By 2005 airworthiness regime convoluted, confused and 'seemingly dysfunctional'

13.131 In its Joint Review of Airworthiness dated 10 January 2005, DASC itself reported:[48]

> *"The MoDs aviation organisation is complex and as a result of successive organisational changes (including increasing industrial involvement) the overlying structure of airworthiness regulations and delegation of responsibility has become convoluted, is easily misunderstood and displays a number of weaknesses."*

13.132 It was pointed out that there were now many departments developing aviation regulations, policy and advice and *"the airworthiness regime is open to misunderstanding in terms of "who is responsible for what?" unless one has intimate knowledge of the subject"*.[49] With admirable honesty, the DASC report concluded:

> *"As has been established, the overall picture of the airworthiness regime is perceived as one of a wide range of interconnected agencies presenting a confusing and seemingly dysfunctional whole".*

LOD chain confused

13.133 The lines of airworthiness delegation were no longer clear following the creation of the DLO. At one stage, DG ES(Air) had LODs from the three Service Chiefs to delegate that authority from them to him to set the policy and regulations across all military aircraft. Figure 13.5 is a rough diagrammatic estimation of the position as it is recalled to have been.

[46] Ibid, Summary, paragraph 10.

[47] Ibid, paragraph 2.4.5.1.

[48] Joint Review of Airworthiness by DASC dated 10 January 2005, DASC/5/8/9, paragraph 26.

[49] George Baber's written statement to the Review of 11 June 2009.

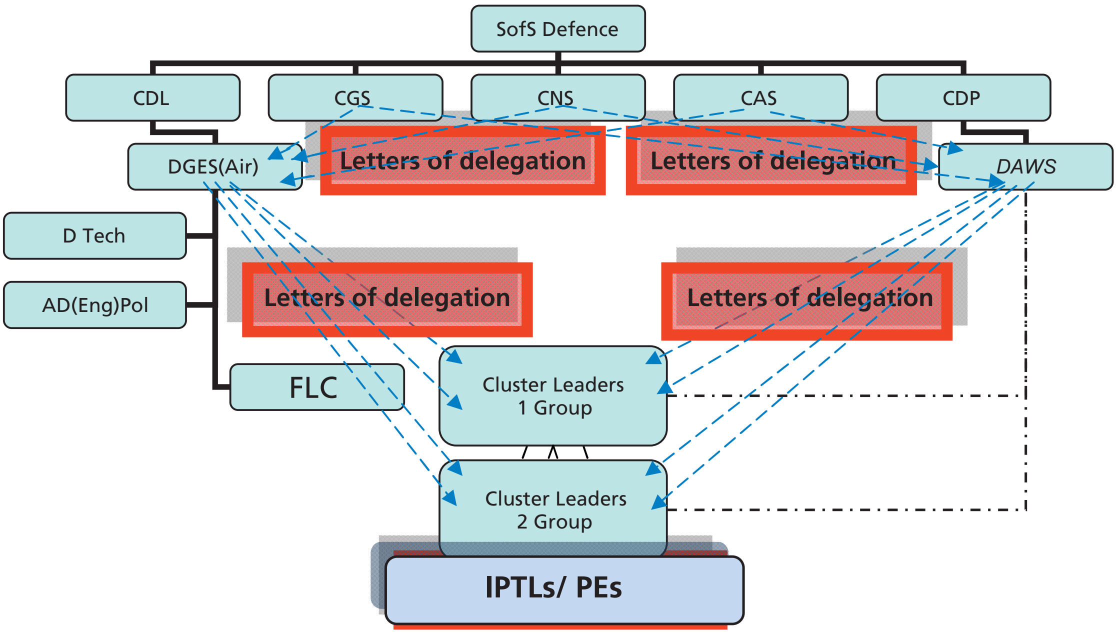

Figure. 13.5: Letters of Delegation Chain(s) in DLO

DASMS, DASSRR, JATAAM, DASC and 'virtual' MAA.

13.134 By 2005, the DASC Joint Review of Airworthiness was already beginning to conclude that the complexity of the MoD's aviation organisation, compounded by successive organisational changes, meant that the structure of airworthiness regulation and delegation was convoluted, easily misunderstood and contained a number of weaknesses (see above). It recommended a two phase solution:

13.135 The first phase included the replacement of the DASC Airworthiness Branch with a Safety Management System Branch, the introduction of a pan-Defence Aviation Safety Management System (DASMS) and the introduction of a Defence Aviation Safety Strategic Risk Register (DASSRR). These recommendations were actioned.

13.136 The second phase was to be a review of pan-Defence aviation management that might lead to the creation of a Military Aviation Authority (MAA). This recommendation was reinforced when the new Chief of Defence Logistics (CDL) and the head of Airworthiness Design Requirements and Procedures (ADRP), wrote to the Vice Chief of the Defence Staff (VCDS) in June 2005 asking him to consider the requirement for a MAA. A MAA Study team was formed, and, in December 2005, it reported that:

a. A stand-alone MAA was not required, but this should be reviewed in two years. The Study envisaged a 'virtual' MAA in which the functions, structure and management would be clearly identified, but the components would not necessarily be collocated.

b. The DASC and the MoD Aviation Regulatory Team (MART) [50] should be co-located. (This co-location occurred in April 2008 when the DASC and the MART merged to form the Directorate of Aviation Regulation and Safety (DARS)).

c. A separate study was required to examine options for the better management of MOD air traffic and airspace issues. It was envisaged that Airspace and Air Traffic Management policy and regulation could be brought under a single organisation: a proposed MOD Directorate of Joint Air Traffic and Airspace Management (JATAM).

13.137 The implementation of the MAA and JATAM Studies was, however, delayed due to a variety of reasons including debates over terms of reference, leadership, 'dual-hatting' and interactions with other Government Departments, together with constraints on physical locations due to estate rationalisation.

[50] The MART was located at RNAS Yeovilton in Somerset, under the line management of Director Air Staff.

2007/09 – DE&S airworthiness regime

13.138 By 2007, the airworthiness regime within the new DE&S had become even more Byzantine, complex and confused. In the DE&S, responsibility for airworthiness was moved to a separate organisation within "Corporate Services". Today, Airworthiness policy is 'brigaded' alongside the other Safety and Environmental disciplines and 'linkage' with the three Front Line Commands achieved through the tri-Service forum inherited from the DLO structure. The primary interface with the single-Services at DE&S Main Board level is through the Chiefs of Material (CoM), with CoM(Air) being a member of the AFB. It still continues to confuse many for reasons which will be apparent from the following diagrams.

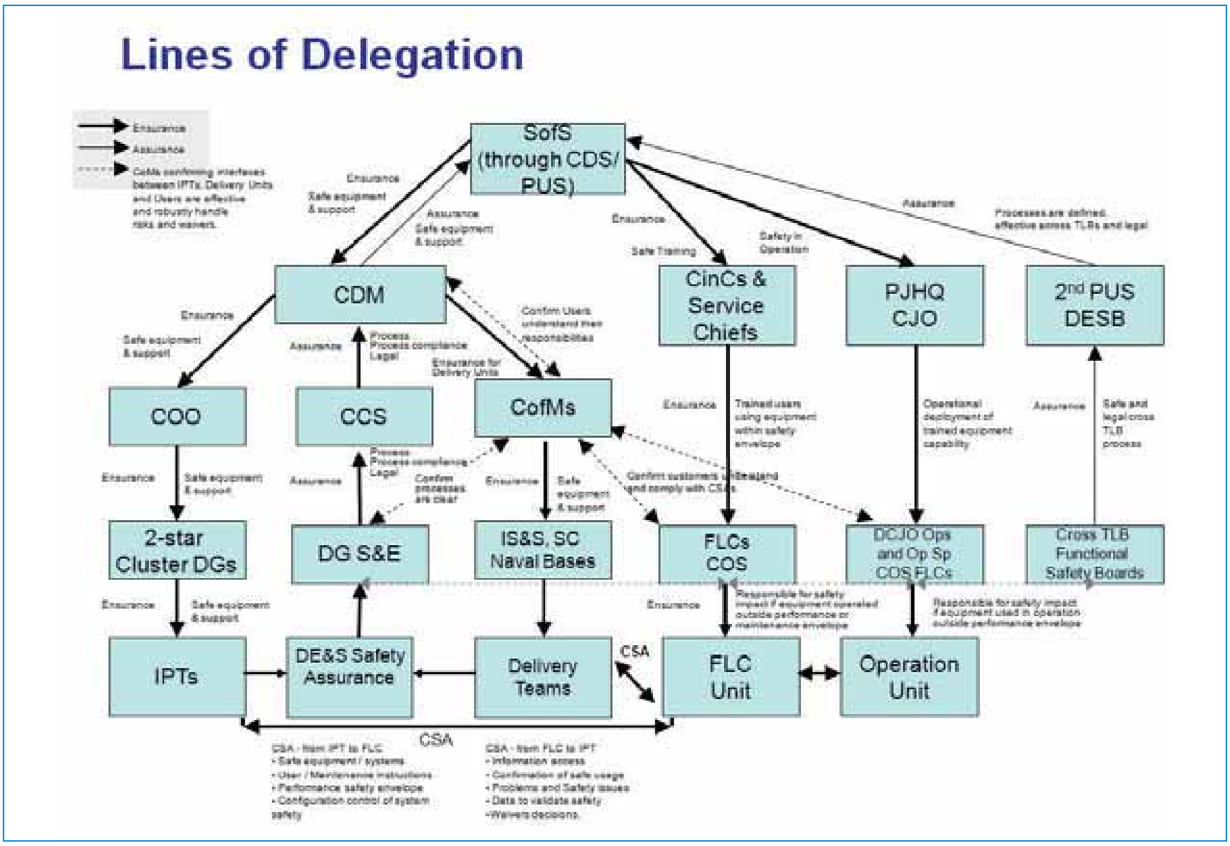

Fig. 13.6: Present MOD/ DE&S Lines of Delegation

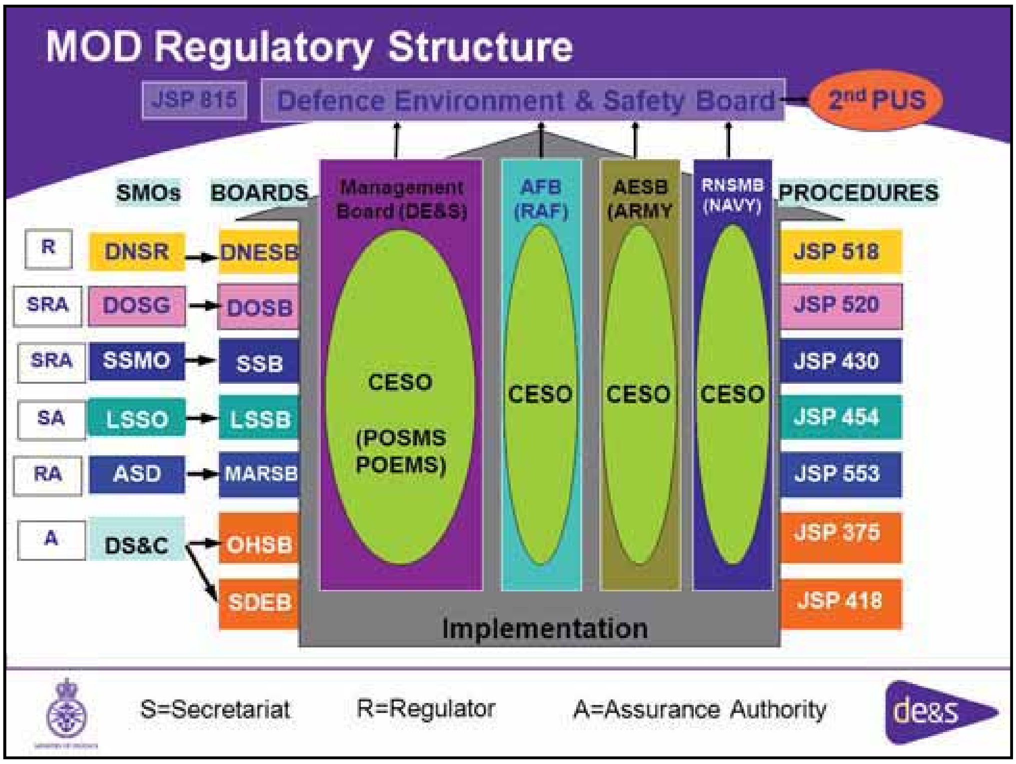

Fig. 13.7: Present MOD Regulatory Structure

Conclusion on MOD airworthiness regime

13.139 During the period 1998 to date, the MOD airworthiness regime suffered from an inexorable descent into the vortex of ever-increasing complexity and confusion. This was due first to the difficulties of constructing and maintaining a simple and coherent safety and airworthiness regime against a backdrop of continuous organisational change; and second to a predeliction in the MOD for complexity as opposed to simplicity. The MOD is not alone in this regard. The instinctive reaction of many governmental organisations to problems is the creation of more complexity, not less, and the 'bolting-on' of more process, procedures, boards, committees, working parties, *etc.* rather than stripping away the excess and getting down to the essential elements. The net result for the MOD was, unfortunately, an increasingly complicated safety and airworthiness system which was accompanied by a significant weakening of airworthiness oversight and culture during the period leading up to the loss of XV230 in September 2006. Over the past decade, responsibility for risk and risk management has been divided, dissipated and dispersed. Risk has effectively been 'orphaned' by being made part of an extended family, with everyone involved but no-one responsible. (See further **Chapter 19**).

Dilution of airworthiness regime

13.140 The period 2000-2005 saw an unfortunate dismantling of some of the key features of the safety and airworthiness regime which had existed in the 1990s. The effect was to undermine further the safety and airworthiness culture and oversight in the MOD.

AESOP Working Group in 2000 and DASB

13.141 A review of the MOD's environmental and safety structures was carried out in 1999 following the launch of the SDR initiative and the formation of the DLO. The review was carried out by a working group of interested parties, known as the AESOP[51] Working Group (AESOP WG). Surprisingly, the AESOP WG did not include any representative from the AOA or the RTSA. Whilst Eng Pol and ADRP were represented (*i.e.* airworthiness policy and acquisition), the representation was only at a low level. It is therefore fair to say that there was no, or at least very little, meaningful airworthiness input into the AESOP study.

[51] All-Embracing Safety Organisation Post-SDR.

13.142 That said, the AESOP study both had very laudable aims and sought to address a number of important issues. The third draft of AESOP's final report[52] recognised that the SDR would have *"major implications for the MOD's management of Safety"*[53] such that *"to do nothing in response is not an option"*. [54] It noted the following in relation to its attempts to improve the existing regime:[55]

> *"Safety and Environmental policies and management systems are becoming increasingly central to the Government's overall strategy. The latter in particular are attracting much interest from Parliament and the media, as well as from environmental pressure groups. Safety is always an issue of great public, Trade Union and employee concern. It is important for MOD to have, and to be seen to have, an effective environmental and safety organisation. MOD will need to reassure its Service and civilian personnel that any new organisation will be an improvement on the present one. Consultations with the staffs affected by changes will need skilful handling."*

13.143 The AESOP study concluded that changes to the MOD's existing safety structures were required in order to match the changing shape of the Department and ensure the development and maintenance of effective and coherent safety management systems. In developing its proposed strategy for change, it began by identifying a set of key principles upon which the MOD's safety systems should be based. These included (amongst other things) the need for: (1) short and clear lines of delegation and accountability, (2) unambiguous ownership of risk by the relevant duty-holder, (3) consistent audit methodologies and (4) proportional allocation of effort and resources.[56] I endorse these sentiments (and embrace them in **Chapters 20** and **21**).

13.144 Regrettably, whilst there was broad agreement upon the principles that should underpin the MOD's safety management systems, it proved impossible to reach consensus within the AESOP WG on the management and organisational structures needed to deliver such a system. Consequently, one of the AESOP WG's key recommendations, that a top level Defence Safety Authority be established with overall responsibility for all aspects of safety and environmental policy and standards, was never implemented. Indeed, the only concrete change that appears to have been implemented following the AESOP study is that the DESC was reformed to become the Defence Environment and Safety Board (DASB) and changed from a ministerial committee to one that was chaired by an official. It is fair to say, however, that this fell somewhat short of the over-arching top level Defence Safety Authority that the AESOP WG considered advisable, in the interests of ensuring that there was a common safety support organisation responsible for pulling together the many and varied strands of responsibility. It is to be regretted, in my view, that this insightful recommendation was not pursued further at the time.

13.145 AESOP does not appear to have considered Airworthiness as a discrete discipline, *i.e.* separate from SHEF.[57]

Retrograde steps which contributed to dilution of airworthiness regime

13.146 Unfortunately, any aspirations of AESOP did not come to fruition. As we have seen above, the airworthiness structure became more and more complex and convoluted. Further, during the period 1998 to 2007, the following retrograde steps were taken which, in my view, led to a further dilution of the airworthiness regime and culture:–

(1) Abolition of "Chief Engineer RAF"

13.147 The post and title *"Chief Engineer RAF"* (CE(RAF)) was a lodestar for airworthiness. The abolition of the post and title of CE(RAF) in 2000 was a mistake and the subsequent subsuming of his role was a retrograde step. From 2000, the airworthiness light shone less brightly. A vital focus point, at the head of the airworthiness

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[52] The AESOP Working Group made an interim report to the Defence Environment and Safety Committee (DESC) in March 1999, following which the DESC endorsed its preliminary findings but requested further investigation of a number of issues raised in the report. Whilst this led to a draft version of a final report, the AESOP team leader informed the Review that it was never published as a formal report, whose contents were endorsed by the DESC.

[53] Paragraph 12 of the third draft of the final report.

[54] Ibid, paragraph 75.

[55] Ibid, paragraph 6.

[56] Ibid, paragraph 18.

[57] Safety, Health, Environment and Firs risk.

apex, was lost. In December 2002, Advantage Technical Consulting made the following recommendation: *"There is a pressing need to bring greater harmony and consistency to the assurance of equipment safety. This will best be prosecuted by the appointment of a 2* champion empowered by the DESB."*[58] This was unfortunately not taken up. The creation of a multi-faceted project-based organisation made the retention of a single, acknowledged point of responsibility for safety and airworthiness all the more important.

13.148 I welcome the decision by the PUS, Sir Bill Jeffrey, and current CDM, General Sir Kevin O'Donoghue, to create the post of Defence Chief Airworthiness Engineer within his organisation in an effort to create the focus for the MOD that was once provided for the RAF by CE(RAF). However, welcome though this initiative is, I believe that there is a need to go considerably further and I make detailed recommendations regarding the future role, duties and position of a CE(RAF) in **Part VI** of this Report.

(2) Demise of full Airworthiness Audits and Support Authority Reviews

13.149 With the demise of the role of CE(RAF), there were fewer full Airworthiness Audits and the rigorous airworthiness review process known as *"Support Authority Reviews"* which had been conducted on a regular basis in the days of Logistics Command disappeared.

13.150 There was a perception in some quarters that such Airworthiness Audits were 'something of an imposition' and not 'adding value' and that to get rid of them would save money. They did not properly reappear again until late 2005, when they were re-started by an AD EngPol (who obtained agreement that that they could take place at the same time as Defence Equipment Safety Group (DESG) audits covering generic equipment safety, health and safety aspects, and environmental aspects). There were audits of IPTs during the period 2000 to 2005. These tended, however, to focus on process and procedure. These initially comprised 'compliance audits' conducted to ensure that IPT staffs were 'following local procedures' and 'surveys' to check the implementation of Safety Management Procedures; and subsequently included 'second party audits' of IPT safety management activities which were introduced under the *aegis* of AD EngPol AW&SHEF.[59] IPTs were also required to report to the Fixed Wing Airworthiness Management Group (FWAMG) on a regular basis using the airworthiness 'Scorecard' method.

13.151 In the days of the CE(RAF), periodic airworthiness reviews, known as *"Support Authority Reviews"*, were conducted of each aircraft type. These were penetrating, rigorous and highly effective. They were conducted in a formal manner in accordance with the then applicable regulations.[60] They were chaired by the CE(RAF) himself. They brought together senior engineering expertise which brought scrutiny to bear. Senior officers in charge of each aircraft type were obliged to make presentations justifying the airworthiness of their aircraft. These were formal 'set piece' meetings in which the CE(RAF) himself played an active role cross-questioning. The presence of the CE(RAF) gave *"a very immediate incentive"* for such presentations to be prepared with great care. They normally were. These meetings were pieces of *"grand theatre",* as Sir Sam Cowan put it in his oral evidence to the Review, with *"a huge gap between the 4-Star 3-Star officer and the poor chap who is marched in to give an account".* But that was the point. Everyone recognised that they had to be on their mettle and weaknesses in the airworthiness case would be exposed. The *"Support Authority Reviews"* had the salutary effect of putting airworthiness at the top of the agenda and keeping it there in everyone's minds. As one former AD(Eng)Pol put it: *"You knew you had to be on top of your airworthiness game. You would get skinned alive if you were not and did not know exactly what was happening to your fleet."*

(3) Downgrading of level at which FWAMG chaired

13.152 There was a steady downgrading of the level at which the Fixed Wing Airworthiness Management Group (FWAMG) was chaired.

13.153 In June 1987, the then CE(RAF), Sir Colin Terry, formed the FWAMG as a specific 'airworthiness' forum. Its terms of reference were *"to monitor, co-ordinate and report on all aspects of equipment airworthiness/ safety relating to MOD fixed-wing aircraft"* and to report every six months to the Defence Aviation Safety Board[61]

[58] *"Safety Process Review"*, dated 23 December 2002, Advantage Technical Consulting, Summary, paragraph 10.

[59] See the Report of AD EngPol on Air Equipment Safety in DLO E&S Report 2003, page 20.

[60] AP100A-01, Leaflet 170 and Business Procedure E1970.

[61] Predecessor of the MOD Aviation and Regulatory Safety Board (MARSB).

via the Aviation Safety Steering Grouup (ASSG) Chairman (with copies to the full ASSG membership) *"on equipment airworthiness/ safety of the MOD [fixed wing] aircraft fleet, with a summary of issues, actions and recommendations for any significant safety policy matters."*[62]

13.154 The FWAMG was chaired by Sir Colin Terry whilst he was CE(RAF). Thereafter, there was a steady downgrading of the level at which FWAMG meetings were chaired. Following Sir Colin Terry's retirement, FWAMG was chaired by DGSM RAF (2-Star level). From January 2000 to February 2002 FWAMG was chaired by D Tech (Air) (1-Star level). From February 2002 onwards FWAMG was chaired by a 1-Star officer, D Log Support (Air) (which under a subsequent re-organisation was re-titled D Tech (Air)). The Fourteenth FWAMG meeting in January 2004 was chaired at Group Captain level. The Fifteenth FWAMG meeting on 16 June 2004 was chaired at 1-Star level but by a pilot who had no engineering background. It is striking that, in 2004, there was a *"serious discussion"* as to whether FWAMG still had any purpose and whether it should be abolished. It is to his credit that, on 19 December 2004, George Baber wrote to AD Eng Pol arguing (successfully) for FWAMG's retention:

> *"Given that Airworthiness... should have primacy in all that we do, it would be extremely off, and probably indefensible, for such a forum not to exist. The FWAMG is the only forum attended specifically by PEs (rather than IPTLs) and the specific remit to discuss AESM [Airworthiness & Environment Safety Management]."*

(4) Dilution of technical support services to air – formation of TES

13.155 There was a dilution of the technical support services available to air IPTs following the creation of the 'purple' Technical Enabling Services (TES).

13.156 In 2004, as a result of further DLO internal re-organisation, the TES was formed by integrating the technical support services for land, sea and air domains. This was said to lead to efficiencies through cuts in personnel. Nevertheless, it led to the loss of services dedicated to support Air IPTs and *"hampered the IPTs ability to understand and analyse equipment serviceability and maintenance trends"* when there were already difficulties arising from trend monitoring using MDS[63] data. The RAF and early Air domain of the DLO had extensive in-house data analysis capabilities associated with RCM and fault trending generally. As the organisation came under ever increasing financial pressures, and associated or additional headcount reductions, those parts of the organisation not in the front line of delivering primary outputs were cut mercilessly. As a result, the ability to exploit maintenance data (such as Nimrod MDS defect records) was severely reduced. IPTs did not have the internal capacity to do the work themselves, and their already hard-pressed budgets could not support outsourcing of this work, even assuming that some third party could be found with the necessary knowledge and expertise.

(5) Downgrading of aircraft engineering skills

> *"It is very easy for people who have never operated aeroplanes to make sweeping judgments that you do not need any particular expertise to look after an in-service aeroplane. It is common sense that you do."(Former AD Eng(Pol))*

13.157 In my view, there was an insidious downgrading and under-valuing of engineering skills at all levels in the MOD during the period 2000 to 2006. This was exemplified most starkly by the abolition of the headline post and title of CE(RAF). But it also manifested itself in variety of other ways:

(1) The DTech Air post was one half of the Air Systems organisation, reduced in capacity and capability.

(2) An attempt to remove the post of AD(Eng)Pol.

(3) The decline in numbers of RAF engineers reaching the top echelons in the past ten years. (The singular achievements of the immediate past Chief of Material (Air), Sir Barry Thornton, who was a long-standing Member of the Air Force Board, are rare and have much to do with his own outstanding abilities).

[62] FWAMG Terms of Reference, 2003 edition.

[63] Maintenance Data System.

(4) Few of the immediate line managers and reporting officers for Air IPTLs had engineering backgrounds. They comprised a navigator (2002 to 2003), a supply officer (2004), a pilot (2004 to 2005) and only in 2005 an engineer. It is noteworthy that, in 2008, DE&S appointed a highly competent and distinguished Naval Architect, with no previous experience of aircraft acquisition or support, to head the air transport, refuelling and reconnaissance IPT grouping including Nimrod.

(5) The abolition of Officer in Command Engineering (OC Eng) at RAF Kinloss in the wake of the imposition of the 'Trenchard' model in place of the 'Binbrook' model.[64] This meant that the dilution of engineering oversight was mirrored at the station level by the removal of the key engineering figure at Base Headquarters and the distribution of engineering personnel to non-specialist leadership. It should be noted that the BOI recommended that consideration be given to reinstating the position of OC Eng at RAF Kinloss[65]. Wing Commander Steve Wilcock was duly appointed to the post of OC Eng RAF Kinloss in April 2007. His skilled leadership, knowledge and hard work has immeasurably strengthened engineering and morale at RAF Kinloss.

13.158 There was an increasingly prevalent view and vogue, which gained currency at ADRP in Abbey Wood and other quarters, that engineering qualifications were less of a pre-requisite for many posts which hitherto might have been the case because: (a) increasing amounts of in-service support for aircraft came from industry; and (b) 'generalist' business management and financial skills and MBAs were required more as the Armed Forces 'modernised' post-SDR. In my view, this was a mistaken and blinkered approach which failed to have regard to the highly technical and specialist nature of aviation and aero-engineering. Heavier-than-air machines are different. Keeping them flying safely is technically very complicated. A safe system requires skilled and qualified engineers at all levels. This is especially true in the military context with the need to be instantly responsive to changing operational and strategic needs.

(6) Demise of Inspectorate of Flight Safety

13.159 With the demise of the Inspectorate of Flight Safety (IFS), the RAF lost a valuable limb of the airworthiness safety regime.

13.160 DASC was formed on 1 April 2002 with 35 staff from the IFS. As part of the 'purpling' exercise, elements of the RAF were replaced by Royal Navy and Army personnel to form the joint DASC unit. Whilst DASC fulfilled the requirement for a joint overarching policy maker, the RAF lost a large proportion of its dedicated Flight Safety staff in the formation of the unit and its 'Flight Safety' communication channel. Given its wider function, DASC did not provide the same support to RAF Stations that IFS had previously afforded. The void left by the formation of DASC could not be filled by the few Flight Safety staffs at HQ STC and HQ PTC.

13.161 Since the restructure of the Group and Command Flight Safety Organisations (FSO) in 1996, the RAF had lost over a half of its Flight Safety personnel. The feelings expressed at the time that, with the formation of DASC, the RAF's Flight Safety structure had been reduced to an unacceptable level have much force:

> *"...the RAF FS organisation had been decimated over the last 8 years. DASC was not seen by FL as an adequate replacement for IFS, and the RAF Commands had not been provided with the assets to "fill the gap". .... The perception at Stn and Sqn level was that FS was not being properly supported, with RAF FS interests only represented by the Command FS staffs. Furthermore, the gapping over the last 2 years had sent a poor FS message to all our units."*[66]

(7) Demise of the Role Office

13.162 In the 1990s, the Role Office at Strike Command at RAF High Wycombe had played a number of important roles. In particular, it provided logistical support to operations and a point of contact, or interface, between Strike Command,[67] the Units and Group Headquarter Staffs.[68] The Role Office also played a key role within

[64] Models of Base organisation (QR640). The 'Trenchard' model took effect at RAF Kinloss by way of a pilot scheme between early 2005 and early 2007.

[65] BOI Recommendation (i).

[66] These concerns voiced at the STC Flight Safety Symposium, 3 June 2003.

[67] Now Air Command.

[68] STC/7/20/AO Eng & Supply – Strike Command Role Office and Airworthiness Responsibilities (attaching Note to Engineering and Supply Staffs No. 18 on Responsibilities of Strike Command Role Offices).

Strike Command's airworthiness framework. Its responsibilities included: (1) advising the Air Staff on operational plans, airworthiness, fitness-for-use and safety issues; (2) evaluating the impact of over-arching policy changes; (3) analysing trends of ground and air incidents and providing specialist comments on BOIs; and (4) evaluating the impact of emerging quality assurance and health and safety policies on current operations.

13.163 The Review interviewed many witnesses who spoke of the Role Office in glowing terms. It was variously described as *"the focal point for all engineering matters"*, *"the day-to-day airworthiness gurus", "the champions of capability"* and *"a centre of strength/excellence who supported the IPTs"*. Unfortunately, however, the Role Office was substantially wound down and some of its personnel rusticated to different Force Headquarter bases as part of a reorganisation of Group staffs in about 2005. These moves assisted the amalgamation of the headquarters of Strike Command and Personnel and Training Command which formed Air Command. The decision was made to locate the amalgamated two Headquarters at RAF High Wycombe, requiring a loss of 1,000 personnel. The rustication of some Group staff was a means of making the joint organisation fit into RAF High Wycombe.

13.164 A number of witnesses testified that a significant effect of the rustication of Group staffs was the loss of the Role Office. In particular, nobody at RAF Kinloss seemed to know quite what had happened to the Role Office, or where it now sat. One view was that, whilst it was supposed to now exist at Force Headquarters on the Unit, the reality was that it did not. Another view was that it remained in the shrunken group within Air Command. In any event, it is plain that the Role Office has at the very least been seriously demoted, if not lost altogether, and this is widely recognised as something to be regretted. In particular, a former Wing Commander Nimrod in the old HQ No. 3 Group explained to the Review that the Role Office would analyse trends across the Units and was responsible for carrying out external audits of the Stations. It is not at all clear that either of these roles is presently being fulfilled by any other body.

(8) Removal of 2-Star tier from Letters of Delegation chain

13.165 The airworthiness structure was further weakened by the removal, on 1 April 2005, of a layer of Letter of Delegation (LOD) holder above IPTLs.

13.166 Prior to this date, IPTLs held LOD airworthiness responsibilities delegated to them from the 2-Star DG ES(Air). On 1 April 2005, following a proposal put forward by the DLO and taken up by ADRP in Abbey Wood, the 2-Star tier was cut out of the LOD chain of delegation and IPTLs henceforth held LODs direct from the 4-Star level of CDL and CDP. It was in this context that George Baber remarked to the Review that he felt *"abandoned".*

13.167 In my view, the removal of this senior link from the LOD chain of delegation further undermined and weakened the airworthiness delegation chain. An LOD delegator has a personal, *i.e.* non-delegable, duty to satisfy him or herself that his or her delegated responsibilities are being discharged properly. Delegation is not abrogation. It involves a continual reciprocal duty. However, the 4-Star LOD delegator delegating airworthiness responsibility direct to IPTLs is in a difficult position for a number of obvious reasons. First, because the former is so far removed in the chain of command from the latter, it would make it difficult to satisfy him or herself that all is well. Second, because with the vast range of responsibilities and people under his command, the 4-Star would find it difficult to give enough personal attention to each delegatee at that level (and the formidable authority gradient would inhibit access the other way). Third, unless an aviation engineer, a 4-Star is likely to have limited knowledge of airworthiness issues. Fourth, the 4-Star would not be making the relevant decisions affecting the IPTLs' business; these would be made at the two-star level which, *ex hypothesi*, would have no responsibility for the airworthiness impact of those decisions. For all these reasons, therefore, the decision to cut out the 2-Star tier in the chain of LOD holders was ill-advised. This has been recognised and the system has now been restored to that which prevailed previously.

(9) 'Rationalisation' of AD Eng Pol with ADRP

13.168 At some stage, a proposal was put forward by ADRP in Abbey Wood to get rid of the post of AD(Eng)Pol and the two SO1 posts and have engineering policy done by an SO2 lead within a more 'generic' organisation, *i.e.* what would eventually become the DE&S. This would have involved merging the role of AD Eng Pol with ADRP and placing within a 2-Star chain of command that had no specific aviation competence. This proposed change was strongly resisted by the AD(Eng)Pol and DG ES(Air) at the time because of: (a) the importance of having airworthiness of in-service aircraft managed by people with an aviation and engineering background; and (b) the importance attached to Front Line Command (FLC) input to the development of Joint Air Publications.

13.169 AD(Eng)Pol ran an engineering policy group forum at which all the FLCs were represented. AD(Eng)Pol's staff would draft policies, circulate these to FLCs and the engineering policy group would discuss and endorse JAP changes. AD(Eng)Pol formed an important link between the FLC and the formulation of engineering and airworthiness policy. If the post of AD(Eng)Pol had been abolished and the generation of JAP policy left to a Squadron Leader, this would have been a serious mistake for obvious reasons of lack of experience and credibility. Such a Squadron Leader: (a) would have been unlikely to have had the relevant breadth of knowledge or experience; (b) would have had little or no credibility with FLCs; and (c) would have been just part of wider 'safety' management group reporting to civil servants with no aviation or front line experience. Suddenly to have given this to somebody with no air background and who was not an engineer and who was solely relying on advice of civil servants who had never worked on front line would amount to a serious dilution of airworthiness experience. It would, in the opinion of one observer, have been 'barking' to have abolished the post of AD(Eng)Pol, but *"this was very much the culture at the time"*. Resistance was successful until the post of AD(Eng)Pol was moved into DE&S under the Director of Corporate Services to become Director Air Safety. George Baber was the first appointee to this post in the summer of 2006.

(10) Dilution of 'airworthiness' to form part of SHEF

13.170 As processes became increasingly 'purple' and 'tri-Service', the discipline of 'airworthiness' increasingly became regarded and treated as just another part of 'SHEF', i.e. Safety, Health & Environmentaland Fire risk. One can identify many potential reasons for this, but most potent was simply the lack of understanding by the non-air community of the complexity of airworthiness management. All RAF personnel (and other aviation specialists) inherently 'get' airworthiness because it is part of the daily fabric of their working life. However, those from non-aviation backgrounds often fail to appreciate the specialist issues and problems involved in keeping aircraft flying safety. In the larger, tri-Service organisations aircraft support activity once carried out in-house by the RAF has been subsumed within a wider 'safety' ambit in which the majority of senior decision-makers have been from other disciplines.

13.171 I have identified evidence of significant and sustained reluctance and lack of understanding over recent years by the DLO senior organisation to recognise the special demands of aviation safety, which has manifested itself in the progressive dismantling of the supervision of those regulating and maintaining airworthiness. This lack of understanding is exemplified by the following statement by Sir Sam Cowan to the Review:

> *"You know, airworthiness is a subset of general safety, and there was the whole business of the safety of the equipment; the general health and safety requirements surrounding the area; and then, of course, airworthiness in terms of, ..., what happens to the equipment in the air."*

13.172 I am pleased to see that within DE&S this major error has begun to recognised and is being addressed. However, strong structural steps need to be taken to ensure that, in the future, attitudes and behaviours cannot prejudice proper management of this highly specialised safety discipline (see **Chapter 21**).

Summary

13.173 Whilst it is difficult to point to particular effects which the above ten factors may have had individually, there is no doubt in my view that, collectively, they served significantly to undermine the efficacy of the airworthiness structure during period 2000 to 2005. They were both causative and symptomatic of a progressive weakening of the airworthiness regime and structure. They stemmed from continual organisational change, an insidious shift in culture, and the lack of sufficient insight into the effect that seemingly logical or innocuous changes in safety structure might have.

'DISTRACTION'

"It must have been very hard to have been in the DPA or DLO at this time. Re-structuring, organisational changes, new initiatives and reports tumbled one after another, with little time to bed down. They had to support two operations and provide savings which had already been taken by LTC [Long Term Costings]." (Former senior Army officer)

"There are lots of 'change managers' but nobody manages change." (a JNCO line engineer, RAF Kinloss).

13.174 There is no doubt, in my view, that dealing with the waves of organisational change and the cuts and savings stemming from the SDR and 'Strategic Goal', proved a major distraction for many in the DLO, particularly during the period 2000-2006. The overriding imperative during this period was to deliver the cuts and change required. This meant that the lion's share of attention, focus, time, energy and resources was devoted to these 'strategic' priorities. Inevitably, the adoption of 'change' and cost reduction as central 'strategic' goals was going to relegate risk management, safety and airworthiness to a secondary position.

13.175 This was particularly true in the case of the Nimrod IPT at this time.

Causation

"The responsibilities of an IPTL at the time were awesome. An IPTL was responsible for putting place everything you need to keep an aircraft flying: all of the engineering, all of the Maintenance Procedures, providing all of the parts, providing and managing all of the staff, managing the finance, managing the contracts. They were doing this under severe financial challenges in a very fluid environment with significant operational pressures. … It was one hell of a juggling act." (An AD(Eng)Pol at the time)

13.176 In my view, the organisational pressures, failures and weaknesses outlined above were a causal factor in the loss of XV230. They significantly contributed to the failures of the Nimrod IPT to ensure the airworthiness of the Nimrod fleet.

13.177 As set out in **Chapters 10** and **11**, there were significant failures by certain individuals within the Nimrod IPT in relation to the Nimrod Safety Case (NSC) which contributed to its poor quality and failure to capture the risks which led to the loss of XV230. The evidence suggests that the Nimrod IPT was under increasing pressure during the period 2000-2005 as a result, in particular, of: (i) the demands of delivering the cuts and savings required by the Strategic Defence Review and 'Strategic Goal'; (ii) the demands of delivering the 'Transformation' required by Defence Logistics 'Change' programme; (iii) the demands of supporting the growing operational roles of the Nimrod MR2 and R1 in the conflicts in Afghanistan and Iraq (Operations 'HERRICK' and 'TELIC'); (iv) the demands of extending the Out-of-Service Date of the MR2 as a result of delays in the In-Service Date of the MRA4; and (v) the wide role and remit of the Nimrod IPT.

13.178 These organisational factors, *i.e.* the cuts, change, dilution and distraction, go some way to explaining (whilst not excusing) the personal failures of George Baber and Michael Eagles. They were, to a significant extent, distracted by and preoccupied with delivering the cuts and change required by the 20% 'Strategic Goal' and Strategic Defence Review and subsequent initiatives, and consequently gave materially less priority and personal attention to the NSC and airworthiness issues during this period than was appropriate. The weakening of airworthiness culture meant that 'business' goals and achieving savings and efficiency targets became the paramount focus of their time and attention, at the expense of safety and airworthiness matters such as the NSC. The weakening of the airworthiness regime meant that there were insufficient checks and balances and less oversight of the Nimrod IPT than was required in all the circumstances during this period.

Evidence of Nimrod IPTL and IPT

13.179 There was evidence from George Baber and others that the Nimrod IPT faced very considerable challenges which increased during the period 2000-2005. These challenges included, in particular: (a) pressure to deliver the savings and change required by the Defence Reviews; (b) pressure to move towards 'partnered' in-service support arrangements as part of the 'transformation' process; (c) the requirement to take on (indirect) responsibility for 'Depth' maintenance at RAF Kinloss; (d) increasing organisational and procedural changes, *e.g.* the change from Release to Service (RTS) to General Airworthiness Release Procedure (GARP); (e) the broad remit of the Nimrod IPT which included *e.g.* responsibility for the Battle of Britain Memorial Flight (BBMF); (f) responsibility for major projects such as Helix; (g) the increasing demands of supporting the growing operational roles of the Nimrod MR2 and R1 in the conflicts in Afghanistan and Iraq; and (h) the demands of extending the Out-of-Service Date of the MR2 as a result of delays in the In-Service Date of the MRA4. The job of Nimrod IPTL during this period has been described as *"awesome".* George Baber said in interview with the Review that, at times, as Nimrod IPTL there was a *"lack of supervision"* by his superiors and he felt *"abandoned"* when the 2-Star tier of airworthiness delegation above him was removed.

13.180 In my view, there is considerable force in this. The evidence strongly suggests that: (i) George Baber was so preoccupied with his other duties that he gave less priority and personal attention to the NSC and safety and airworthiness issues than was appropriate; (ii) the Head of Air Vehicle at the Nimrod IPT (NIM(ES) AV), Michael Eagles, was so preoccupied with negotiating Nimrod Integrated Support Contracts (NISC 2 and 3) that he gave less priority and personal attention to the NSC and safety and airworthiness issues than was appropriate; (iii) the Safety Manager, Frank Walsh, lacked oversight and insight in relation to the NSC and airworthiness issues which he was left to handle; (iv) there was a general sense in which 'business' issues, and achieving savings and efficiency targets, was paramount and airworthiness and safety issues were less of a priority and would look after themselves; and (v) IPTs and IPTLs were 'empowered' and very much left to their own devices. Further, the *"awesome"* scale of the Nimrod IPTL's role is evident from the LOD George Baber received from DG ES(Air) on 26 November 2003. It was in standard form, but was in many ways a remarkable document for: (a) its length and complexity; (b) the number of regulatory references in it; (c) the great emphasis it placed on achieving the DLO 'Change' Programme; and (d) the relatively little emphasis it placed on the delegated airworthiness responsibility (which forms the last of 31 paragraphs).

13.181 The debilitating effect of the sheer volume of change has been felt at all levels of the Nimrod community, as QinetiQ noted in a 2008 Report:[69]

> *"In recent years there have been a number of change programmes that have had a direct impact on the Kinloss structure and the NLS [Nimrod Line Squadron] in particular. While each of these may have delivered benefits in one form or another, the sheer volume of the changes has had a debilitating affect on the personnel who work in the NLS. It is suggested it is time to revaluate the impact of these programmes to ensure benefits were or are being realised, that the total change programmes have not weakened the make up of NLS and that the communication strategy adopted for these activities continues to be effective."*

Lack of supervision and oversight of Nimrod IPT and IPTL

13.182 In my view, there was a lack of adequate supervision and oversight of the Nimrod IPT and IPTL during this period. This meant that the Nimrod IPT and IPTL were very much left to their own devices as to striking the balance between the allocation of time and resources to project as opposed to safety issues. It also meant insufficient regular re-iteration of functional values such as safety and airworthiness. But, as I explain below, lack of supervision was, in a sense, the inevitable product of the 'project-orientated' structure set up by the SDR which deliberately aimed to put decision-making into the hands of one person by 'empowering' IPTLs and 'de-layering' above them and allowing them to chose to be 'dual-hatted', *i.e.* to be their own Project Engineers. The airworthiness regime in the period 2000 to 2006 was inadequate to the task. The *"long screwdriver"* of the CE(RAF) would have been better suited to inject orthogonal values into IPTs during this period as it had been in the early days of MDGs.

[69] QinetiQ *Nimrod Fuel System Safety Review Report* dated October 2007, paragraph J 2.3.6.

13.183 In my judgment, the lack of supervision was a problem of the system and changes in operation during this period rather than something which is appropriately the subject of criticism of those in the delegation or authority chain above. I say this for five reasons.

13.184 First, as emphasised above, the whole point and construct of IPTs was to make them 'self-standing' project-orientated bodies led by strong IPTLs who would be 'empowered' to take all relevant decisions covering the life of the platform. This was the model, and intent, of the fundamental shift brought about by the SDR, *i.e.* to move from 'functional-oriented' to 'project-orientated' ways of military equipment acquisition and management.

13.185 Second, the supervisory structure established within the DLO following the SDR reforms did not easily lend itself to strong, functional engineering-led, hands-on supervision of air IPTs. George Baber received delegated airworthiness authority directly from the 2-Star post DG ES(Air). DG ES(Air), however, had inherited a 'flat' management structure and sat above approximately 25 IPTs and could not, in practice, exercise personal supervision or responsibility for 25 IPTLs, not least because of the extensive range of other roles and responsibilities which DG ES(Air) was expected to carry out at the time. A new 'cluster' arrangement of IPTs was introduced in 2004. However, as stated above, George Baber's immediate line managers and reporting officers were Air Commodores at 1-Star rank who, until 2005, had no engineering background. He initially reported to a navigator (2002 to 2003), a supply officer (2004), a pilot (2004 to 2005) and only in 2005 did he report to an engineer. The former could not realistically be expected to second-guess what steps he was taking to manage airworthiness in his IPT.

13.186 Third, there were a number of audits carried out on the Nimrod IPT during this period which gave it a clean bill of health. For instance, on 17 February 2004, a Preliminary Report on the Safety Audit of the Nimrod IPT concluded that Nimrod IPT had developed a *"comprehensive and robust (albeit probably expensive) SMS* [Safety Management System]*"*. In September 2005, an ASEMS Procedure audit evaluated the adequacy and effectiveness of the safety and environmental management systems established by the IPTL and concluded that *"the majority of the IPT's activities adequately address the requirements for safety and airworthiness"*. The audit highlighted the following *"Areas of Strength"* of the Nimrod IPT:

1. *"The Nimrod Safety and Environmental Panel was working well, providing the IPT with good two way communications and advice from stakeholders.*
2. *Data held on both the electronic Cassandra Hazard Log and Aircraft Data Configuration Tool was being managed well.*
3. *Staff training records were accurate and up to date.*
4. *The IPT was represented on the Safety Manager's Forum, a mechanism for Safety Managers from various IPT's to share experience and ideas.*
5. *The process for delegating appropriately was robust and thorough.*
6. *Particular praise goes to the BBMF Safety Manager who was managing the BBMF Safety Management System extremely well."*

13.187 Fourth, there was nothing ostensibly which would have suggested all was not well with the Nimrod IPT. Indeed, quite the opposite: for the most part the Nimrod IPT functioned well, particularly in delivering the increasing Front Line capability required by the Afghanistan and Iraq conflicts; and its IPTL, George Baber, would have presented well on all fronts, particularly in the area of airworthiness process and regulation where he had a growing reputation (his standard 'competencies' set was rolled out in the RAF). There would have been little to alert the DG ES(Air) at the time or anyone in the ES(Air) Management Board that any lack of care, priority and attention was being given by the Nimrod IPTL and Head of Air Vehicle in the Nimrod IPT to the NSC. Regular reports were made to the FWAMG as to its progress: see, *e.g.* the report to the Thirteenth FWAMG meeting on 13 June 2003, signed by George Baber, which stated *"The CASSANDRA Hazard Log has been populated by BAE Systems under Phase 1 work, Phase 2 of the task, scheduled for completion 31 Jan 04 will be to mitigate the hazards. QinetiQ has been appointed as the Independent Safety Assessor"*.

13.188 Fifth, whilst it was inadvisable to give IPTLs the option to choose to be their own Project Engineer (PE) as well as IPTL, it was standard practice at the time to give IPTLs who were themselves qualified aeronautical engineers (such as George Baber) the option of being their own PEs. Further, it is difficult to criticise this decision (other than with hindsight) given there was no indication that George Baber was not more capable of fulfilling both roles; indeed, he was intelligent and energetic and would have appeared to be an eminently suitable candidate to be 'dual-hatted'.

13.189 There is a natural inherent tension between the functions of an IPTL, whose role is 'delivery' of the project, on time and within budget, and that of a PE, whose role is ensuring best practice, safety and airworthiness. Where an IPTL is also qualified to be the PE, there will be a natural tendency, for reasons of professional pride, for him or her to elect to fill both roles, whether or not that decision is sensible in the light of other leadership commitments at that stage of the project life cycle. I am aware that, currently, on some large projects, the IPTLs have chosen not to fill both roles, but I believe that this decision is too important to be left to the individual themselves.

Conclusion

13.190 In conclusion:

13.190.1 Airworthiness was a casualty of the process of cuts, change, dilution and distraction commenced by the 1998 SDR.

13.190.2 Organisational pressures, weaknesses and failures were a significant cause of the loss of XV230.

13.190.3 These organisational failures were both failure of leadership and collective failures to keep safety and airworthiness at the top of the agenda despite the seas of change during the period 1998 to 2006.

CHAPTER 14 – PROCUREMENT

> *"The defence ministry's capacity to waste money is legendary. Procurement is a dismal story of delays and extortion. The defence contractors, assured their prosperity is vital to national security, have a captive customer and no incentive to cut costs."*[1] (Philip Stephens, Financial Times, 1998)

> *"Every one of our servicemen and women has the right to know that we are doing everything possible to ensure that every pound of investment in our equipment programme goes towards the front line and is not wasted in inefficient or weak processes of acquisition."* (Former Secretary of State for Defence, the Rt Hon. John Hutton MP, 4 June 2009)[2]

Contents

Chapter 14 deals with Procurement issues and, and answers the following questions:

- What is the Procurement history of the replacement Nimrod MRA4 programme?
- What effect have delays in the MRA4 programme had on the MR2?
- What is the history of Procurement in the MOD generally? What significance do delays and cost overruns in Procurement have for the wider health of Defence In-Service Support?
- What changes in the Procurement system have there been? Have these been effective? Are there current proposals?
- What is the current state of Procurement? Does it pose a risk to the health of other functions of the MOD, in particular In-Service Support and safety and airworthiness?

Summary

1. The Procurement history of the replacement 'Nimrod 2000' (subsequently re-named 'Nimrod MRA4') programme has been one of continuous delays and cost over-runs. 'Nimrod 2000' was originally scheduled to come into service in 2000; but the In-Service Date of the replacement programme subsequently slipped on at least six occasions (in 1999, 2001, 2003, 2004, 2005 and 2008). The current scheduled In-Service Date of the Nimrod MRA4 is now December 2010, *i.e.* over 10 years later. The total cost over-run is currently approximately £789 million.

2. But for the delays in the Nimrod replacement programme, XV230 would probably have no longer have been flying in September 2006, because it would have reached its Out-of-Service Date and already been scrapped, or stripped for conversion.

3. The serial delays in the In-Service Date of the replacement Nimrod 2000/MRA4 programme caused commensurate delays in the Out-of-Service Date of the Nimrod MR2. This has had a baleful effect on In-Service Support for the MR2: (a) because the MR2 was perceived to be 'just about' to go Out-of-Service, it did not benefit from longer-term investment decisions; and (b) because the uncertainty has led to difficulties of planning and sourcing sufficient spares for its remaining expected life.

4. The history of Procurement generally in the MOD has been one of years of major delays and cost over-runs. This has had a baleful effect on In-Service Support and safety and airworthiness. Poor Procurement practices have helped create 'bow waves' of deferred financial problems, the knock-on effects of which have been visited on In-Service Support, with concomitant change, confusion, dilution and distraction (see the post-Strategic Defence Review period 1998-2006 and **Chapter 13**).

[1] Financial Times 1998.

[2] *Hansard* Debates, Thursday 4 Jun 2009: Column 438.

5. The immediate past Secretary of State for Defence, the Rt Hon. John Hutton MP, stated recently in the House of Commons on 4 June 2009[3] that he was not satisfied that the current programme of change in Procurement was sufficient to meet the combat challenges now faced and *"we have no choice but to act with urgency"*. He commissioned a report from a Procurement expert, Mr Bernard Gray, which he was confident would be *"both honest about the scale of the task that confronts us and clear in describing a detailed and radical blueprint to reform the process of acquisition in the MOD from top to bottom"*. He said that: *"Given the size of the challenge that we face, I am in no doubt whatever that change must happen and that it must be radical."* He promised to publish the Report before the Parliamentary summer recess. Unfortunately, the Rt Hon. John Hutton MP resigned the next day. Regrettably, Mr Bernard Gray's Report has still not been published.[4]

6. I understand from Mr Bernard Gray that that the MOD's own figures showed that: (i) the *average* time over-run on MOD procurement projects is currently 80%; and (ii) the *average* cost over-run on MOD procurement projects is currently 40%.

7. These figures are a matter of great concern. Further major 'bow waves' of deferred financial problems (potentially) and other Procurement problems threaten the future integrity of other vital functions within the MOD such as safety and airworthiness, in the event of further punishing rounds of stripping out or squeezing costs from In-Service Support, and the concomitant change, confusion, dilution and distraction that this can bring, as in the past.

8. The recent history of Nimrod and its replacement are classic examples of the fundamental procurement problems which the Bernard Gray Report identifies and seeks to address.

9. The Rt Hon. John Hutton MP, the former Secretary of State, said that addressing the Procurement problem is urgent.

Procurement History of Nimrod replacement programme

14.1 The following brief history of the procurement of the Nimrod replacement programme is taken from published documents all of which are in the public domain.

14.2 In November 1992, the Equipment Approvals Committee (EAC) approved a Request for Information exercise whereby 17 companies were invited to provide responses to the draft Maritime Patrol Aircraft Staff Requirement. Following analysis of the industry responses, the EAC endorsed the requirement and approved an Invitation to Tender phase, whereby four companies (British Aerospace, Lockheed Martin, Loral and Dassault) were invited to provide detailed technical and commercial proposals for an aircraft to meet the endorsed Staff Requirement. Dassault withdrew from the competition in January 1996. Lockheed Martin and Loral merged in May 1996 but maintained their two separate proposals until the competition was concluded.

1996: British Aerospace offer accepted – Initial ISD 2000

14.3 In July 1996 British Aerospace's *"Nimrod 2000"* concept was approved by the EAC and Ministers in July 1996 (later to be re-named *"Nimrod MRA4"*). This involved re-using the fuselages of existing MR2s. In December 1998, British Aerospace was formally appointed as the prime contractor for an order for 21 aircraft with an In-Service Date (ISD) of 2000. Responsibility within the Procurement Executive (PE) for the project moved to the Nimrod MRA4 IPT in November 1998.

[3] Ibid.

[4] Bernard Gray's Report was suddenly published on 15 October 2009, after completion of this Report for printing.

1999: ISD 'slipped' to May 2005

14.4 In late 1998, British Aerospace formally notified the MOD that it had encountered problems with the programme and was unlikely to meet the intended ISD. As a result, the main development and production contact was renegotiated. The EAC approved the changes in April 1999 and the contract amendment was agreed with British Aerospace in May 1999. The ISD was 'slipped' by 55 months to March 2005. The first flight was scheduled for December 2001, with delivery of the first aircraft in August 2004. The ISD was defined as delivery of the seventh aircraft. The original ISD had been set because of expected equipment obsolescence of the MR2 and yet there were no warnings of the problems of continuing with the MR2. As a result of the renegotiation, the programme showed a saving on the original budget. British Aerospace Plc became BAE Systems Plc (BAE Systems) in November 1999 on the merger with Marconi Electronic Systems.

2001: ISD 'slipped' to December 2005

14.5 In 2001, the first flight of the first development aircraft slipped to June 2002 and the ISD to December 2005. The operational impact of the ISD delay was described in the National Audit Office (NAO) Major Projects Report (MPR) as follows:

> *"The consequence of the Nimrod MRA4 in-service slip is that the Nimrod MR2 will remain in service until mid-2008. This slip will delay introduction of the improved Anti-Submarine and Anti-Surface Unit Warfare capability of the Nimrod MRA4 and will require the ageing Nimrod MR2 fleet to be maintained in service longer than expected. The operational impact of this slippage will be partly mitigated by measures already in hand to introduce upgrades to some MR2 systems, notably Replacement Acoustic Processors (RAP), navigation systems, data links and other communications to address interoperability issues. The RAP programme has benefited by making use of acoustic processors procured for Nimrod MRA4."*[5]

14.6 After the publication of the NAO 2001 MPR, a routine review of the requirement for future maritime reconnaissance capability concluded that only 18 aircraft were required for the operational task. In the NAO 2002 MPR it was noted that the MOD had concluded a Heads of Agreement with BAE Systems. In order to mitigate risk of further delay, it was agreed to take an incremental approach to aircraft delivery. The NAO 2002 MPR again explained the operational impact of the ISD (additional wording to the above paragraph is underlined):

> *"The consequence of the Nimrod MRA4 in-service slip is that the ageing Nimrod MR2 will remain in service until mid 2008, <u>longer than expected</u>. This slip will delay introduction of the improved Anti-Submarine and Anti-Surface Unit Warfare capability of the Nimrod MRA4. <u>Nimrod MRA4 has a world wide autonomous operational capability with a reach extending to some 6,000 miles. This is a considerable improvement on the current MR2 capability which is some 3800 miles. Other capability improvements over MR2 include time on station, a major improvement in overall sensor performance and weapon carrying capability. Utilising state-of-the-art equipment, the crew complement has been reduced by 25%.</u> The operational impact of this slippage will be partly mitigated by measures already in hand to introduce upgrades to some MR2 systems, notably Replacement Acoustic Processors (RAP), navigation systems, datalinks and other communications to address interoperability issues. The RAP programme has benefited by making use of the acoustic processors procured for Nimrod MR4."*[6]

[5] NAO Major Project Report 2001 dated 19 November 2001, page 120.
[6] NAO Major Project Report 2002 dated 2 December 2002, page 120.

2003: ISD 'slipped' to March 2009 and £394m over budget

14.7 In late 2002, BAE Systems disclosed further slippage and an appreciation of the extent to which the technology risks of the programme had been under-estimated, together with the consequent cost pressures on BAE Systems. In February 2003, the MOD announced that the contract would have to be restructured. Commenting to the House of Commons Defence Committee (HCDC), the then Chief of Defence Procurement (CDP) stated that the difficulties on Nimrod stemmed from "...*"the design challenge being hugely underestimated by industry"*. The HCDC went on to comment: *"...perhaps as a result of continuing to see the project as if it were the adaptation of an existing aircraft, as it was originally intended to be when in fact some 95 per cent of the aircraft is new"*, and *"With the MOD having negotiated a fixed price contract with the prime contractor to manage the risk of delivering this project, the puzzle is why the firm (and indeed the MOD) so badly miscalculated. The previous Chief of Defence Procurement, Sir Robert Walmsley, told us in January 2002 that from the Nimrod case there were lessons to learn about accepting too readily a bid from industry (BAE Systems in this case) which was going to be too technically demanding to deliver within the cost and time offered"*.[7] Additionally the fixed price contract, the consequent cost pressure and financial losses was said to have provided little incentive for BAE Systems to deliver. As a result, the project was £394m and 71 months over the original approval. On 19 February 2003, the MOD announced that it had reached an agreement with BAE Systems to change the fixed price contract to a Target Cost Incentive Fee contract. The ISD was slipped to 2009 with first flight likely to occur in mid-2004. The operational impact statement reverted to word-for-word that of two years previously.

2004: ISD 'slipped' to September 2009 and cost increased by £408m

14.8 The 2004 NAO MPR reported the MRA4 programme had suffered a further cost increase of £408m and a slip in the ISD of 6 months to September 2009. However, the first flight was made in August 2004. The Secretary of State announced that reductions in the submarine threat meant that 16 Nimrod MR2 aircraft could be replaced by around 12 MRA4 aircraft. This would clearly free up some resources. The NAO Operational Impact statement stated:

> *"The consequence of the Nimrod MRA4 ISD slip is that the Nimrod MR2 will remain in service until March 2011. This slip will delay introduction of the improved Anti-Submarine and Anti-Surface Unit Warfare capability of the NimrodMRA4 and will require the ageing Nimrod MR2 fleet to be maintained in service longer than expected. The operational impact of this slippage will be partly mitigated by measures already in hand to introduce upgrades to some Nimrod MR2 systems, notably the Acoustic Suite (AQS 971), navigation systems, data links and other communications to address interoperability issues. The AQS 971 programme has benefited from making use of acoustic processors procured for Nimrod MRA4 AQS 970 programme."*[8]

2005: ISD 'slipped' to 2010 and further cost growth of £100m

14.9 The 2005 NAO MPR reported the MRA4 programme suffered a further increase in costs of £215m and a further slip in the ISD of 12 months (to make the overall programme affordable within Departmental funding constraints). It noted that the variation in-year to the ISD *"did not impact support budgets for MR2 or MRA4. The support requirements to meet the revised ISD will be assessed when the approval for production is received, with the target of containing costs within existing provision"*.[9] In other words, there was no new money. The operational impact statement stated that *"…either the Nimrod MR2 would remain in service beyond the current out-of-service date of March 2011 or a capability gap will be endured…"*.[10] The 2006 NAO MPR reported no change to the ISD. During 2007, there was a saving of £16m, but again no change to either the ISD or to the impact statement.

[7] House of Commons Select Committee on Defence: Eight Report of Session 2002-03 (HC694), paragraphs 60 and 61.

[8] NAO Major Project Report 2004 Project Summary Sheets, page 71. (10 November 2004)

[9] NAO Major Project Report 2005 Project Summary Sheets, page 72. (25 November 2005)

[10] NAO Major Project Report 2006 Project Summary Sheets, page 88. (24 November 2006)

2008: ISD slips a further 3 months

14.10 In 2008, the NAO MPR reported that the Nimrod MRA4 programme was a key factor in a forecast aggregate increase in the cost of projects of £205 million. The MRA4 programme was reported to have suffered a further £102 million increase in costs and a further three month slip in the ISD to December 2010. The MPR noted that:

> *"The project has had a long history of delays (a total of 89 months was reported in Major Projects Report 2007) and cost increases (£687 million reported in Major Projects Report 2007, a 24 per cent increase over approved costs) reflecting a mixture of technical problems, resourcing shortfalls and the need to incorporate the cost increases within the constrained defence budget."*[11]

14.11 Thus, the total slippage in the MRA4 ISD is currently over 10 years with the consequential increase in the Out-of-Service Date (OSD) of the MR2. According to the NAO 2008 MPR, the total cost overrun of the MRA4 programme is approximately £789 million.

Baleful effect of moving OSD of MR2

14.12 In my view, it is clear that the regular moving back of the OSD of the Nimrod MR2 has had a baleful effect on the aircraft, namely *e.g.*:

14.12.1 As long ago as July 1990, a recommendation for the replacement of certain Nimrod Hot Air Ducts was not pursued *inter alia* because of *"the now planned earlier retirement of the aircraft"*.[12]

14.12.2 In the late 1990s, it was decided that Nimrod fleet should not be put onto the Logistics Information Technology Strategy (LITS) system because of its impending OSD.

14.12.3 In July 2006, the Nimrod IPT decided not to proceed with implementing BAE Systems' recommendation following the XV227 incident for the fitting of a hot air leak warning system because it was not practicable to do so given the length of time it would take to introduce such a Mod into service compared against the MR Mk2's OSD.[13]

14.13 I turn to explain next the changes to the procurement system that occurred during the procurement history of Nimrod MRA4.

Changes in Procurement System

14.14 Nimrod MRA4 started its procurement life as part of the process known as the 'Downey Cycle' whereby a military platform programme went through the seven stages of 'Concept, Feasibility, Project Definition, Full Development, Production, In Service, and Disposal'. One of the perceived problems with the Downey Cycle, however, was insufficient funding allocated to reduce risk at the early stages of procurement projects.

1998: SDR – Smart Procurement

14.15 In 1998, McKinsey & Co (McKinsey) presented its recommendations to deal with what it described as the MOD's *"serious failings"* in the process of developing and purchasing major military systems.[14] The Strategic Defence Review (SDR) of 1998 introduced the so-called 'Smart Procurement', aimed at making procurement 'faster, cheaper, better'. In October 2000 the initiative was renamed 'Smart Acquisition' to stress the point that the MOD was concerned with both procurement and in-service support, *i.e.* both buying the equipment and supplying the means to support it throughout its in-service life.

[11] NAO 2008 Major Project Report 2008, page 18. (18 December 2008)

[12] Loose Minute concerning the supply of Nimrod hot air ducts dated 24 July 1990.

[13] BOI Report, Exhibit E [E-2].

[14] *Transforming the UK's Procurement System*, McKinsey & Co., 20 February 1998, page 1.

14.16 Four organisations were involved in the acquisition of equipment:

a. The *Equipment Capability Customer* (ECC) who determined the future capability requirements.

b. The *Defence Procurement Agency* (DPA) which was responsible for procuring equipment capable to meet the requirements.

c. The *Defence Logistics Organisation* (DLO) which was responsible for supporting the equipment that was in service.

d. The *Second Customers* (Customer 2), namely the single service staffs who advised the ECC on operational needs and the Front Line Commands who determined the availability and sustainability requirements for in-service equipment.

14.17 The core of the new DPA was the newly-formed Integrated Project Teams (IPTs). The leader of each team was answerable to a Director of Equipment Capability in the ECC with whom outputs and working methods were agreed. In 1998, ten pilot IPTs were established for a three-month trial. The Nimrod IPT was one of them. Because the project had begun under the Downey cycle, it was defined as a 'legacy' project. Towards the end of the trial period, the then Secretary of State for Defence said: *"The 10 pilot projects where we have been trialling Smart Procurement techniques and the IPT concept are already starting to indicate new savings running to several hundreds of millions of pounds over their life. They have also identified significant opportunities to get equipment into service faster, or – for equipment already in service – improve its availability and reliability."*[15] McKinseys, who were the retained consultants advising the MOD on the change to Smart Procurement, advised that £2 billion of savings would be achieved in the first 10 years.[16]

2004: Problems with Smart Procurement

14.18 Six years on, however, the House of Commons Defence Committee (HCDC) Defence Procurement Equipment Report stated in the 2003-2004 Equipment Report:

> *"Six years ago the Ministry of Defence introduced Smart Acquisition. Its objectives were to procure equipment faster, cheaper, better. On almost all counts, it has failed to deliver. In 2002–03 the top 20 defence equipment projects experienced in-year cost increases totalling £3.1 billion. They also suffered time slippage – on average delivering a year and a half late. More cost increases and time slippages can be expected when the 2003-04 figures are published.*[17] *...The then CDP's assessment of the DPA identified long running systemic problems and a failure to implement the principles of Smart Acquisition. The CDP said that 'the major MOD procurements include the management of huge uncertainties and whether or not we actually invest enough time in de-risking before we make a major capital investment generally determines whether a project does or does not go astray."*[18]

14.19 Giving evidence to the House of Common Select Committee on Public Accounts a few months earlier, the Chief of Defence Procurement, Sir Peter Spencer said: *"The situation is encapsulated by the National Audit Office Report which recognises that the so-called Smart projects are doing better than the legacy projects, but there are worrying signs that they are not going to deliver the results expected"*; and not all seven principles identified in the SDR had yet been put into place comprehensively.[19]

'Conspiracy of optimism' (or cynicism)

14.20 John Howe, Vice-Chairman of Thales UK, giving evidence to the HCDC regarding risk reduction in the early parts of procurement programmes said:

[15] *Hansard* Written Answers to Questions, 31 March 1999. Column 678.

[16] McKinsey and Co "Transforming the UK's Defence Procurement System Final Report", 20 February 1998.

[17] House of Commons Defence Selected Committee: Sixth Report of Session 2003-04, published 28 July 2004, Summary.

[18] Ibid, paragraphs 21 and 23.

[19] Minutes of Evidence of Giving of House of Common Select Committee on Public Accounts Questions 216-217.

"[I]f there is one error, if you like, which has led consistently to setbacks, disappointment and difficulties in procurement, it is because the whole community – industry, the MOD and, if I may say, at the political level and the press – has conspired to be optimistic about the cost of military capability and has conspired to neglect the degree of risk that is involved in major defence projects where one is actually buying equipment that does not yet exist and it is what McKinsey's, I think called a conspiracy of optimism in their work on Smart procurement."[20]

14.21 In my view, the 'conspiracy of optimism' might equally be called a 'conspiracy of cynicism', given the conscious pre-disposition of those involved in initial procurement to under-estimate the time and cost of initial acquisition of equipment, as well as subsequent through-life costs, in order to get the project up and running. This suits all parties who have an interest in heralding new military equipment acquisition projects.

2006: creation of DE&S announced

14.22 There was little time for the DPA and DLO to bed in further because, in July 2006, the Government announced plans to create a new joint organisation to carry out integrated defence equipment procurement and support. The DPA and DLO were amalgamated to form the Defence Equipment & Support (DE&S) organisation. The new organisation had some 29,000 staff and a budget of £16 billion or 43% of the defence budget. The merger was a major task and undertaken at a time when the organisation was supporting operations in Iraq and Afghanistan. In order to achieve targeted savings, the staff of the new organisation would have to be reduced by 27% by 2012. Commenting on this, the HCDC said:

"It is vital that the DE&S has a skilled workforce. We find it inexplicable that the number of DE&S staff is to be substantially reduced when staff are currently so busy that they have insufficient time to attend the training and upskilling courses they need."[21]

2007-08: HCDC reported continuing procurement problems

14.23 The 2007-08 HCDC Defence Equipment Report concluded as follows:

"Seven of the largest equipment programmes which featured in the Major Projects Report 2007 have experienced in-service date slippage in 2007-08 totalling some 6.5 years. Once again, the MOD has failed to control slippage on key equipment programmes. We are concerned that the MOD only now acknowledges that it needs to include in the project management skills of its staff the ability to examine critically a contractor's programme schedule and consider whether it is credible……The Nimrod MRA4 programme has experienced further cost growth of some £100 million in 2007-08 bringing the total cost forecast growth on this programme to £787 million or 28% of the Approved Cost. The programme has also experienced further slippage in 2007-08 which now totals 92 months, some 7.5 years. …"[22]

Statement by Secretary of State to House of Commons on 4 June 2009

14.24 On 4 June 2009, the immediate past Secretary of State for Defence, the Rt Hon. John Hutton MP told the House of Commons:[23]

"Today we do not just have to plan for contingent threats against a sophisticated state adversary, where the practical implications of our planning assumptions are tested in large part by their deterrence effect. As the past decade has instead proved, today our armed

[20] Ibid, page 12.

[21] House of Commons Select Committe on Defence: Tenth Report of Session 2007-08 published 27 March 2008. (HC295) (Summary)

[22] Ibid,

[23] *Hansard* Debates, Thursday 4 June 2009. Column 438.

forces are engaged in less conventional, counter-insurgency and peace enforcement operations in defence of our national security, so now our planning assumptions are tested in the heat of battle, with no room for delay or failure. Every one of our servicemen and women has the right to know that we are doing everything possible to ensure that every pound of investment in our equipment programme goes towards the front line and is not wasted in inefficient or weak processes of acquisition.

That is why I asked Bernard Gray in December last year to conduct a detailed examination of progress in implementing the MOD's acquisition change programme, as I hope right hon. and hon. Members will recall. I have to be satisfied that the current programme of change is sufficient to meet the challenges of the new combat environment that we now face. To date, I am not. I expect to receive the report shortly. Bernard Gray has conducted a thorough and wide-ranging analysis. I am confident that when his report is published, it will be both honest about the scale of the task that confronts us and clear in describing a detailed and radical blueprint to reform the process of acquisition in the MOD from top to bottom. That is something that we must get right. There can be no room for complacency, and given the current tempo of operations, we have no choice but to act with urgency. I will publish Bernard Gray's report before the summer recess, and I will come to the House again to outline the Government's response to it.

Given the size of the challenge that we face, I am in no doubt whatever that change must happen and that it must be radical. There must be changes to the system and structure of acquisition process, changes to the incentives that drive and determine behaviours – behaviours that have often led to waste, delay and efficiency, bedevilling the efforts of both Labour and Conservative Governments over a long period – and changes to the skills sets of those involved in acquisition. I am committed to doing everything that I can to make it possible for our armed forces to be better served, and I will make future announcements in due course."

14.25 Unfortunately, the Rt Hon. John Hutton MP resigned as Secretary of State for Defence the very next day, on 5 June 2009.

Mr Bernard Gray's evidence

14.26 I had the benefit of meeting Mr Bernard Gray. He is an extremely knowledgeable expert on Defence Procurement. He was Special Advisor to the Secretary of State for Defence in the period 1997-1999 and played an important role in drawing up the 1998 SDR. He told me that he presented the final version of his Report on Defence Procurement to the new Secretary of State for Defence, the Rt Hon. Bob Ainsworth, in July 2009. As at the date of sending this Report to the publishers, Bernard Gray's report has still not been published.[24]

14.27 Bernard Gray told me that the MOD's own figures showed that:

14.27.1 The average time over-run on MOD procurement programmes is currently 80% (or about 5 years from the time specified at initial approval through to in service dates);

14.27.2 The average cost over-run on MOD procurement programmes is currently 40% programmes is c. 40% (or about £300 million); and

14.27.3 The frictional costs[25] to the MOD of this systematic delay is in the range of £900m – £2.9 billion p.a.

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[24] Bernard Gray's Report was suddenly published on 15 October 2009, after completion of this Report for printing.

[25] By which I mean the money that is wasted each year (and which would otherwise be available to spend, whether within the MOD budget or elsewhere) as a result of the delays.

'Bow wave' has knock-on effect

14.28 In my view, these figures are a matter of great concern. They give rise to the spectre of a further 'bow wave' of deferred financial problems which dwarfs anything faced in the late 1990s. My particular concern, for the purposes of this Report, is the knock-on effect which such a 'bow wave' might again have on the future integrity of safety and airworthiness in the MOD, in the event of further punishing rounds of stripping out or squeezing costs from In-Service Support and the concomitant change, confusion, dilution and distraction that this can bring, as in the past.

Salient points in Bernard Gray's Report

14.29 I asked Bernard Gray what he had found and he told me the following:

(1) The MOD has a substantially overheated equipment programme with too many types of equipment being ordered for too large a range of tasks at too high a specification. This programme is unaffordable on any likely projection of future budgets.

(2) This overheating arises from a mixture of incentives with MOD. In particular, the Armed Forces competing for scarce funding quite naturally seek to secure the largest share of resources for their own needs and have a systematic incentive to underestimate the likely cost of equipment and downplay the technical difficulties. Industry and the Armed Forces have a joint vested interest in sponsoring the largest programme at the lowest apparent cost in a 'conspiracy of optimism'. This 'conspiracy' gives rise to an over-large programme, and the deep reluctance to cancel projects means that these pressure are not relieved.

(3) When this over-large and inflating programme meets the hard cash totals that the MOD has been allocated each year, the Department is left with no choice but to slow down its rate of spend on programmes across the board.

(4) The result is that programmes take significantly longer than originally estimated, because the Department cannot afford to build them at the originally planned rate. They also cost more than they would otherwise because the overhead and working capital costs of keeping teams within Industry and the MOD working on programmes for a much longer period soaks up cash. The MOD also has to bear significant costs in running old equipment because the new equipment is not yet ready for service. This builds up an increasing bow wave of risk as the years go by, compounding the pressures on the equipment programme and forcing cuts in other areas.

(5) In reality, the bow wave allows the MOD to maintain a position that a whole variety of Defence capabilities are in the process of being procured. This feels reassuring to the country about the size and scope of Britain's Armed Forces, but behind this comforting thought is the cold fact that the budget does not exist and has arguably not existed since the end of the Second World War. The policies of successive governments, and a lack of political will to present to the electorate the unpleasant reality of the position, has been a significant force behind this phenomenon.

(6) The global political map has shifted substantially in the last decade but the MOD's strategic framework has not kept pace with that environment. Even the authors of the SDR felt it was a framework that would only last for about five years. They fully expected it to be replaced by a wholly new SDR in 2002-2003 and that was before the events of 9/11 changed the world. This out-dated road map left the MOD poorly equipped to conduct two simultaneous major conflicts (namely, Iraq and Afghanistan).

(7) Similar pressures to those that exist in the new equipment programme also exist within the support of in-service equipment.

Conclusion

14.30 The history of the Nimrod MRA4 programme (set out above) is a paradigm example of the fundamental procurement problems which the Bernard Gray Report seeks to address.

14.31 The 'Strategic Goal' of 20% savings in output costs imposed on the DLO in 2000 (see **Chapter 13**), is a paradigm example of the damaging knock-on effect that a 'bow wave' of deferred acquisition expenditure can have on In-Service Support.

14.32 I understand that, despite the Rt Hon. John Hutton's clear statement immediately prior to his resignation, Bernard Gray's Report has still not yet been published.[24] As the Rt Hon. John Hutton was at pains to emphasise, however, the problem is urgent. If the problems identified by Bernard Gray are not addressed, in my view, it is inevitable that there will be further casualties of the financial pressures within the system.

PART V:
AFTERMATH

PART V: AFTERMATH

Introduction to Part V

1. A large number of measures have been taken since the loss of XV230 to address airworthiness issues with Nimrod aircraft, including those identified both by the Board of Inquiry and subsequent technical investigations (see **Chapter 15**).

2. I have been kept abreast of these measures and would have issued an interim report if anything had come to my attention which gave me immediate cause for concern.

3. The successful continued operation of the Nimrod fleet in support of our Armed Forces, whilst coping with problems identified and arising in the aftermath of XV230, is a tribute to the dedication of the RAF Nimrod community.

4. I address issues arising in relation to the Inquest in **Chapter 16.**

CHAPTER 15 – BOI RECOMMENDATIONS AND POST-XV230 EVENTS AND MEASURES

Contents

Chapter 15 covers the implementation of the Board of Inquiry recommendations and other post-accident events and measures. It answers the following questions:

- What specific measures have been taken in the light of the loss of XV230 to safeguard the Nimrod fleet and its crews?
- What formal recommendations by the Board of Inquiry have been implemented?
- What other incidents have occurred post-XV230 which have a bearing on the safety of the Nimrod fleet? What action was taken?
- What other measures have been taken post-XV230 to ensure the safety of the Nimrod fleet and its crews?
- Are there any other post-XV230 matters meriting investigation?
- What has been the outcome of the Board Of Inquiry's recommendation that the Nimrod Safety Case be reviewed with the involvement of operators?[1]

Summary

1. During the Review, I have been kept closely informed by the MOD of all incidents, problems, surveys and findings pertaining to the technical safety of the Nimrod fleet, together with progress in implementing the Board of Inquiry's post-XV230 recommendations and informed of other programmes aimed at ensuring the airworthiness of the Nimrod fleet.

2. Pursuant to my Terms of Reference, I would have issued an immediate interim report if, at any stage, a matter of concern had come to my attention which I felt affected the immediate airworthiness of the Nimrod fleet or safety of its crews. I have not issued any interim reports. I have not felt it necessary at any stage to do so.

3. The loss of XV230, the findings of the Board of Inquiry and subsequent reported incidents and events, led to intense focus on addressing the potential for fuel leaks and hot-air duct failures in the Nimrod fleet.

4. Key post-XV230 Nimrod safety management measures have been:

    (1) the implementation of the majority of the XV230 BOI recommendations, in particular, the prohibition on the use of the Supplementary Conditioning Pack and Cross-Feed duct in flight;[2]

    (2) the total suspension of all Air-to-Air Refuelling;

    (3) the targeted Fuel Seal Replacement Programme;

    (4) the Hot Air Duct Replacement Programme;

    (5) the Avimo seal material replacement programme; and

    (6) the forensic teardown programme.[3]

[1] Board of Inquiry Recommendation, paragraph 65a(3).

[2] Board of Inquiry, paragraph 42c [2-38].

[3] Which may be the first full-scale forensic teardown of an aircraft to examine systems that has ever been conducted anywhere in the world.

5. The total cost of implementing the Board of Inquiry recommendations has been estimated as being in the region of £30-35 million.
6. I am satisfied that appropriate and timely steps have been, and continue to be, taken by the MOD and the RAF to address the immediate airworthiness issues raised by the loss of XV230 and the Board of Inquiry report and subsequent discoveries about the Nimrod fleet. Indeed, the level of scrutiny now applied to the Nimrod fleet is such that it is probably one of the most closely monitored operational military aircraft fleets in the world.
7. The successful continued operation of the Nimrod fleet post-XV230 is a tribute to the Nimrod community and leadership at RAF Kinloss and RAF Waddington, and their parent Headquarters.
8. On the evidence to date, the review of the Nimrod Safety Case by BAE Systems in 2008-2009 (Safety Case 2) has been largely valueless and a waste of time and money.

Introduction

15.1 Following my appointment to conduct this Review in December 2007, I requested that I be kept up-to-date on all matters and developments relating to the technical safety of the Nimrod fleet as they came to light. In accordance with my request, I have been kept closely informed by the MOD of: (a) all incidents, problems, surveys and findings pertaining to the technical safety of the Nimrod fleet; (b) progress in implementing the Board of Inquiry's (BOI) post-XV230 recommendations; and (c) other programmes aimed at ensuring the airworthiness of the Nimrod fleet and the safety of its crews.

15.2 I have not felt it necessary to issue an interim report in relation to any matter which has come to my attention regarding the immediately safety or airworthiness of the Nimrod fleet; and, accordingly, have not done so.

15.3 The loss of XV230, the findings of the BOI and subsequent reported incidents and events, led to intense focus on addressing the potential for fuel leaks and hot air duct failures in the Nimrod fleet. Following the loss of XV230, there was an increase in reported fuel leaks. This was probably due to the increasing frequency of inspection and the fact that leak inspections are now conducted with tanks and lines under pressure.

15.4 In the three years since the loss of XV230, the MOD and RAF have introduced a large number of measures to safeguard the Nimrod fleet and its crews. This Chapter does not list every measure enacted, but simply outlines some of the principal measures and significant post-XV230 events.

15.5 I am satisfied that appropriate and timely steps are being, and have been, taken by the MOD and the RAF to address the immediate airworthiness issues raised by the loss of XV230, the BOI report and post-XV230 subsequent discoveries about the Nimrod fleet.

15.6 Indeed, the level of scrutiny now applied to the Nimrod fleet is such that it is probably one of the most closely monitored operational military aircraft fleets in the world.

Immediate aftermath – UTIs and RTIs

15.7 In the immediate aftermath of the loss of XV230 and its crew, the Aircraft Operating Authority (AOA) and the Nimrod Integrated Projected Team (IPT) placed a number of restrictions on the use of certain systems within the aircraft. These restrictions were based on the reports of the Harrier pilot eyewitness who observed the aircraft's final moments and the content of the MAYDAY radio transmission made by the crew of XV230. The former reported a fire on the starboard wing root of the aircraft, close to the fuselage, with a secondary fire in the vicinity of the starboard rear fuselage, whilst the MAYDAY reported a fire in the aircraft's bomb bay. The implication of the fact that the aircraft had undertaken Air-to-Air Refuelling (AAR) a few minutes before the fire began was also considered.

15.8 Initial actions were implemented by Urgent Technical Instruction (UTI) and Routine Technical Instruction (RTI), in which a signal from the IPT directs aircraft operators to inspect, to modify, or to cease use of, particular systems within the aircraft. In this case, the IPT identified all systems that might provide a means of ignition or source of fuel in the area of the reported fire and instructed their regular inspection[4] and, where possible, isolation.[5] These inspections were in addition to the pre- and post-flight inspections conducted by the aircraft's ground crew. AAR enabled the Nimrod to extend significantly the time that it could remain on task in support of Coalition Ground Forces. The presence of a Nimrod had enabled the successful completion of a number of operations and had undoubtedly reduced the casualty toll among those fighting the Taliban on the ground. Nonetheless, because the fire had commenced shortly after AAR, AAR was henceforth authorised for individual flights only, at the express request of the force commander, when deemed operationally necessary.[6] Prior to any AAR sortie, a pressure test of the aircraft's refuel system was to be conducted.

XV255 incident – 4 September 2006

15.9 Two days after the loss of XV230, a fuel pipe within the Rib 1 area on XV255 was discovered to have been leaking and spraying fuel[7] and was replaced at the Deployed Operating Base.[8] A UTI was issued to check all other aircraft for similar failures. The leak was traced to a pinhole failure in a weld on the pipe, which was not replicated on any other aircraft. Occurrences such as this led to an extension of the fuel system inspection regime to include those elements of the system between the engines, including the fuselage. Nonetheless, preventing all leaks was considered to be an engineering *chimera*, as experience suggested that all aircraft types would leak fuel to varying degrees. MOD measures thus concentrated on eliminating ignition sources, whilst acknowledging an aspiration to reduce leaks as far as practicable.

Reported incidents in last quarter of 2006

15.10 A series of fuel leaks during AAR sorties were reported in the last quarter of 2006. These included a corrosion-induced leak to a fuel feed pipe behind the fairleads in the Rib 1 area, which was reported on XV236 on 22 November 2006.[9] This and other incidents were considered by a meeting of experienced aircrew, ground engineers, the IPT and BAE Systems representatives[10] at RAF Kinloss. This group determined, however, that from the position of the reported leaks within the aircraft fuel system, it was extremely unlikely that they could have been provoked by AAR.[11]

15.11 A subsequent incident was reported in December 2006,[12] in which a tanker crew reported off-loading more fuel than appeared to have been received by the Nimrod. This proved more problematic to resolve. Although there were clear signs that fuel had flowed over the aircraft fuselage and fuel was found to have entered external fuselage compartments, only a relatively small leak could be traced in the fuel system. However, subsequent examination proved that the No. 1 tank had been incorrectly assembled and that this error would have caused the reported symptoms and the fuel found on the aircraft fuselage after flight. As a result of this incorrect assembly, blow-off would be activated when this tank held approximately 75% of its full load. Following this incident, crews were restricted to only filling the No. 1 tank to 10,000lbs of fuel during AAR[13] to ensure a

[4] UTI 038/UTI 039/RTI 172 and successors instructed *inter alia* inspection of the fuel feed system (pressurised), hot air system and electrical system. Note that TIs can be amended, often referred to as 'uplifted', to an 'A', 'B' etc version following the incorporation of amendments or additional instructions; references within this chapter to a given TI serial refer to the original and all subsequent uplifts, unless specifically stated otherwise.

[5] RTI 169/RTI 173 instructed inter alia that the SCP and the bomb bay heating were not to be used, that the cross-feed selector switch should be set to windmill post engine start and that AAR was only to be conducted if required by the force commander to meet operational needs (RTI 170 specified the actions to be taken should AAR be required). RTI 169 required the draining and isolation of the No 7 fuel tanks in the wing roots.

[6] Detailed in RTI 168/RTI 170.

[7] Reported at SFR H80/KQA, dated 4 September 06.

[8] Serious Fault Signal, dated 4 September 2006 (BOI Report, Exhibit 46).

[9] Serious Fault Signal, dated 22 November 2006 (BOI Report, Exhibit 47).

[10] Held on 13 November 2006 at RAF Kinloss. Attended by two members of the BOI investigating the loss of XV230.

[11] The leaks were either from fuel tanks or from the fuel feed system. Fuel enters the aircraft through the refuel system which conveys it to the fuel tanks. It is pumped from the tanks into the fuel feed system, which is not affected by pressure in the refuel system, because refuel pressure is dissipated in the fuel tanks. One theory propounded to explain fuel leaks during AAR is that they are provoked by increases in refuel system pressure during AAR; clearly this theory cannot explain leaks from fuel tanks or the fuel feed lines.

[12] Air Incident Kin 066/06.

[13] No. 1 tank maximum capacity is 16,000lbs.

significant safety margin to prevent blow-off. This 10,000lbs limit remained in force notwithstanding that the original problem had been caused by an incorrectly constructed fuel tank.

Enhanced fuel and vent system maintenance regimes: 2007

15.12 An independent fuel system hazard analysis carried out by QinetiQ[14] identified the requirement to inspect the fuel system in a number of areas not previously considered.[15] Pressure testing of the fuel system vent pipes was also introduced, to check and ensure their integrity.[16]

XV235: November 2007 incident led to total cessation of AAR

15.13 In November 2007, whilst carrying out AAR from a Tristar over Afghanistan, XV235 experienced a fuel leak in the bomb bay. A crew member noticed what appeared to be a spray of fuel emitting from the fuel system and, in view of the crew's understanding of what had occurred to XV230, the aircraft issued a Mayday and diverted to Kandahar. The aircraft was examined on landing and traces of fuel in the bomb bay confirmed that there had indeed been a leak. However, despite extensive trials, the aircraft's engineers were unable to replicate the leak on the ground. The inability to reproduce the leak, even when subjecting the fuel system to pressures similar to those experienced during AAR, meant that there could be no guarantee that leaks could be detected during pre-flight inspections. The increased risk to the Nimrod crews should they continue flying AAR sorties was balanced against the increased risk to ground forces inherent in any reduction in Nimrod coverage concomitant on a cessation of AAR. Following considered analysis of the issue, the AOA decided that Nimrod AAR should cease. It should be noted that, during the investigation into XV235, an Avimo coupling was dismantled and was found to have a pipe-to-pipe gap which was outside specified limits. A leak had been noticed from it by the ground crew at about 1 drip per minute and so it was thought unlikely to have been the cause of the leak seen in the air.

BOI recommendations implemented from December 2007 onwards

15.14 The BOI made a total of 33 formal recommendations in its Report which was published on 4 December 2007. 28 of the BOI's recommendations were accepted. Five of the BOI's recommendations were rejected. Of these, the effect of three was achieved by an alternative course of action. Of the remaining two, a study was undertaken into the utility of parachute escape from the Nimrod, but it was decided that any solution could not be incorporated within the remaining life of the aircraft; a similar decision was made as to the recommendation to fit a crash protected means of recording position and intercom voice. The most recent update on progress with the BOI's recommendations is to be found at **Appendix A** at the end of this Chapter.

15.15 Implementation of the BOI's formal recommendations began in December 2007. Amongst the first of these was the inclusion of more detailed information within the aircraft's Topic 1 engineering manuals on the assembly of FRS and AVIMO fuel system couplings. A number of the BOI recommendations, such as the review of maintenance policy, a review of the Nimrod Safety Case to correct errors within it and the conduct of an Ageing Aircraft Systems Audit (AASyA),[17] were extensive tasks and it was realised that they would take some time to complete. As the Review went to publication, it was predicted that all remaining recommendations, with the exception of the Safety Case Review, would be completed by the end of October 2009. The Safety Case Review has resulted in the production of Safety Case 3 (SC3), as explained further below.

[14] Nimrod Fuel System Safety Review Report QINETIQ/EMEA/IX/SCRO702915.

[15] RTI 207.

[16] RTI 196.

[17] BOI Recommendation 2 at paragraph 65 a (2) of the BOI Report.

Fuel Seal Replacement Programme

15.16 As a result of a key BOI recommendation,[18] a Fuel Seal Replacement Programme (FSRP) was instituted. This targeted for replacement 42 fuel seals in areas where an independent study[19] had shown that a fuel leak would be particularly undesirable. This programme is being undertaken by a specially trained team who ensure that their work does not disturb the alignment of the fuel system pipes. Contrary to some prognostications by those who believed that fuel seals were best left undisturbed, the FSRP has so far produced encouraging results.

Hot Air Duct Replacement Programme

15.17 As a result of a further key BOI recommendation,[20] a Hot Air Duct Replacement Programme (HADRP) was instituted. The BOI recommendation was made in the light of the disintegration of part of the SCP duct at the 'elbow' on XV227 in November 2004, following which BAE Systems was commissioned to complete a survey of the ducting within the system and, if necessary, recommend the 'lifing' of the components. The initial BAE Systems report[21] recommended setting lives for the ducts which were significantly lower than those that the RAF had experienced in actual use. As a result, BAE Systems was tasked to reconsider its proposals in the light of practical experience and fatigue tests of actual ducts. BAE Systems produced a further series of papers and letters in 2007 and 2008; the result of this activity was a decision, agreed with the Nimrod IPT, that a life of 2,500 hours for the aircraft's hot air ducts would be appropriate. This in turn triggered the HADRP. The residual risk inherent in continuing to use the system was mitigated by the fact that the prohibition on SCP use would continue, the Cross-Feed ducts would only be used on the ground for engine start and all high-temperature ducting in use in the air is contained within a fire zone.

15.18 As explained in **Chapter 7**, as a result of BAE Systems' work and the BOI's recommendation, in June 2008, the Nimrod IPT issued a Special Technical Instruction (STI 926) regarding a fleet-wide duct replacement programme, requiring the replacement of the high pressure hot air ducts between the ECU and the Cross-Feed valves, and also those that formed the Cross-Feed system. The Nimrod IPT determined that, for the risk to the aircraft to remain ALARP, the replacement programme should be completed by 31 March 2009 and that aircraft that had not had their hot air ducts replaced by this time would not be flown until the work had been completed. Although it had originally been planned that the programme would be completed by 31 March 2009, delays in the provision of replacement parts made this unachievable. As at the date of writing, eight Nimrod MR2s and two R1s have been through the HADRP. The only aircraft that have not been through the HADRP are those in scheduled maintenance; these aircraft will have their ducts replaced before returning to service.

Teardown by QinetiQ commenced August 2008

15.19 While scoping the work necessary to complete the AASyA, the IPT concluded that the most effective means of achieving the BOI's intent would be physically to dismantle a Nimrod to identify areas of concern; indeed, this would enable an examination of the condition of the entire aircraft, not just its systems. The Chief of Defence Materiel authorised a forensic 'teardown' of a Nimrod to be carried out. I understand that this may be the first full-scale forensic teardown of an aircraft to examine systems that has ever been conducted anywhere in the world. On 1 August 2008, QinetiQ was contracted to undertake this major task. The task was completed in July 2009 and the total cost is estimated to be £2.6 million. The aircraft chosen (XV236) was one which would have been due a Major maintenance procedure; by virtue of the time since it had last undergone an extensive maintenance procedure, this aircraft would exhibit the greatest range of defects and degradation. This approach proved fruitful. A large number of issues were found and raised by QinetiQ. The majority of arisings were of a relatively minor nature and would have been identified and corrected during the previously planned Major.[22]

[18] Following the decision not to life fuel system seals (BOI Recommendations 5 and 6 at paragraphs 65a (1) and (2)), other means were sought to address the issue of fuel leaks; the Fuel Seal Replacement Programme was one of these measures.

[19] "Nimrod Fuel System Zonal Hazard Assessment", QINETIQ/EMEA/IX/SA0701788, Issue 1.

[20] BOI Recommendation 11 at paragraph 65 c of the BOI Report recommended measures to prevent the hot air system acting as a source of ignition, including that *"the study into corrosion....undertaken following the hot air leak on XV227 is completed and its recommendations acted upon"*. The decision to replace the hot air ducts was a direct result of this study.

[21] MBU-DEB-R-NIM-FF0786, dated 1 June 2005.

[22] Comment by QinetiQ personnel to Review member during Review inspection of XV236 at Boscombe Down.

A small percentage, however, were identified as potential airworthiness risks; nonetheless, the Nimrod Project Team, in consultation with the Platform Safety and Environmental Working Group determined that no single issue, or combination of issues, had undermined the airworthiness of the platform.[23] Nonetheless, the overall findings of QinetiQ in the initial stages of the teardown highlighted a marked and worrying drop in 'husbandry' levels of the Nimrod fleet in recent years, as summarised by OC Engineering Wing RAF Kinloss:[24]

> *"It is evident that ac entering Depth maintenance – particularly those returning from the Middle East – are of a lower standard of husbandry than would have been expected a decade ago; sand and detritus mask general husbandry degradation, a problem compounded in the Gulf where dust and grime is pervasive. A concession has been granted to defer ac washes to every 105 days periodically given the dry environment the ac are operating in (UK 35 days). The decline in ac husbandry witnesses in this audit reflects a cultural shortfall, an accepted gradual decline in husbandry over several years and is not restricted to a particular maintenance or operating area."*

15.20 I deal with the topic of the teardown in further detail in **Chapter 23**.

QinetiQ inspections of RAF Kinloss aircraft

15.21 As an extension to the teardown project, and to provide some independent assessment of the inspections being undertaken at RAF Kinloss and RAF Waddington following the loss of XV230, the Nimrod IPT Team contracted QinetiQ to conduct an examination of two aircraft at RAF Kinloss in June and July 2009. An extremely thorough examination was carried out by QinetiQ, who determined that there were a number of, mainly husbandry, issues which had escaped detection during the inspections undertaken by maintenance personnel in both Forward and Depth. Once again, some potential airworthiness issues were raised, but these were determined not to present an airworthiness risk on closer study. This latest examination has underlined the need for constant vigilance and thorough training of all personnel in the standards expected of them and has highlighted the benefits of the auditing processes implemented by the MOD. The reports will be used to improve further standards of maintenance across the MOD. Some of the deficiencies detected appear to have arisen as a result of misunderstandings among maintenance personnel as to what was required of them, both in general terms and specifically within the requirements of RTIs issued by the Nimrod IPT; RTI 212[25], for example, has been reissued twice since the QinetiQ inspections, to clarify the IPT's intent. It is important that the MOD use the opportunity provided by these reports to ensure that the training and supervision of maintenance personnel is of the highest standard, but also that communication within and between its organisations is conducted as efficiently and clearly as possible.[26]

XV249 incident in January 2008

15.22 In January 2008, smoke residues were discovered on the Cross-Feed duct and surrounding area of Nimrod R1 XV249 following a flight.[27] These were found to have resulted from short-lived combustion in this area. The XV249 discovery caused considerable consternation since a fundamental tenet of the safety measures put into place following the loss of XV230 and the BOI recommendations was that the Cross-Feed pipe was no longer capable of providing a source of ignition. Concurrent with the inquiry into the event, the IPT issued UTIs to check all Nimrods for similar smoke residue[28] and to ensure that the Cross-Feed duct temperature on all aircraft was below that needed to auto-ignite an accelerant.[29] Checks on the condition of the Cross-Feed duct both before

[23] DE&S/WYT/4/3/12/1/Nim, dated 15 September 2009.

[24] 20080920-Nimrod Airworthiness Audit, dated 20 September 2008.

[25] Which provided instructions on the Nimrod enhanced systems integrity checks introduced following the loss of XV230.

[26] A Maintenance Error Investigation was undertaken by the RAF to determine more fully the reasons for the QinetiQ findings; its results were not available as the Review went to press.

[27] F765-WAD/9155/3/FSWHQ/8/08, dated 7 May 2008.

[28] UTI 049.

[29] UTI 051 and UTI 052.

and after flight were also introduced, along with functional checks of the Cross-Feed shut-off valves[30] and a check for hydraulic fluid leaks.[31] The testing of the Cross-Feed valves revealed that some were leaking and the IPT decided that the safest option would be to replace these items on all aircraft.[32] Although the investigation into the smoke residue discovered on XV249 was unable to reach a definitive conclusion as to its precise genesis, it determined that the only viable point of ignition was the Cross-Feed duct. In considering when the event had occurred, the investigation determined that a fire during engine start prior to flight was 'unlikely' and that it was 'highly unlikely' that it occurred during the flight itself. The investigation determined that "*it is likely that residual AVTUR on [an element of the Cross-Feed ducting] ignited during one of the 3 Engine Ground Runs between 23 and 25 Jan 08"*.[33] The reason for the Cross-Feed duct reaching a temperature high enough to ignite AVTUR may have been that the aircraft was *"operated in a configuration other than described and documented"*.[34] Thus, the IPT determined that the rationale and efficacy of the safety measures introduced following the loss of XV230 remained valid, *i.e.* not using the Cross-Feed/SCP duct in the air.

Avimo seal material replacement: September 2008

15.23 As explained in **Chapter 5**, in September 2008, it was discovered that the Avimo seals installed in Nimrods since 2000 had been made from a neoprene compound which did not conform to the required material specification and which resulted in early degradation. A programme to develop a new Avimo seal compound was instituted which has resulted in Avimo seals now being manufactured from a nitrile material similar to that used in the FRS coupling. An Interim Declaration of Design and Performance[35] has been issued which sets strict criteria on the life of the new seals: this is currently set at 600 flying hours, but as more evidence of the seal's performance is received this will be reviewed. A programme to replace the old neoprene seals is underway and those aircraft that have yet to be modified operate under restrictions that mitigate any risk in retaining the old seals.

Safety Case 2

15.24 The BOI recommended that the Nimrod Safety Case (NSC) should be reviewed to remove any remaining factual errors and reassess hazard categorisation. In May 2007, pursuant to Task 06-3725, the Nimrod IPT tasked BAE Systems to carry out a review of the NSC.[36] The wisdom of the decision to give BAE Systems the task of reviewing its own work is questionable. It is not easy to be entirely objective when marking one's own homework, especially work which has been the subject of express criticism (by the BOI). An independent third party should have been instructed to carry out the review of the NSC.

15.25 At a relatively early meeting with the Review in July 2008, BAE Systems' Military Airworthiness Solutions (MAS) Chief Engineer, Martin Breakell, vigorously denied that BAE Systems was in any sense 're-writing' the NSC and sought to emphasise that the review (or 'Safety Case 2' as it has come to be known) was no more than a 'periodic review', previously planned and agreed with the Nimrod IPT. He also indicated that BAE Systems expected to complete it by the end of 2008. As I explain below, regardless of what the original intentions may have been, both propositions have proven, in the event, to be demonstrably wide of the mark.

The early meetings

15.26 The first 'Safety Case 2' (SC2) review meeting took place in December 2007 and was attended by the Nimrod IPT, BAE Systems, QinetiQ, and front-line operators from RAF Kinloss. A further nine meetings took place in 2008. The early meetings quickly identified that it was inefficient to tackle the whole aircraft from the beginning. Therefore, it was decided that 11 zones considered to be a priority in terms of safety (primarily those zones

30 RTI 234 and RTI 235.

31 RTI 230.

32 Conducted under RTI 243.

33 F765-WAD/9155/3/FSWHQ/8/08 dated 7 May 2008, page 13.

34 Ibid.

35 Taunton Aerospace DDP4126 Issue2-Interim, dated 3 June 2009.

36 Following discussions between the Nimrod IPT and BAE Systems as to the precise scope of the project, BAE Systems submitted amended versions of its Proposal in September and November 2007, with a further version being prepared in 2008. A further revised Statement of Work was finally signed off by the Nimrod IPT on 11 March 2009.

between the engine bays and including the fuselage under-floor compartments) would be the starting point for the further analysis to satisfy the BOI recommendation.

The problems identified

15.27 Having examined the existing Pro-Formas for the 11 priority zones, the front line operators from Kinloss reported that they found the Pro-Formas difficult to follow and raised a number of observations, including the following:

15.27.1 There was a lack of standard terminology in the Pro-Formas.

15.27.2 BAE Systems' recommendations in respect of the *"further work"* that was required needed to be clearly identified.

15.27.3 There was a lack of standard format for the zonal Pro-Formas.

15.27.4 Some of the Pro-Formas contained erroneous mitigation.

15.27.5 Some of the Pro-Formas showed a confusion between the MR2 and R1.

15.28 Following discussions at the SC2 meetings, it was decided between the Nimrod IPT and BAE Systems that the structure of the Pro-Forma would be modified. The original Pro-Forma for each hazard included all possible causes of the hazard and all mitigations; this led to difficulty in identifying which mitigation applied to which cause. In order to improve the clarity of the Pro-Formas, it was decided that individual causes and their specific mitigations should be separated out and placed in their own individual Pro-Forma.

QinetiQ input

15.29 During the course of the early SC2 meetings, the QinetiQ Capability Leader – Safety raised a number of issues and concerns about the underlying structure of the Safety Case with the Nimrod IPT.[37] These included the following:

15.29.1 It was difficult to see the linkage between accidents and hazard controls.

15.29.2 The subsuming of individual hazards into one hazard made the linkage of hazards to accidents incorrect.

15.29.3 It was difficult to identify what the specific controls were, and the status of their implementation.

15.29.4 Accident controls had been incorrectly applied to hazards, resulting in an incorrect definition of hazard probabilities, *e.g.* fire extinguishers may mitigate the severity of the accident but do not mitigate the probability of a hazard occurring.

15.30 At the meeting on 5 February 2008, QinetiQ also suggested that the method by which the accident probability was defined was incorrect. QinetiQ had additionally highlighted in a Platform Safety Review,[38] that the existing Hazard Log used the worst-case hazard probability as the overall accident probability. The overall accident probability for a zone is, however, a combination of the probability of all the potential hazards and their causes, not just the probability of the worst-case scenario occurring.

15.31 It is, therefore, apparent that, contrary to what BAE Systems sought to suggest, the early meetings identified problems with the NSC which went far beyond the mere correction of a few factual errors and re-categorisation of associated hazards. Rather, it was discovered and determined that there were significant underlying structural issues to be addressed, coupled with flaws in the logical analysis.

[37] QINETIQ/EMAE/lx/SES/Nimrod/597732/009/Platform Safety Review.

[38] Ibid.

The Process

15.32 In an attempt to address the above issues, BAE Systems suggested that advantage could be taken of an updated version of CASSANDRA, which permitted the separation of individual causes and their mitigations. This proposal was accepted by the Nimrod IPT and a revised draft Pro-Forma was produced taking advantage of this facility. Work on the new drafts was further prioritised to a sub-set of four of the 11 priority zones. The initial versions of the new Pro-Formas were approximately four to five pages long. The intention was that, as the draft Pro-Formas were produced, they would be circulated for comment among the stakeholder group and a final version produced, suitable for publication. Further, advice was provided from the front line engineers at RAF Kinloss as to their subjective assessment of the probability of some of the identified hazards.

15.33 The minutes of the meeting on 13 March 2008 record the aspiration to have the selected four of the 11 priority zones completed in draft form and passed to the Nimrod IPT by 21 March 2008. By December 2008, this had still not happened.

Lack of Progress

15.34 Two further SC2 meetings were held in April and May 2008, but the revised Pro-Formas were still not available for review outside BAE Systems Chadderton. In April 2008, it was proposed by BAE Systems that an 'on aircraft assessment' should be added to the process and that it was possible that new 'causes' might be found which were not identified in the original NSC. Difficulties were encountered in separating out individual causes and, on 21 May 2008, the Nimrod IPT agreed to allow BAE Systems to treat any emergent causes as new, additional work under separate tasking, *i.e.* the price continued to rise. It was also noted at the meeting on 21 May 2008 that the Pro-Forma for Hazard H44 was 80% complete and that for Hazard H73 (No. 7 Tank Dry Bay) 85% complete.

15.35 By 2 July 2008, a review of 'causes' for the 11 priority zones was "*still ongoing and dates have yet to be finalised for the on aircraft visit*". At a 'senior stakeholder review', including the Nimrod IPT Leader (IPTL), on 15 July 2008, it was agreed that the maintained condition of the aircraft would be recognised during the zonal surveys, in addition to the original *'as designed'* condition. A programme 'end date' of December 2008 was announced and agreed.

Extraordinary review

15.36 By December 2008, none of the draft Pro-Formas had reached any of the other parties involved and an extraordinary review meeting was arranged at BAE Systems Chadderton. The representation was at a senior level and included the IPTL and BAE Systems' Chief Engineer for the Nimrod, Martin Breakell. Early in the agenda, and notwithstanding the comprehensive manner in which the original NSC had been restructured throughout 2008, it was re-affirmed that the review of the NSC was in fact a 'periodic review' which would have taken place in any event five years after the original NSC was produced. A new target date of end of March 2009 was agreed by the Nimrod IPT.

15.37 The December 2008 meeting also involved a review of the progress made in respect of both the functional and zonal hazard Pro-Formas. By this time, the on-aircraft inspections of zones had commenced and work was progressing in relation to other zones in addition to the original 11 high priority ones. Of the 202 functional hazards, 55 Pro-Formas were presented as 80% complete and 17 were between 50 – 80% complete. It was noted by a BAE Systems attendee that, as a 'sanity check' of progress, this represented only one third of the total of functional hazards since the beginning of the project. He was clearly referring here to the fact that completion of only 30% of the total number of functional hazards since May 2008 (this 30% being at best 80% complete) did not bode well for meeting the March 2009 deadline. Zonal hazards were presented as having been tackled in several different packages. Package 1 was 85% complete and Package 2a had all causes complete to 65%. It would appear that Hazards H44 and H73 had not advanced very far since their designation in May as 80/85% complete respectively. The summary slide noted *"High Risk Zones will be complete in March 2009"* and May 2009 was the predicted overall completion date.

15.38 In keeping with its previous completion estimates, BAE Systems failed to achieve this deadline.

15.39 A further meeting at RAF Kinloss in March 2009 began the process of distributing the zonal and functional Pro-Formas to stakeholders such as front line operators and QinetiQ. This process continued over the ensuing months, with no real evidence of progress being achieved.

The new Pro-Forma

15.40 Pursuant to the Review's request (and, it has to be said, after displaying some considerable reluctance to do so), BAE Systems provided draft copies of some of the restructured Zonal Hazard Pro-Formas, as they existed as at 1 July 2009. In particular, the Review was provided with, and duly read, copies of the Pro-Formas pertaining to Hazard H73 (No. 7 Tank Dry Bay/Zone 614). In the draft versions of the new Pro-Formas, Hazard H73 was identified as having eight potential causes, each one having its own zonal analysis Pro-Forma. As an example, I discuss below the Pro-Forma relating to Cause NM/Z143; this describes the potential for fuel and hot air to interact and cause a fire or explosion.

15.41 The original Zone 514/614 Pro-Forma ran to seven pages and included all potential causes of fire and explosion in the No. 7 Tank Dry Bay. As already noted, there were significant weaknesses in the structure and analysis of the original Pro-Formas. Turning to the new Pro-Forma, NM/Z143 is only one of eight individual 'causes' and consists of 23 pages. All of the Pro-Formas for the eight causes together total over 100 pages. Unfortunately, the growth in size has not been matched with an improvement in clarity. On the contrary, the current size and structure of the Pro-Formas have served to create a dense, almost impenetrable document. In an attempt to provide a discrete audit trail, there is a great deal of unnecessary repetition and minutiae. Each Pro-Forma records in minute detail the thoughts, analysis and recommendations of the reviewing engineer, again much to the detriment of clarity. This sort of defensive engineering, which appears to have more to do with protecting the back of engineer in question than with genuinely improving the safety of the aircraft, is most unhelpful. It is also, in my view, detrimental to safety because it: (a) serves to submerge and obscure the real points under a welter of unnecessary detail; and (b) distracts operator manpower from its vital day-to-day work because they have to spend an inordinate amounts of time reading and checking the material in question when they could be otherwise better occupied.

15.42 It was disturbingly evident even from the few drafts provided to the Review that some of the weaknesses from the original NSC had migrated into the new documents. For instance, there was evidence of a 'cut and paste' mentality which is perhaps an inevitable consequence of endless repetition in a long series of very similar documents. Rather worryingly, there were also factual errors, which although seemingly minor, have resulted in much labour for those front line operators and the IPT charged with the duty of reviewing the draft Pro-Formas. Examples of these errors are :

a. Hazard H68 Cause Z320 describes the potential for fire to be caused by the interaction of fuel and electrical components. One of the indications of a fuel leak is given as possible loss of engine performance. Hazard 68 Cause Z322 describes the potential for fire to be caused by interaction of hydraulic fluid and electrical components. It goes on, however, to describe that one of the indications of a hydraulic fluid leak would be loss of engine performance; this is not true as hydraulics do not determine or affect engine performance. Virtually all other paragraphs in these two proformas are identical apart from the words "fuel" and "hydraulics". They are both (an inordinate) 13 pages long.

b. Hazard H46 Cause Z209, the potential for fire caused by interaction of hot air and electrical systems, is related to the No. 6 tank fuel compartment. Unfortunately, it wrongly describes the location of the tail anti-icing delivery pipe as being on both the port side and the starboard side of the compartment.

15.43 The latter error may appear small but is indicative of a lack of real familiarity with the airframe, as this would be instantly spotted by any front-line operator. The former is of concern as it is buried within the dense, 13 page structure, should have been easily recognisable as a 'silly typo', and has obviously occurred due to a cut and paste operation being completed without proper thought or proof reading. Neither inspire confidence in the eventual product. BAE Systems will undoubtedly point to the fact that these are draft Pro-Formas. Unfortunately, they have been a long time in the drafting still to contain such basic mistakes.

The Cost

15.44 It is currently estimated that the work on the never completed SC2 and the (still in progress) SC3 (see below) has cost the MOD approximately £3.3 million.

15.45 The costs however, have not just been financial. A substantial commitment in terms of manpower and hours has been required from both the Nimrod IPT and personnel at RAF Kinloss and RAF Waddington over the past 20 months to service the drawing up of SC2, *i.e.* in attending meetings, reading, reviewing and checking Pro-Formas, assisting with aircraft visits, discussing operational procedures, and generally monitoring progress. All of this might have been time and effort well spent if the end product had been worthwhile and a valuable enhancement to the safety of the Nimrod fleet. To date, however, the end is not in sight and the material so far produced suggests that SC2 will add little or no value to sum total of knowledge and safety for the Nimrod fleet. I regret to say that SC2 is far too prolix, impenetrable and unsatisfactory to be of any real use.

Safety Case 3

15.46 The continued lack of progress with SC2 led to the Nimrod IPT considering alternative means of providing a Safety Case for the Nimrod. It was decided effectively to side-line SC2 and contract QinetiQ to produce a *third* Safety Case (SC3). I understand that SC3 will utilise the findings from the teardown and some of the material from SC2 but will have an entirely different structure. I understand that it is estimated that SC3 will have completed its independent review and evaluation by Christmas 2009.

Summary

15.47 If the original Safety Case had been fundamentally sound and contained few errors, a 'review' of its contents would not have taken long. It was far from sound and contained numerous errors (as explained in **Chapter 11**). This has made the task of 'reviewing' it more difficult and extensive. In retrospect, SC2 would probably have benefitted from starting with a clean sheet altogether.

15.48 In my view, however, even taking this into account, the delays in producing the never completed SC2 were unacceptable, the cost of SC2 in terms of both money and manpower disproportionate, and the outcome of SC2 far from satisfactory. I have concluded that the work done by BAE Systems on SC2 has added little or nothing to the *net* safety of the Nimrod fleet; and, arguably, has had a *negative* effect on airworthiness: (a) because it has made the task of monitoring airworthiness issues immeasurably more difficult and problematic because of the unnecessary complexities introduced by SC2; and (b) because of the inordinate amount of time Nimrod IPT and Unit engineers have spent tied up dealing with SC2. It was defensive engineering at its worst.

15.49 In my judgment, BAE Systems' work on SC2 was largely valueless and a waste of time and money.

"Stop Press Folder" documents disposed of in September 2006

15.50 Finally, an issue was drawn to my attention regarding the destruction of some documents in the immediate aftermath of the loss of XV230. I have carefully looked into this matter and am satisfied that: (a) the 'shredding' of these documents was in the normal course of activities, was inadvertent and innocent; and (b) none of the documents concerned was of any significance. The circumstances were as follows.

15.51 Following the loss of any RAF aircraft, it is required procedure for the Squadron concerned to take a number of pre-determined actions to safeguard evidence for the BOI. Among these actions is the impounding of specified documentation, such as engineering records and operations documents.

15.52 Upon being advised of the aircraft's loss, the detachment commander at XV230's Deployed Operational Base immediately took the requisite action and temporarily impounded the relevant documents. He was also advised that Nimrod operations in support of Coalition Ground Forces must continue without interruption. Nimrod flying operations could not, however, continue without the relevant operational documents that he had temporarily impounded. In a remote overseas location, within the timescale he needed them, the detachment commander could not simply request a set of replacement documents from the United Kingdom. He could, of course, have photocopied the documents, but to do so would have involved a significant and disproportionate amount of effort by detachment personnel, who were at this time heavily engaged in the conflict. Accordingly, the detachment commander released the documents to his operations staff.

15.53 One of the documents returned to the operations room to enable the Nimrod detachment to continue to fulfil its tasking was the *"Stop Press Folder"*. This folder housed all the recently issued documents that the detachment commander and operations staff felt that aircrew should be aware of, for example, details of ground operations, local airfield reports, flight safety reports. To keep the folder to a manageable size, those papers that no longer have any validity, or had been incorporated in other documents, are regularly destroyed. This was standard practice on all Nimrod squadrons and detachments.

15.54 On a night between the loss of XV230 and the arrival of the BOI, the (busy) detachment commander sanctioned a request by one of his staff to conduct a routine destruction of material in the Stop Press Folder. This was a mistake. All of the material should have been safely retained ready for examination by the BOI when it arrived. Nonetheless, as soon as the BOI arrived in theatre, the detachment commander realising the mistake, appraised them of what had occurred and the fact was recorded formally in the BOI's evidence.[39] The BOI took a copy of the list of destroyed documents and determined that there was nothing within them that could be immediately relevant to their investigation. Indeed, over the months that followed none of the documents was required by the BOI. The file was unlikely to contain anything of direct relevance to the loss of XV230 and it could, in the main, have been reconstituted if required.

15.55 The matter of the destruction of some of the contents of the *"Stop Press Folder"* was understandably raised by the families' Counsel at the Inquest in May 2008 and the detachment commander was called to give evidence to explain what happened.

15.56 In my view, the detachment commander's immediate admission of his error to the BOI displayed admirable honesty and integrity. He must have been working under intense pressure at the time in coping both with the aftermath of the accident and ensuring the continuance of current operations (and, by all accounts, he showed considerable leadership and professionalism). It was a small and, as it transpired, irrelevant error made by someone who was exceptionally busy and under significant pressure. Individuals must be confident that they can admit such errors without attracting undeserved criticism or sanction. In this case, I am pleased to note that the RAF authorities placed this mistake in its proper context and made no negative comment whatsoever. I entirely concur with that approach.

15.57 Having carefully looked into the matter, I have no doubt that the destruction of these few documents was entirely inadvertent and innocent and is of no significance.

Professionalism and dedication of Nimrod community and leadership

15.58 The continued operation and deployment in theatre of the Nimrod fleet following the loss of XV230 in September 2006 has not been easy. Those charged with operating and maintaining the Nimrod fleet have had to cope with unprecedented but understandable media and public attention, numerous visits from top brass, intense scrutiny from outside agencies (including the Nimrod Review) and the implementation of a welter of numerous new inspection, maintenance and repair procedures. The fact that the Nimrod fleet has continued to fly successfully in support of Coalition Forces, in the face of all these challenges, is a tribute to the cool professionalism and dedication of the RAF Nimrod community at RAF Kinloss and RAF Waddington and the strong leadership shown by the Station Commanders (Group Captain Jerry Kessell and Group Captain Robbie Noel at RAF Kinloss and Group Captain Andy Fryer and Group Captain Rich Powell at RAF Waddington and Senior Executives

[39] Evidence of Detachment Commander.

(in particular Wing Commander Martin Cannard, Wing Commander Ian Torrance and Wing Commander Steve Wilcock at RAF Kinloss). Both stations have, I know, received particular support over many trying and turbulent months from the three senior officers who have held the position of Air Officer Commanding No. 2 Group (Air Vice Marshal Iain McNicoll, Air Vice Marshal Andy Pulford and Air Vice Marshal Steve Hillier).[40]

[40] Ranks are those held at the time the individuals occupied the positions shown.

Appendix A to Chapter 15

<u>AIRCRAFT</u>: TYPE: NIMROD MR2 TAIL NO: XV230 <u>DATE OF INCIDENT</u>: 2 SEP 06

<u>BRIEF DESCRIPTION</u>: Crash 14nm West of Kandahar Airfield, Afghanistan. 14 fatalities.

<u>CONVENING AUTHORITY</u>: AOC 2 Gp

Serial Number	Recommendations	Status
1	The Nimrod Maintenance Policy is reviewed to ensure that maintenance procedures reflect the increasing age of the aircraft.	**Short-Term Action Complete.** The fuel system, the hot air system and electrical system maintenance policies have been enhanced by supplementary inspections through RTIs. The Fuel System has been reviewed as part of an Independent Fuel System Safety Review by QinetiQ. Its Zonal Hazard Analysis has been used to identify couplings whose seals could be replaced as a precaution and this will be completed under the actions detailed at Serials 5 and 6. A study undertaken by DE&S DG Safety and Engineering, involving widespread consultation, both civilian and military, has been unable to find any other organisation that sets a life for fuel seals. The study determined that there was no requirement to set a life for fuel seals, but recommended a number of other means to reduce seal failures. **Medium-Term Action Continuing.** The Nimrod Team has developed a 3 strand process to complete this recommendation: a. An audit of all those systems assessed as having a potential impact on safety or airworthiness has been completed. b. The Nimrod Support Policy Statement is being reviewed. c. The NIMROD TEAM is establishing a robust ‘continuing airworthiness’ regime to ensure that mechanisms are in place to maintain the effectiveness of maintenance policy until OSD. The results of the Maintenance Policy Review have now been incorporated into the Aircraft Maintenance Schedule and a final report has been accepted by the Nimrod Team. Once the Aircraft Operating Authority agrees this report the recommendation will be closed.

Serial Number	Recommendations	Status
2	The Nimrod Ageing Aircraft Audit is reviewed to include aircraft systems. This work should be incorporated within the review of Nimrod maintenance policy.	Action Continuing. Ageing Aircraft Systems Audits (AASysA) were not mandated as MOD policy until Sep 06. Prior to this date Ageing Aircraft Audits were only required to consider structures. Detailed guidance and requirements for AASysA are now agreed. The Nimrod Team contracted a tear-down inspection of Nimrod MR2 XV236 to provide factual information to support the AASysA. XV236 was delivered to Boscombe Down for physical tear-down on 31 Jul 08 and this activity is now complete. The Nimrod Team tailored the AASysA of aircraft systems to reflect the Nimrod's approaching OSD. AASysA requirements to support an aircraft which has a lengthy Service life before it (for example ensuring the long-term availability of suppliers of aircraft systems) were not pursued. The AASysA focused on assuring the physical condition of the Nimrod's systems for its remaining Service life and concentrated on the results of the tear-down of XV236. The final AASysA report was delivered to the Nimrod Team on 22 Jul 09. This report was distributed to the Platform Safety and Environmental Working Group (PSEWG) for review prior to an extraordinary meeting, which took place on 11 Aug 09 at RAF Wyton. The meeting confirmed that Nimrod remained safe to fly with the mitigation currently in place. Once the Aircraft Operating Authority agrees this final report the recommendation will be closed.

Serial Number	Recommendations	Status
3	The Nimrod Safety Case (SC) is reviewed, reassessing the factual data used for interpretation and categorization of hazard and risk. The review should include widespread operator (air and ground crew) involvement. This work should be incorporated within the review of Nimrod maintenance policy.	Action Continuing. Review commenced by BAES on 3 Dec 07 and initial target completion date was Apr 08. However, as work progressed it became clear that the review would require more extensive effort than initially planned. The changing strategy imposed additional work and concomitant delays in completion dates. BAES estimated that they would be unable to complete the SC until 2010. Although the SC review is not yet complete the Nimrod MR2 Safety Engineer, supported by the PSEWG, is confident that the wide-ranging, complementary, independent studies, and the XV 236 tear-down, have provided enough information for him to confirm that the Nimrod remains safe to operate. In addition no evidence has been produced from the ongoing work on the SC that would call into question Nimrod airworthiness. Nonetheless, in view of the delays in the provision of the SC, the Nimrod Team has developed an alternative means of completion. The Nimrod Team has been working with QinetiQ to produce a SC (based on a model successfully completed for the BBMF), whilst still using BAES information where available. The Nimrod Team approach was endorsed during the D AS Nimrod 2* Airworthiness Review held on 21 Jul 09. The Nimrod PT Project Engineer reported to an Extraordinary meeting of the PSEWG on 2 Oct 09 that he intended to recommend to the RTSA that the Nimrod Equipment Safety Case (ESC) be accepted. The ESC will now be independently reviewed. This review will comprise 2 elements. The Independent Safety Audit (auditing the structure, method and logic of the safety case) will take approximately 6 week. However, an Independent Technical Evaluation of BAES's zonal and functional hazard analysis (which is a major contributor to the equipment safety case) will be conducted in parallel and is estimated to require 8 – 12 weeks. While these tasks are underway the Nimrod PSEWG agrees that work already completed will continue to support the safe operation of the Nimrod. Final confirmation of the integrity, accuracy and applicability of the ESC will be provided by this process and, thus, this action will remain open until both independent checks have been completed.

Serial Number	Recommendations	Status
4	A safety review of the Nimrod fuel and hot air systems is completed. In particular the safety review should consider the suitability of corrective maintenance for these systems. The review should also consider mitigation of the risk of fire and hot air leaks within airframe hidden compartments, such as the No 7 tank dry bay and the Rib 1 landing; mitigation might involve introduction of fire detection and suppression systems, fire retardant coatings, or a change in procedures, which reduces the risk of fire. Nimrod operators (air and ground crews) should be involved closely with the review. This work should be incorporated within the review of Nimrod maintenance policy.	Recommendation Closed. The reviews undertaken by QinetiQ into the Nimrod fuel and hot air systems are complete. Related Action. The recommendations of the QinetiQ fuel and hot air system reviews are being tracked by the Nimrod Integrated Project Team. On completion of the final recommendation this related action will be closed.
5	A life for the FRS Series 1 fuel seal be determined, based on the designer's recommendation that fitted seals are replaced after 25 years.	Recommendation Rejected (Intent achieved by other measures). Implementation of this recommendation would not improve aircraft safety or availability. The recommendations intent is served by the enhanced inspection regime for the fuel system and the targeted seal replacement programme._ A study undertaken by DE&S DG Safety and Engineering, involving widespread consultation, both civilian and military, has been unable to find any other organisation that sets a life for fuel seals. The study determined that there was no requirement to set a life for fuel seals, but recommended a number of other means to reduce seal failures. However, as part of the QinetiQ Fuel System Safety Review, a Hazard Analysis of the fuel system was undertaken and the output from this has been used to establish a targeted seal replacement programme (42 seals on each aircraft); this will replace, as a precautionary measure, some of those seals not normally replaced in routine maintenance (180 are replaced during Major maintenance.)
6	A maximum installed life for fuel seals of other material types is determined.	Recommendation Rejected (Intent achieved by other measures). Implementation of this recommendation would not improve aircraft safety or availability. The recommendations intent is served by the enhanced inspection regime for the fuel system and the targeted seal replacement programme._ Detail as serial 5.

Serial Number	Recommendations	Status
7	A one-off inspection of the integrity of each Nimrod's fuel system, between Ribs 3 starboard and port, be conducted with access panels removed and the system pressurised. The inspection is to check for leaks, physical damage and is also to include visual confirmation that fuel couplings have been assembled and locked correctly. This inspection will establish a baseline pending action on other recommendations.	Recommendation Closed. Under RTI 212 the area between Rib 3 and Rib 3 is de-panelled and the fuel system pressurised and checked for leaks every 30 days. It is impossible to physically check all couplings for correct assembly and locking under this regime, but this is being conducted under the related long-term action below. Related long-term action: Under STI/922 a targeted fuel seal replacement programme (FSRP) of 42 seals on each aircraft is being undertaken by a dedicated, trained team of depth tradesmen. Only 3 aircraft have not had FSRP implemented. One of these aircraft will have FSRP embodied in Nov 09 during Equalised Maintenance, while the others will retire shortly and will not have FSRP embodied. It is planned that no Nimrods will fly beyond Dec 09 without FSRP incorporated.
8	An inspection regime for fuel seals be initiated as recommended by Eaton Aerospace (para 32a (2)). The inspection should be a visual check of the fuel coupling, in-situ and under pressure, with panels removed. In view of the potential age of some Nimrod fuel seals this inspection should be annual, until a life is determined for the seals and any seal replacement programme is complete.	Recommendation Rejected (Intent achieved by other measures). The actions taken following the loss of XV230 have instigated a more rigorous regime than that recommended by Eaton Aerospace. Current inspections cover the key hazard areas identified in the independent work undertaken by QinetiQ. These procedures will remain in place unless or until more appropriate measures are identified.
9	A procedure is developed to pressure test the fuel vent system at the fuselage to wing interface.	Recommendation Closed. This original test under RTI/NIM/196 has now been replaced by RTI 248 which provides a more effective long term solution.
10	Detailed instructions for the correct fitting and locking of FRS couplings and seals be incorporated formally within the Nimrod AMM and publicized widely.	Recommendation Closed Amendments to publications have been issued detailing correct fitting and locking of FRS couplings and seals.

Serial Number	Recommendations	Status
11	Hot Air System. Existing limitations, prohibiting the use of the SCP and of the cross-feed pipe in the air be continued, unless: the pipe insulation is modified in such a way that the pipe cannot act as an ignition source; the BAES study into corrosion within cross-bleed pipes, undertaken following the hot air leak on XV227, is completed and its recommendations acted upon; a hot air leak detection system capable of detecting any leak within the cross-feed pipe and SCP (to the venturi) is fitted.	Recommendation Closed. Immediately following the accident both the Supplementary Conditioning Pack and the cross-feed pipe systems were prohibited from being used in the air. These limitations will stay in force until the aircraft is taken out of service. Related Action. Following the publication of the BAES study into fatigue and corrosion within hot-air ducts a decision was taken to replace all engine bay and cross-feed hot air ducts. To date, 8 MR2 and 2 R1 aircraft have been completed and 3 MR2 and one R1 aircraft (all currently undergoing scheduled maintenance) are in work. Aircraft that have not had their ducts replaced will not be flown until the replacement has been undertaken.
12	Nimrod AAR procedures are reviewed in the light of the Board's report, to establish appropriate levels and rates of refuel, which will prevent overspill of fuel from tanks.	Recommendation Closed. Air-to-air refuelling (AAR) for the Nimrod MR2 and R1 is now prohibited (ALs 9 and 22 respectively to the aircraft's RTS). As this recommendation is only relevant to AAR it no longer has any utility and has been closed.
13	A study be initiated to determine the cause of pressure surges during AAR and their long-term effect on aircraft fuel systems.	Recommendation Closed. Work undertaken since the loss of XV230 indicates that there are a number of reasons for fuel coupling leaks, including misaligned couplings, rather than AAR induced pressure. AAR for the Nimrod MR2 and R1 is now prohibited (ALs 9 and 22 respectively to the aircrafts' RTS). As this recommendation is only relevant to AAR it no longer has any utility and has been closed.
14	A statement specifying that the maximum normal operating pressure of 50 psi during AAR be reintroduced into the Nimrod ACM.	Recommendation Closed. AAR for the Nimrod MR2 and R1 is now prohibited (ALs 9 and 22 respectively to the aircrafts' RTS). As this recommendation is only relevant to AAR it no longer has any utility and has been closed.
15	AAR refuel rates in the dynamic simulator are changed to reflect actual refuel rates to provide more realistic training.	Recommendation Closed. AAR for the Nimrod MR2 and R1 is now prohibited (ALs 9 and 22 respectively to the aircrafts' RTS). As this recommendation is only relevant to AAR it no longer has any utility and has been closed.
16	Existing limitations, prohibiting the use of the No 7 fuel tanks, introduced following the loss of XV230, be discontinued.	Recommendation Closed. RTS clearance for reinstatement of No7 tank was issued on 9 Jun 08.

Serial Number	Recommendations	Status
17	A study be undertaken into the utility of parachute escape on the Nimrod MR2.	Recommendation Rejected After completion of reports into the feasibility and cost of incorporating a parachute escape facility within the Nimrod it was decided that the capability could not be fitted within the remaining life of the Nimrod airframe.
18	Nimrod STANEVAL consider the lessons identified at Annex P and their potential impact on crew emergency procedures.	Recommendation Closed. The Nimrod STANEVAL have reviewed Annex P to the main report and produced recommendations which will be taken forward by RAF Kinloss and HQ 2 Gp
19	The port rear emergency oxygen bottle is relocated to a more central position, or another oxygen bottle is provided in this position.	Recommendation Closed. All MR2 and R1 aircraft have been modified (SM 505/ 506).
20	The design of No 1 fuel tank is reviewed to reduce the effect of asymmetric filling.	Recommendation Closed. AAR for the Nimrod MR2 and R1 is now prohibited (ALs 9 and 22 respectively to the aircrafts' RTS). As this recommendation is only relevant to AAR it no longer has any utility and has been closed.
21	The outlet pipes for fuselage fuel tank blow-off valves be modified to ensure that blown-off fuel cannot run down the exterior of the fuselage.	Recommendation Closed. AAR for the Nimrod MR2 and R1 is now prohibited (ALs 9 and 22 respectively to the aircrafts' RTS). As this recommendation is only relevant to AAR it no longer has any utility and has been closed.

Serial Number	Recommendations	Status
22	The connections of the No 1 tank vent pipes be modified to reduce the risk of fuel leakage.	Action Continuing – Recommendation Reopened. This recommendation arose from concern that, as the No 1 tank reached full during AAR, fuel could enter the vent pipe. The connection of the No 1 tank to the vent system was not deemed adequate to ensure no fuel leakage in such a situation. Although this recommendation was initially closed, as the Nimrod no longer undertakes AAR, the tear-down of XV 236 specifically examined the structure of the vent pipe connection and determined that the design could be improved. If the aircraft manoeuvres with the No 1 tank close to full, small amounts of fuel can also enter the vent system. Any leak would be of a significantly smaller quantity than might occur during AAR and the cross-feed/ SCP ducts no longer pose a potential source of ignition. Additionally the vent system is checked for leaks during equalised maintenance. As an interim measure RTI/334 has been issued, to ensure that a correct seal is achieved on the vent pipe, thus ensuring the risk remains ALARP. STI/Nimrod/944A introduces a revised design for the connection and was issued on 14 Aug after a successful trial installation carried out on XV226. The planned completion date for the modification is 13 Oct 09.
23	The drainage of the lower panel in the No 7 tank dry bay be improved to prevent any accumulation of fuel.	Recommendation Closed. This modification has now been incorporated.
24	A crash-protected means of recording aircraft position and intercom voice is introduced to the Nimrod.	Recommendation Rejected. It was determined that the cost of implementing this recommendation would be disproportionate to the remaining life of the aircraft. Moreover, it could not be fitted to the Nimrod fleet within the remaining life of the aircraft. As mitigation it was also noted that XV 230's BOI had been able to extract considerable data from the aircraft mission tape despite the fact that it was not crash protected. DARS has added a note to its web site instructions for Incident Officers at crash sites to ensure that all magnetic media is recovered for analysis.
25	The Defence Aviation Safety Centre (DASC) should investigate the provision of details of type specific emergency equipment (ADR, etc) and key internal components (for example the ADR tape unit and housing) on their website to enable Post Crash MOD Incident Officer (PCMIO) to provide guidance to search teams.	Recommendation Closed. This recommendation has been accepted and the Defence Aviation Safety Centre has already updated its website with the relevant information.

Serial Number	Recommendations	Status
26	Instructions for PCMIO are revised to provide guidance when attending crash sites that are likely to become inaccessible.	Recommendation Closed. The PCMIO course now includes guidance on Post Crash Management priorities during operations. Additionally, the MOD UK Aircraft Post Crash Management policy now includes Out Of Area Operations.
27	Instructions for PCMIO at crash sites which are likely to become inaccessible should include advice to make every effort to ensure the widest possible photographic coverage of the crash site, at the highest possible resolution. This should take priority over all other tasks for any photographic team.	Recommendation Closed. The PCMIO course now emphasises the requirement for collecting visual evidence. Additionally, the Post Crash Management Aide Memoire now details the requirement for visual evidence.
28	DASC should increase their current stock of post-crash BOI kits.	Recommendation Closed. Four Post-Crash BOI kits are suitable for current tempo; a local agreement is now in place with RNFSAIC which allows for the provision of one of their 4 kits (containing the same equipment) on a case-by-case basis should circumstances dictate.
29	Body bag fluid proof liners should be stored within the outer ruggedised bags in crash kits to ensure that they always arrive on scene together.	Recommendation Closed. Instructions have been issued to all 3 services.
30	The Nimrod Mod Form 700 Sections 2 and 3 (F703/F704) should be copied and retained before the document is carried on the aircraft.	Recommendation Closed JAP 100A has been modified to require this.
31	The use of non-approved mission system panel blanks be discontinued.	Recommendation Closed. Procedures have been put in place to ensure that this does not happen again.
32	Consideration be given to reinstating the SO1 engineering post in Forward at RAF Kinloss to provide senior oversight of station engineering matters.	Recommendation Closed. Complete. A Wg Cdr Engineer is in place at RAF Kinloss.
33	A review of engineering training is undertaken to identify those areas which, while relevant to Nimrod capability, are not encompassed within existing formal training courses.	Recommendation Closed. Specific action has already been undertaken at RAF Kinloss to address Nimrod engineering training.

CHAPTER 16 – INQUEST

Contents

Chapter 16 covers the Inquest and answers the following questions:

- What, in law, is the true nature of an Inquest?
- What evidence relevant to the Review emerged from the Inquest?
- Was the Coroner's narrative verdict regarding the source of the fuel for the fire on XV230 correct?
- Was the Coroner's Rule 43 recommendation justified?

Summary

1. A Coroner's Inquest is essentially a limited factual inquiry into the circumstances leading to the loss of life.
2. The Inquest, in fact, produced little factual evidence of value to the Review.
3. The Coroner's finding as to the likely source of fuel did not accord with the realistic probabilities, or the evidence before him.
4. The Coroner's Rule 43 recommendation (that the Nimrod fleet should be grounded pending certain repairs) was based on his misunderstanding of the meaning of ALARP.
5. I have found nothing to justify the Coroner's widely-publicised remark that the MOD had a "*cavalier approach to safety*". The fundamental problems are ones of structure, culture and procedure, not indifference (see **Chapter 19**).

The Nimrod Inquest: May 2008

16.1 Coronial jurisdiction is geographical. On 13 September 2006, the bodies of the crew of XV230 were repatriated to RAF Brize Norton in Oxfordshire with full military honours. Jurisdiction for conducting the inquests into the deaths of the crew of XV230 lay, therefore, with the Oxfordshire Coroner's Court. A joint Inquest took place before the Oxfordshire Assistant Deputy Coroner (Andrew Walker) between 6 and 23 May 2008. The major parties, namely the MOD, BAE Systems, QinetiQ and the families, were represented by legal Counsel (and Michael Bell represented the siblings and parents of Flight Sergeant Gerard Martin Bell). I closely monitored the proceedings using Counsel present throughout the hearing (Peter Ferrer), and Counsel to the Review (Luke Parsons QC and Caroline Pounds) who were present for certain parts of the evidence. The Inquest lasted three weeks and attracted much sensational publicity. On analysis, however, the Inquest produced little factual evidence of value to the Review.

Legal nature of an Inquest

16.2 A coroner's inquest is essentially a limited factual inquiry into the circumstances leading to the loss of life. A coroner is required by s. 11(5)(b) of the Coroners Act 1988 and Rule 36(1)(b) of the Coroner's Rules to set out the particulars regarding the identity of the deceased and when, where and how the deceased came by their death. Rule 42 of the Coroner's Rules specifies that *"No verdict shall be framed in such a way as to appear to determine any question of (a) criminal liability on the part of any person or (b) civil liability..."*. *"How"* was interpreted by the Court of Appeal in *ex parte Jamieson* [1995] QB 1 as meaning simply *"by what means"*. It was argued by Counsel for the families (Michael Rawlinson) that the circumstances of the XV230 accident gave rise to questions of *"actual or potential state responsibility"*[1], and, accordingly, there should be a coroner's investigation under Article 2 of the European Convention on Human Rights (ECHR)[2] applying the wider definition of *"how"* set out by Lord Bingham in *R (Middleton) v West Somerset Coroner* (2004) 17 BHRC 49,[3] namely *"by what means and in what circumstances"*. The Coroner ruled, however, that this was not necessary on the basis that the State's duty to carry out an Article 2 investigation would be satisfied *"jointly"* by his inquest and the Nimrod Review.[4]

16.3 The Coroner's task in a case as complex as XV230 was far from straightforward. Moreover, an inquest with an emotionally charged atmosphere is not an ideal forum for analysing highly technical matters.

Coroner's verdict

16.4 The Coroner, sitting without a jury, gave a lengthy narrative verdict and entered a verdict of *"Accidental Death"*. I have studied the Coroner's narrative verdict and make the following points regarding his findings:[5]

16.4.1 First, the Coroner's finding as to the most likely fuel source did not accord with the realistic probabilities. He said the most likely source for the fuel was a leak from the fuel feed system to engines Nos. 3 and 4 which would have provided *"a continuous source of fuel"* which would *"travel along the aircraft into dry bay 7"* to the seat of the fire. I am satisfied, however, that this mechanism is highly unlikely. As I explain in **Chapter 5**, it is highly unlikely that a leak from the fuel feed system to engines Nos. 3 and 4 would have resulted in a sufficient quantity of fuel making its way into the starboard No. 7 Tank Dry Bay. The pipes for the fuel feed system to engines Nos. 3 and 4 are located at the leading edge of the starboard wing. For fuel to reach the No. 7 Tank Dry Bay from this point it would have to follow a convoluted path which would involve: (a) tracking back some 17 feet; (b) crossing numerous lateral members; (c) passing through an almost solid dividing wall; and (d) avoiding air vent holes in Rib 1 which would also act as fluid drains, before reaching the point of ignition. There is no significant history of leaks from this location. As the US Air Force Safety Centre commented, this scenario has *"a very low probability with no supporting evidence of feasibility"* (see **Chapter 3**). There are other, far more probable, scenarios.

[1] *C.f. R(Hurst) v London Northern District Coroner* [2007] 2 AC 189; and *Jordan v UK* (2001) 11 BHRC 1, where the court held that in appropriate cases deaths involving state bodies the investigation was *"to ensure their accountability for deaths occurring under their responsibility"* (paragraph [105]).

[2] The European Convention on Human Rights (ECHR) was incorporated into domestic law by the Human Rights Act 1998 on 2 October 2000.

[3] Ibid*,* paragraph [35].

[4] Inquest transcript, 7 May 2008, page 5, fourth paragraph.

[5] Coroner's narrative verdict, 23 May 2008.

16.4.2 Second, the Coroner misunderstood the QinetiQ Combustion Report.[6] He said that at "*11:13:45 the combustion analysis demonstrates that at the time of observation by the camera the fuel couplings would still be intact*".[7] This is incorrect. The QinetiQ Combustion Report Timeline has the fuel pipes in the No. 7 Tank Dry Bay starboard starting to leak, and the No. 7 tank vent pipe starting to deteriorate, before the camera observation at 11:13:45, depressurisation having taken place 1 minute 25 seconds before at 11:12:20.[8] The QinetiQ Combustion Report concluded that *"it appears likely that the elastomer seals experienced minor early [heat] deterioration that caused fuel leaks"* which then became *"self-limiting due to fuel cooling"*.[9] The Coroner did not understand the logical and compelling sequence of events explained in the QinetiQ Combustion Report: (1) only a small amount of fuel (no more than 300 mls) was required to start a pool fire in the tray at the bottom of the No. 7 Tank Dry Bay starboard;[10] (2) this pool fire would have generated sufficient heat to cause damage to the nine elastomer seals in the bay such that they began to leak fuel themselves; (3) the deterioration of these seals would, however, have been gradual and self-limiting because of the cooling effect of the fuel in the pipes; (4) these damaged and leaking seals would nonetheless have provided a sufficient secondary fuel source prior to the pool fire burning out, or the loss of the lower panel; and (5) the ensuing conflagration would become self-sustaining and led to all surfaces in the bay being subjected to temperatures well in excess of the melting point of aluminium, including the No. 7 fuel tank itself.[11]

16.4.3 Third, the Coroner appears to have misheard the evidence of the Harrier pilot. The Coroner suggested "*if the source of fuel was a fuel feed pipe then the fire would burn gradually forward towards the source of the fuel leak*" and "*this would accord with the description first given by the Harrier pilot of a fire further forward as set out within the Accident Investigation Report*".[12] In fact, the Harrier pilot said clearly twice in evidence to the Inquest that the fire was *"half-way down the wing root"*,[13] *i.e.* near the area of the No. 7 Tank Dry Bay starboard and nowhere near the leading edge of the wing. Moreover, it is difficult to see how a fire could burn forward in the face of a 400 knot airstream.

16.4.4 Fourth, as explained elsewhere in this Report, the absence of surviving physical evidence means one cannot, of course, rule out any one of a number of theoretical or possible fuel sources and fluid paths in the aircraft. Any realistic assessment of the probabilities, however, points to a leak in the immediate vicinity of the Cross-Feed/SCP duct from one of no less than eight fuel couplings within the No. 7 Tank Dry Bay starboard itself, some located inches immediately above the SCP elbow, leading to a pool fire[14] in the bottom corrugated panel, with the ensuing consequences outlined above. (See generally **Chapter 5**).

16.4.5 Fifth, the Coroner was wrong to dismiss the possibility of blow-off from the No. 1 tank blow-off valve during Air-to-Air Refuelling (AAR) as a source of fuel for the fire on XV230. He did so on the grounds that "*not one person has reported seeing a blow-off from number 1 tank during air-to-air refuelling...*" which "*...would be spectacular with a huge amount of fuel being sent out from the side of the aircraft*".[15] The evidence showed that the phenomenon of blow-off has, in fact, been observed during refuelling on the ground and will occur if similar conditions are imposed on a fuel tank during refuelling in the air, although it will not necessarily be visible to the crew of the Nimrod or the tanker. There was, moreover, evidence that blow-off did in fact occur on XV230 on several occasions during AAR sorties prior to XV230's final flight. (See generally **Chapter 6**).

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[6] *Combustion Analysis of Nimrod MR2 XV230 Accident Issue 3*, QinetiQ.

[7] Coroner's narrative verdict, 23 May 2008, page 23, first paragraph.

[8] *Combustion Analysis of Nimrod MR2 XV230 Accident Issue 3*, QinetiQ, page 45.

[9] *Combustion Analysis of Nimrod MR2 XV230 Accident Issue 3*, QinetiQ, paragraph 11.2(c).

[10] About a Coke can.

[11] *Combustion Analysis of Nimrod MR2 XV230 Accident Issue 3*, QinetiQ, page 16.

[12] Coroner's narrative verdict, 23 May 2008, page 27, third paragraph.

[13] Inquest transcript, 12 May 2008, pages 157 and 163, fourth and third paragraphs respectively.

[14] And probably a stoichometric mix.

[15] Coroner's narrative verdict, 23 May 2008, page 16, second paragraph.

16.5 The Coroner's Rule 43 recommendation[16], that the Nimrod fleet should be grounded, was the result of a misunderstanding by him of the meaning of the term ALARP (As Low As Reasonably Practicable). The 'R' in ALARP has a temporal element: a reasonable time is allowed to implement appropriate measures to mitigate identified risks. If this were not the case, few commercial or military aircraft would ever fly. (See generally **Chapter 9**).

16.6 I have conducted a detailed and wide-ranging investigation lasting many months, including interviewing hundreds of witnesses and examining thousands of documents. I have found nothing to justify the Coroner's (widely-publicised) remark that the MOD had a *"cavalier approach to safety"*.[17] Nor, in my judgment, was there anything before him to justify such a remark.[18] The problem is not indifference to safety. The problem is the numerous systemic shortcomings in the MOD's safety and airworthiness structure, culture and procedure which need addressing. (See generally **Chapters 19** to **28**).

16.7 The difficulties arising from inquests running in parallel to inquiries was highlighted in 1987 by Mr Desmond Fennell QC in his Report into *The King's Cross Underground Fire.*[19] Reform of the 'arcane' Coroner's system was recommended by Sir Anthony Clarke in 2001 in his Report into the identification issues following *The Marchioness Disaster*.[20] A Draft Coroners Bill was published by the Government in June 2006. The Government announced its intention to bring forward the Coroners Bill in the Queen's Speech in December 2008. This long overdue reform is to be welcomed.

[16] Rule 43 of the Coroners Rules provides: "*A Coroner who believes that action should be taken to prevent the recurrence of fatalities similar to that in respect of which the inquest is being held may announce at the inquest that he is reporting the matter in writing to the person or authority who may have power to take such action and he may report the matter accordingly.*"

[17] Coroner's narrative verdict, 23 May 2008, page 49, second paragraph.

[18] See, in particular, his misunderstanding of 'ALARP'.

[19] *The Investigation into the King's Cross Underground Fire* (Cm 499) by Mr Desmond Fennell QC (p. 141).

[20] *Report of the Public Inquiry into the Identification of Victims Following Major Transport Accidents* (Cm 5012) by the Rt. Hon. Lord Justice Clarke, dated March 2001.

PART VI:

LESSONS AND RECOMMENDATIONS

PART VI: LESSONS AND RECOMMENDATIONS

"The only source of knowledge is experience"
(Albert Einstein, 1879-1955)

1. The lessons to the learned from the loss of Nimrod XV230 are profound and wide-ranging.

2. Many of the lessons to be learned are not new. The organisational causes of the loss of Nimrod XV230 echo other major accident cases, in particular the loss of the Space Shuttles *Challenger and Columbia, and cases such as the Herald of Free Enterprise, the King's Cross Fire*, the *Marchioness Disaster* and *BP Texas City* (see **Chapter 17**).

3. Those involved in Military Aviation Airworthiness would benefit from an understanding of Accident Theory (see **Chapter 18**).

4. The shortcomings in the current airworthiness system within the MOD are manifold (see **Chapter 19**).

5. I have found:

   (1) a failure to adhere to basic Principles;

   (2) a Military Airworthiness System that is not fit for purpose;

   (3) a Safety Case regime which is ineffective and wasteful;

   (4) an inadequate appreciation of the needs of Aged Aircraft;

   (5) a series of weaknesses in the area of Personnel;

   (6) an unsatisfactory relationship between the MOD and Industry;

   (7) an unacceptable Procurement process, leading to serial delays and cost over-runs with a baleful effect on In-service Support; and

   (8) a Safety Culture that has allowed 'business' to eclipse Airworthiness.

6. In my view, wide-ranging reform and a sea-change in attitudes and approach is required in order to address the deficiencies revealed by Nimrod XV230 and the subsequent investigations by the Review.

7. I make Recommendations in the following eight key areas:

   (1) <u>A new set of Principles</u> (see **Chapter 20**).

   (2) <u>A new Military Airworthiness Regime</u> (see **Chapter 21**).

   (3) <u>A new approach to Safety Cases</u> (see **Chapter 22**).

   (4) <u>A new attitude to Aged Aircraft</u> (see **Chapter 23**).

   (5) <u>A new Personnel Strategy</u> (see **Chapter 24**).

   (6) <u>A new Industry Strategy</u> (see **Chapter 25**).

(7) A new Procurement Strategy (see **Chapter 26**).

(8) A new Safety Culture (see **Chapter 27**).

8. I also make a number of further Recommendations (see **Chapter 28**).
9. The ultimate aim of this Report is to improve Safety and Airworthiness for the future.
10. The duty of those in authority reading this Report is to bring about, as quickly as possible, the much-needed and fundamental improvements for the future which I have identified. This is not only for the safety of the men and women in the Services most immediately at risk, but also for the benefit of the effectiveness of Defence generally.
11. A safe and airworthy fleet is a more capable and effective fleet.

CHAPTER 17 – COLUMBIA AND OTHER LESSONS

"Bureaucracy and process trumped thoroughness and reason."
(Columbia Accident Investigation Board Report, 2003)[1]

"From top to bottom the body corporate was infected with the disease of sloppiness."
(David Steel QC, Formal Investigation into *m.v.* Herald of Free Enterprise)[2]

Contents

Chapter 17 examines some of the lessons learned from previous catastrophic accidents.

Summary

1. The lessons to be learned in the case of Nimrod XV230 are not new.

2. There are 12 uncanny, and worrying, parallels between the organisational causes of the loss of Nimrod XV230 and the organisational causes of the loss of the NASA Space Shuttle 'Columbia':

    (1) The 'can do' attitude and 'perfect place' culture.

    (2) Torrent of changes and organisational turmoil.

    (3) Imposition of 'business' principles.

    (4) Cuts in resources and manpower.

    (5) Dangers of outsourcing to contractors.

    (6) Dilution of risk management processes.

    (7) Dysfunctional databases.

    (8) 'PowerPoint engineering'.

    (9) Uncertainties as to Out-of-Service date.

    (10) 'Normalisation of deviance'.

    (11) 'Success-engendered optimism'.

    (12) 'The few, the tired'.

3. The Columbia Accident Investigation Board Report[3] emphasised the importance of identifying the fundamental 'organisational causes' of accidents rather than just focusing merely on errors and omissions by individuals. It should be required reading for anyone involved in aviation safety.

4. The present case also has parallels with other catastrophic accidents such as the *Zebrugge Disaster* (1987), *King's Cross Fire* (1987), *The Marchioness* (1989), and *BP Texas City* (2005).

5. Columbia and other cases have shown that, usually, there are fundamental organisational causes which lie at the heart of many major accidents, and these have to be addressed in order to learn the real lessons for the future.

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[1] Page 181, Columbia Accident Investigation Board Report, August 2003.

[2] David Steel QC, Counsel to Inquiry, Formal Investigation into m.v. Herald of Free Enterprise before The Hon. Sir Barry Sheen, 1987.

[3] The Columbia Accident Investigation Board was set up by President George W. Bush to report into the loss of the NASA Space Shuttle *COLUMBIA* which disintegrated on re-entry into the Earth's atmosphere on 1 February 2003.

NASA Space Shuttle "Columbia" (2003)

> *"The dwindling post Cold War Shuttle budget that launched NASA leadership on a crusade for efficiency in the decade before Columbia's final flight powerfully shaped the environment in which Shuttle managers worked. The increased organisational complexity, transitioning authority structures and ambiguous working relationships that defined the restructured Space shuttle program in the 1990s created the turbulence that repeatedly influenced decisions made before and during STS-107".*
> (Columbia Accident Investigation Board Report, 2003)

17.1 There are uncanny, and worrying, parallels between the organisational causes of the loss of Nimrod XV230 and the organisational causes of the loss of the NASA[4] Space Shuttle *"Columbia"* in 2003.

17.2 *Columbia* was lost on 1 February 2003 as a result of a breach in the thermal protection system on the leading edge of the left wing. This was caused by a piece of insulating foam which, after launch, separated from the left bipod ramp section of the external tank, and struck the leading edge of the port wing in the vicinity of the lower half of the reinforced carbon-carbon panel number 8. During re-entry to the Earth's atmosphere this breach in the thermal protection system proved fatal: it allowed super-heated air to penetrate through the leading edge and progressively melt the aluminium structure of the port wing, resulting in a weakening of the structure until increasing aerodynamic forces caused loss of control, failure of the wing, and the breakup of the orbiter.

Columbia Accident Investigation Board Report (2003)

17.3 The Columbia Accident Investigation Board (CAIB)[5] emphasised the importance of identifying the fundamental 'organisational causes' of accidents rather than focusing merely on errors and omissions by individuals:

> *"Many accident investigations make the same mistakes in defining causes. They identify the widget that broke or malfunctioned, then locate the person most closely connected with the technical failure: the engineer who miscalculated an analysis, the operator who missed signals or pulled the wrong switches, the supervisor who failed to listen, or the manager who made bad decisions. When causal chains are limited to technical flaws and individual failure, the ensuing responses aimed at preventing a similar event in the future are equally limited: they aim to fix the technical problem and replace or retrain the individual responsible. Such corrections lead to a misguided and potentially disastrous belief that the underlying problem has been solved. The Board did not want to make these errors. A central piece of our expanded cause model involves NASA as an organisational whole."*[6]

17.4 The CAIB found that the organisational causes of the loss of *Columbia* were rooted in the Space Shuttle's history and culture:

> *"The organisational causes of this accident are rooted in the Space Shuttle's history and culture, including the original compromises that were required to gain approval for the Shuttle program, subsequent years of resource constraints, fluctuating priorities, schedule pressures, mischaracterisations of the Shuttle as operational rather than developmental, and lack of an agreed national vision. Cultural traits and organisational practices detrimental to safety and reliability were allowed to develop, including: reliance on past success as a substitute for sound engineering practices (such as testing to understand why systems were not performing in accordance with requirements/specifications); organisational barriers which prevented effective communication of critical safety information and stifled professional differences of opinion; lack of integrated management across program*

[4] U.S. National Aeronautics and Space Administration.

[5] CAIB was set up by President George W. Bush and reported in August 2003.

[6] CAIB Report, Chapter 7, page 177.

> *elements and the evolution of an informal chain of command and decision making processes that operated outside the organisation's rules."*

17.5 The CAIB pointed out that *"cultural norms"* tend to be fairly resilient and *"bounce back into shape"* and that beliefs held in common throughout an organisation *"resist alteration"*. The CAIB defined *"organisational culture"* as follows:

> *"Organisational culture refers to the basic values, norms beliefs, and practices that characterise the functioning of a particular institution. At the most basic level, organisational culture defines the assumptions that employees make as they carry out their work; it defines "the way we do things here". An organisation's culture is a powerful force that persists through reorganisations and the departure of key personnel."*[7]

Echoes of Challenger in Columbia

17.6 Only 17 years before, on 28 January 1986, NASA had lost the Space Shuttle *"Challenger"* in an explosion on take-off as a result of a defective 'O-ring'. The Presidential Commission investigating the *Challenger* accident (1986) found that NASA had increased reliance upon contractors for safety, relegating many NASA technical experts to desk-jobs whose role was essentially one of 'oversight' of contractor activities. NASA's increasing dependence on contractors served to undermine its in-house technical expertise. A 1990 review concluded that *"NASA did not have an independent and effective safety organisation"*. It was dependent for funds from those whose safety-related performance it was responsible for overseeing.[8]

17.7 There were many 'echoes' of the *Challenger* accident in *Columbia*. Lessons had not been learned the first time. This was one of the reasons which led the CAIB to concentrate on examining the organisational causes of the *Columbia* accident.

12 parallels between Nimrod XV230 and Columbia

17.8 There are 12 striking parallels between the organisational causes of the Nimrod XV230 and Columbia accidents and between the organisational traits and experiences of NASA and the MOD/RAF in the lead up to these two accidents. I discuss these below.

(1) The attitude was 'can do' and culture 'the perfect place'

17.9 NASA took great pride in its history and its *"can do"* attitude.[9] NASA saw itself as *"the perfect place"* following the success of its Apollo programme. NASA had a *"self confidence"* about possessing *"unique knowledge"* as to how safely to launch people into space. NASA did not take easily to criticism from outside, and tended to react by imposing the party line rather than reconsidering it. NASA was not a 'learning organisation'.[10] NASA suffered from *"flawed decision making, self deception, introversion and a diminished curiosity about the world outside the perfect place"*.[11]

17.10 The same can be said of many parts of the RAF and MOD.

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[7] CAIB Report, page 101.

[8] CAIB Report, page 179.

[9] CAIB Report, page 101.

[10] CAIB report, page 127.

[11] CAIB Report, page 102.

(2) 'Torrent of changes' and organisational 'turmoil'

17.11 The White House appointed a new NASA Administrator in 1992 who was to remain in post until November 2001. He was an *"agent of change"* favouring *"administrative transformation"*. He set in train *"not one or two policy changes, but a torrent of changes. This was not evolutionary change, but radical or discontinuous change. His tenure at NASA was one of continuous turmoil."*

17.12 The decade 1998-2008 has been one of continual administrative turmoil in the MOD resulting in 'change-fatigue'.

(3) Imposition of 'business' principles

17.13 Business management principles[12] were imposed on NASA during this period. These included that headquarters should not attempt to exert bureaucratic control over a complex organisation but simply set strategic direction and provide operating units with the authority and resources needed to pursue those directions; checks and balances should be removed; and those carrying out the work should bear primary responsibility for its quality. The CAIB said: *"It is arguable whether these business principles can be readily applied to a government agency operating under civil service rules and in a politicised environment."*[13]

17.14 The 'McKinsey effect' and the 1998 Strategic Defence Review (SDR) led to the imposition of business language and methodology on large swathes of the MOD.

(4) Cuts in resources and manpower

17.15 The end of the Cold War meant an end to defence budget increases. NASA was expected to become *"more efficient"* and to do *"more at less cost"*. There was *"schedule pressure"*. NASA was *"an agency trying to do too much with too little"*.[14] NASA's motto in the 1990s became *"faster, better, cheaper"*. Between 1991 and 1994, there was a reduction of 21% in operating costs. There were substantial reductions in the manpower and a decrease in the involvement of NASA's engineering workforce with the Space Shuttle program. This all caused uncertainty, tension and distraction.

17.16 During the period 1998-2008, the MOD and the Services have been repeatedly told to *"do more with less"*, and have been subject to round-upon-round of 'salami' cuts in funding and manpower.

(5) Dangers of outsourcing to contractors

17.17 The search for cost reductions led NASA leaders *"to down size the shuttle work force, outsource various shuttle program responsibilities - including safety oversight - and to consider the eventual privatisation."*[15] NASA staff reductions had led to important technical areas being left 'one-deep'. The Shuttle Independent Assessment Team (SIAT)[16] had given a stern warning about the quality of NASA's Safety and mission assurance efforts and noted that the shuttle programme had gone through a massive change in structure and was transitioning to a *"slimmed down, contractor run operation"*.[17] The SIAT said that workforce augmentation must be realised principally with NASA personnel rather than with contractor personnel. NASA had grown dependent on contractors for technical support, contract monitoring requirements increased and NASA positions were subsequently staffed by less experienced engineers who were placed in management roles. The CAIB said: *"Collectively this eroded NASA's in-house engineering and technical capabilities and increased the agency's reliance on the [main contractor] and its subcontractors to identify, track and resolve problems. The contract also involved substantial transfers of safety responsibility from the government to the private sector."*

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[12] The management approach advocated by Edwards Demin and used in Japan in the 1980s.

[13] CAIB Report, page 106.

[14] CAIB Report, page 102.

[15] CAIB Report, page 102.

[16] Shuttle Independent Assessment Team (SIAT) reported in 2000.

[17] CAIB Report, page 179.

17.18 In the past decade, the MOD has seen a further shrinking of the uniformed Services' and civilian workforce and an increase in outsourcing to, and reliance upon, Industry.

(6) Dilution of risk management processes

17.19 There had been an erosion in risk management processes. The SIAT said that NASA Safety Mission and Assurance should be restored to its previous role of an independent oversight body and not simply a safety auditor. NASA had had a system of checks and balances, including cross-government/contract engineering teams with a large-scale contract entered into with Lockheed Martin/Rockwell (the Space Operations Contract). Safety managers did not speak up and did not fulfil their stated mission to provide 'checks and balances'.[18]

17.20 There was a similar steady dilution of MOD Airworthiness management and structure in the period 1998-2006.

(7) Dysfunctional databases

17.21 The information systems that supported the Shuttle program were extremely cumbersome, dysfunctional and difficult to use.[19] The CAIB said: *"The Program has a wealth of data in multiple databases without a convenient way to integrate and use the data for management, engineering or safety decisions."*[20]

17.22 The data collection and database system for the Nimrod was also increasingly cumbersome, incoherent, vestigial, and dysfunctional (as well as vestigal).

(8) 'PowerPoint engineering'

17.23 The CAIB criticised the endemic use of PowerPoint briefings instead of technical papers as symptomatic of the problems of technical communication at NASA. PowerPoint was used to 'demonstrate' engineering rather than explain a proper technical analysis. When engineering analysis and risk assessments are condensed to fit on a standard form or overhead slide, information is inevitably lost. Dr Tufte of Yale University, an expert in information presentation, criticised the sloppy language on the slides, *e.g.* the use of the vaguely quantitative words 'significant' or 'significantly'.

17.24 The use of PowerPoint in the MOD is endemic. PowerPoint can, however, be dangerous, mesmerising, and lead to sloppy (or nil) thinking.[21]

(9) Uncertainties as to Out-of-Service date

17.25 There was uncertainty in the White House and NASA as to how long the Shuttle would fly before being replaced. This resulted in delays to the upgrades needed to make the Shuttle safer and to extend its service life. The CAIB said that, between 1986 and 2002 *"the planned replacement date for the Space shuttle was consistent only in its inconsistency"* and changed from 2002 to 2006 to 2012 to 2020, or later.[22]

17.26 There has been considerable uncertainty as to how long the MR2 would be required to fly as a result of numerous slippages in the replacement MRA4 In-Service Date.[23]

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[18] CAIB Report, page 178.

[19] CAIB Report page 189.

[20] CAIB Report, page 193.

[21] As the Nimrod Safety Case Acceptance Conference demonstrates: see **Chapter 10**.

[22] CAIB Report, page 102.

[23] 1999 to 2008 MRA4 In-Service Date slipped six times from 2000 to 2010: see **Chapter 14.**

(10) 'Normalisation of deviance'

17.27 Shuttle managers had become conditioned over time not to regard foam loss or debris as a safety issue. A foam strike (FOD)[24] was considered a *"maintenance and turnaround concern rather than a safety issue"*.[25] Over 22 years, foam strikes were normalised to the point where they were simply regarded as a maintenance issue which did not threaten a mission's success. Examination of photograph records confirmed that there had been some foam loss on 82% of previously photographed Shuttle take-offs.[26] The acceptance of events that are not supposed to happen is pithily described by sociologist Diane Vaughan as the *"normalisation of deviance"*.[27] Flying with foam losses became viewed as *"normal and acceptable"*. The parallels with Challenger, where flights continued despite known 'O'-ring problems, were said to be striking.[28]

17.28 Fuel leaks on large 'legacy' aircraft in the MOD were regarded as an inevitable fact of life (and to some extent still are).

(11) 'Success-engendered optimism'

17.29 NASA suffered from *"success-engendered safety optimism"*, *i.e.* a belief that because a risk had been successfully avoided in the past it was unlikely to transpire in the future. The SIAT warned that NASA *"must rigorously guard against the tendency to accept risk solely because of prior success"*.

17.30 The good track record of the Nimrod led to the prevailing *"high level of confidence"* in the safety of the fleet. The view that the Nimrod was 'safe anyway' and 'acceptably safe to operate' blinded many of those involved in the Nimrod Safety Case.

(12) 'The few, the tired'

17.31 One experienced observer of the space program described the shuttle workforce as *"The few, the tired"* and suggested that *"...a decade of downsizing and budget tightening has left NASA exploring the universe with a less experienced staff and older equipment"*.[29]

17.32 This is increasingly true of the RAF and parts of the MOD (see **Chapter 19** and the 2008 Capability Health Check).

Further citations from the CAIB Report

17.33 The following citations from the CAIB Report are strongly reminiscent of the organisational causes of the loss of Nimrod XV230 and the problems with the MOD safety and airworthiness culture found by the Nimrod Review:

17.33.1 *"NASA's safety culture has become reactive, complacent, and dominated by unjustified optimism. Over time, slowly and unintentionally independent checks and balances intended to increase safety have become eroded in favour of detailed processes that produce massive amounts of data and unwarranted consensus, but little effective communication. Organisations that successfully deal with high risk technologies create and sustain a disciplined safety system capable of identifying, analysing and controlling hazards through a technology's life cycle."*[30]

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[24] Foreign Object Damage (FOD).

[25] CAIB Report, page 126.

[26] Photographs images were taken of 79 out of the total of 113 Space Shuttle missions, of which 65 showed some foam loss, i.e. 82%.

[27] See Diane Vaughan's book:"The Challenger Launch Decision: Risky Technology, Culture and Deviance at NASA", The University of Chicago Press (1996)

[28] CAIB Report, page 130

[29] CAIB Report, page 118.

[30] CAIB Report, page 180.

17.33.2 *"Years of workforce reductions and outsourcing have culled from NASA's workforce the layers of experience and hands on systems safety that once provided a capacity for oversight. Safety and Mission assurance personnel have been eliminated, careers in safety have lost organisational prestige and the program now decides on its own how much safety and engineering oversight it needs."*[31]

17.33.3 *"NASA's culture of bureaucratic accountability emphasised chain of command, procedure, following the rules, and going by the book. While rules and procedures were essential for co-ordination, they had an unintended but negative effect. Allegiance to hierarchy and procedure had replaced deference to NASA's engineers' technical expertise"*.[32]

CAIB's conclusions on organisational problems at NASA

17.34 The CAIB's conclusions on the deep-seated organisational problems that it found in NASA included the following thoughts:

17.34.1 *Leaders create culture.* It is their responsibility to change it. Top administrators must take responsibility for risk, failure, and safety by remaining alert to the effects their efforts have on the system. Leaders are responsible for establishing the conditions that lead to their subordinates' successes or failure. The past decisions of national leaders, the White House, Congress, and NASA headquarters, set the *Columbia* accident in motion by creating resource and schedule strains that compromised the principles of a high-risk technology organisation. NASA's success became measured by cost reduction and whether the schedule was met.

17.34.2 *Changes in organisational structure should be made only with careful consideration of their effect on the system and their possible unintended consequences*. Changes that make an organisation more complex may create new ways that it can fail. When changes are put in place the risk of error initially increases as old ways of doing things compete with new. Institutional memory is lost as personnel and records are moved and replaced. Changing the structure of organisations is complicated by external budgetary and political constraints, the inability of leaders to conceive the full ramifications of their actions, and the failure to learn from the past. Nonetheless, change must be made. NASA's blind spot was that it believed it had a strong safety culture. Programme history shows that the loss of a truly independent, robust capability to protect the system's fundamental requirements and specifications inevitably compromised those requirements, and therefore increased risk.

17.34.3 *Strategies must increase the clarity, strength and presence of signals that challenge assumptions about risk.* Twice in NASA's history the agency embarked down a slippery slope that resulted in catastrophe. Each decision taken by itself seemed correct, routine and indeed insignificant and unremarkable, yet their effect was stunning. A safety team must have equal and independent representation so that managers are not again lulled into complacency by shifting definitions of risk. It is worth acknowledging that people who are marginal and not in positions of power may have useful information that they do not express. Even when such people are encouraged to speak, they find it intimidating to contradict a leader's strategy or a group consensus.

17.34.4 *Responsibility and authority for decisions involving technical requirements and safety should rest with an independent technical authority.* The CAIB said there were lessons to be learned from other organisations that had been accident-free, including *e.g.* the US Navy Submarine and Reactor Safety programs:[33] *"Organisations that successfully operate high risk technology have a major characteristic in common: they place a premium on safety and reliability by structuring their programs so that technical and safety engineering organisations <u>own</u> the process of determining, maintaining and waiving technical requirements with a voice that is <u>equal to yet independent</u> of Program managers*

[31] CAIB Report, page 181.
[32] CAIB Report, page 200.
[33] CAIB Report, page 182.

who are governed by cost, schedule and mission accomplishment goals".[34] The CAIB recommended the establishment of an independent Technical Engineering Authority which would be responsible for technical requirements and all waivers of them. It would build a disciplined, systematic approach to identifying, analysing and controlling hazards throughout the life cycle of the shuttle system. As a minimum, the authority would: develop and maintain technical standards; be the sole waiver-granting authority; conduct trend and risk analysis at the sub-system and enterprise level; own the effective analysis and hazard reporting systems; conduct integrated hazard analysis; decide what is and is not an anomalous event; and independently verify launch readiness, approve rectifications set out in CAIB's report. This technical authority was to have no connection to, or responsibility for, schedule or programme costs.

Other observations following the CAIB

17.35 The following observations following the CAIB report are also valuable:

17.35.1 By Brigadier General Duane Deal: *"If reliability and safety are preached as "organizational bumper stickers", but leaders constantly emphasize keeping on schedule and saving money, workers will soon realize what is deemed important and change accordingly. Such was the case with the shuttle program."*[35]

17.35.2 By Diane Vaughan: *"Although all mishaps, mistakes, and accidents cannot be prevented, both of NASA's accidents had long incubation periods, thus they were preventable. By addressing the social causes of gradual slides and repeating negative patterns, organisations can reduce the probability that these kinds of harmful outcomes will occur. To do so, connecting strategies to correct organisational problems with their organization system causes is crucial."*[36]

The Herald of Free Enterprise (1987)

17.36 In his report into the *Zebrugge Disaster*, in which a passenger/car ferry *The Herald of Free Enterprise* sank off Zebrugge on 6 March 1987 because the bow door had been left open, Sir Barry Sheen acknowledged the shipboard (or 'active') errors of the Master, the Chief Officer, and the Assistant Bosun, but said that the underlying or 'cardinal' faults lay higher up in the company. Sir Barry Sheen had the following observations about the part played by Townsend Thorensen's management in the catastrophe, in which 193 passengers and crew died:[37]

> *"At first the faults which led to this disaster were the aforesaid errors of omission on the part of the Master, the Chief Officer and the assistant bosun, and also the failure by Captain Kirk to issue and enforce clear orders. But a full investigation into the circumstances of the disaster leads inexorably to the conclusion that the underlying or cardinal faults lay higher up in the company. The Board of Directors did not appreciate their responsibility for the safe management of their ships. They did not apply their mind to the question: What orders should be given to the safety of our ships? The directors did not have any proper comprehension of what their duties were. There appears to have been a lack of thought about the way in which the HERALD ought to have been organized for the Dover/Zeebrugge run. All concerned in management, from members of the Board of Directors down to the junior superintendants, were guilty of fault in that all must be regarded as sharing responsibility for the failure of management. From the top to bottom the body corporate was infected with the disease of sloppiness." The failure on the part of the shore management to give proper and clear directions was a contributory cause of the disaster.*[38]

[34] CAIB Report, page 184.

[35] See Brig Gen Duane W. Deal, USAF, Member of CAIB Board, ASPI article *'Beyond the Widget'*.

[36] See Diane Vaughan's article *"System Effects: On Slippery Slopes, repeating Negative Patterns, and Learning from Mistake"* in *"Organization at the Limit: NASA and the Columbia Disaster"*, William Starbuck and Moshe Farjourn eds. Blackwell, 2005.)

[37] Formal Investigation in the *m.v. Herald of Free Enterprise* (Report of the Court No. 8074) (1987) into the Zeebrugge Disaster on 6 March 1987 (Mr. Justice Sheen sitting with Assessors).

[38]

King's Cross Underground Fire (1987)

17.37 The King's Cross Underground Fire has similar lessons of 'normalisation of deviance' and 'success-engendered optimism'.

17.38 On 18 November 1987, a fire broke out under an escalator at King's Cross Underground Station which led to a flashover and the deaths of 31 people. There had been some 800 previously recorded incidents of small or incipient fires in the underground. Such 'smoulderings' were regarded as an occupational hazard and 'inevitable'. They were not looked upon as an obvious safety risk. The management approach was *'We won't prevent fires, but if we have one we will deal with it'*. In his Report into the circumstances of the fire, the Inspector, Desmond Fennell QC,[39] said:

17.38.1 *"…[M]anagement remained of the view that fires were inevitable on the oldest and most extensive underground system in the world. In my view they were fundamentally in error in their approach."*[40]

17.38.2 *"…London Underground rightly prided themselves on their reputation as professional railwaymen; unhappily they were lulled into a false sense of security by the fact that no previous escalator fire had caused a death."*[41]

17.38.3 *"…[T]heir attitude towards fire (which they insisted should be called 'smouldering' and regarded as an occupational hazard) gave the staff a false sense of security."*[42]

17.38.4 *"In truth London Underground had no system which permitted management or staff to identify, and then promptly eliminate hazards."*[43]

17.38.5 *"Mr Warburton said that he looked in vain for evidence of someone within the organisation questioning what the worst possible consequences of fire could be. Nobody had asked "what if…"* [44]

17.38.6 *"I have said unequivocally that we do not see what happened on the night of 18 November 1987 as being the fault of those in humble places."*[45]

The Marchioness Disaster (1989)

17.39 On 20 August 1989, the passenger vessel *Marchioness* and the dredger *Bowbelle* collided on the River Thames. The *Marchioness* sank and 51 people lost their lives. A subsequent Inquiry was conducted by Sir Anthony Clarke,[46] and in his Interim Report (Volume 1: 121-123) he made the following valuable observations in relation to risk assessments, both on the Thames and elsewhere:

17.39.1 *"As this Inquiry has proceeded I have become more and more convinced of the importance of risk assessment as the correct approach…"*

17.39.2 *"The purpose of risk assessment is to try to assess relevant risks in advance so that appropriate steps can be taken to put measures in place to eliminate or minimise them. It contrasts starkly with the historical approach which involved waiting until a casualty occurred before trying to learn lessons from it and improving say, methods of design, construction, equipment or operation of ships. It is, of course, important to learn from casualties in order to try to ensure that no similar casualty occurs again but the disadvantage of such an approach is that preventive measures may not be taken until some disastrous event has occurred, perhaps involving considerable loss of life. Such an approach is surely no longer acceptable."*

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[39] Report of the Investigation into the King's Cross Underground Fire by Desmond Fennell QC (Inspector sitting with four Assessors) dated November 1988 (Cm 499).

[40] King's Cross Fire Report, page 17, paragraph 12.

[41] King's Cross Fire Report, page 18, paragraph 15.

[42] King's Cross Fire Report, page 18, paragraph 18.

[43] Ibid, page 121.

[44] Ibid, page 120.

[45] King's Cross Fire Report, page 125, paragraph 2.

[46] The Rt Hon. Lord Justice Clarke (now Lord Clarke of Stone-cum-Ebony).

17.39.3 *"It enables all relevant factors to be considered and assessed from many different points of view, including cost. There is no reason why a risk assessment should necessarily be elaborate. All will depend on the nature of the particular problem being considered. Thus it may be possible to apply a scientific approach or it may not. As so often, all will depend on the circumstances."*

17.39.4 *"It is also essential that the relevant risks and the measures taken to combat them be kept under review because it is not sufficient to just one snapshot of a problem. Conditions change all the time."*

BP Texas City oil refinery explosion (2005)

17.40 On 23 March 2005, the BP Texas City oil refinery suffered an explosion which resulted in the deaths of 15 workers and left more than 170 injured. It was the most serious workplace disaster in the U.S. in two decades. The U.S. Chemical Safety Hazard Investigation Board conducted a detailed investigation into the causes.[47] This was followed by a review of BP's corporate safety culture, safety management systems, and corporate safety oversight at its U.S. refineries, by a panel headed by former US Secretary of State, James A. Baker III.[48]

'Initiative overload'

17.41 The Panel found that BP's U.S. refineries had been subjected to 'initiative overload' in the seven years before the accident which potentially had had a detrimental effect on process safety. BP's corporate organisation had launched *"an avalanche of programs and endeavours that compete for funding and attention"*, each of which required the refineries *"to develop plans, conduct analyses, commit resources, and report on progress"*.[49] The 'ripple' effects, of what some workers termed this 'flavour of the month' phenomenon, were then felt throughout the refinery.

De-centralisation and culture

17.42 BP had a decentralised management system and 'entrepreneurial' culture which had delegated substantial discretion to the U.S. refinery plant managers without clearly defining process safety "expectations, responsibilities or accountabilities" or holding managers accountable for process safety performance. The Panel found *"Each refinery had its own separate and distinct process safety culture"*.

Vigilance not complacency

17.43 The Panel emphasised the importance of vigilance to counter complacency:

> *"Preventing process accidents requires vigilance. The passing of time without a process accident is not necessarily an indication that all is well and may contribute to a dangerous and growing sense of complacency. When people lose an appreciation of how their safety systems were intended to work, safety systems and controls can deteriorate, lessons can be forgotten, and hazards and deviations from safe operations can be accepted. Workers and supervisors can increasingly rely on how things were done before, rather than rely on sound engineering principles and other controls. People can forget to be afraid."*[50]

[47] US Chemical Safety Hazard Investigation Board Report (March 2005) (Report No. 2005-04-0I-TX).

[48] Report of The BP U.S. Refineries Independent Safety Review Panel (January 2007).

[49] The BP U.S. Refineries Independent Safety Review Panel Report, page 84.

[50] The BP U.S. Refineries Independent Safety Review Panel Report, Panel Statement, page i.

'Ten Commandments' for business failure

17.44 It is instructive to have regard to Donald Keough's *'Ten Commandments of Business Failure'*:[51]

1. *Stop taking risks.*
2. *Be inflexible.*
3. *Isolate yourself [i.e. work in silos].*
4. *Assume infallibility.*
5. *Play close to the game line.*
6. *Don't take time to think.*
7. *Put faith in [external] consultants.*
8. *Love bureaucracy.*
9. *Send mixed messages.*
10. *Be afraid of the future.*

17.45 As explained above, many of these ills are to be found in the RAF and MOD, which have become ever-increasingly reliant on a complex matrix and culture of process, paper, meetings, and 'box-ticking' as a substitute for sound thinking.

17.46 Donald Keough said (memorably) regarding the Eighth Commandment:

> *"Love your bureaucracy... There are layers upon layers of people, yet when a customer calls, nobody's home. They are all in meetings. These meetings generate more paperwork, more e-mails, more calls, more meetings. In fact, most often there are meetings to plan meetings. Meetings are the religious service of a great bureaucracy…."*

Conclusion

17.47 Columbia and other cases have shown that, often, fundamental organisational causes lie at the heart of many major accidents, and these have to be addressed in order to learn the real lessons for the future. Many of the Recommendations later in **Part VI** of this Report seek to address these root organisational causes.

[51] Donald Keough, former Chief Executive of Coca-Cola, *Ten Commandments of Business Failure*, pages 116 & 120.

CHAPTER 18 – ACCIDENT THEORY AND HIGH-RISK TECHNOLOGIES

"Experience without theory is blind,
but theory without experience is mere intellectual play"
(Immanuel Kant)[1]

Contents

Chapter 18 discusses Accident Theory in relation to high-risk technologies and academic research and writing in this field.

Summary

1. It is useful to have an understanding of Accident Theory, particularly in the context of managing safety in relation to high-risk technologies.
2. There is a valuable body of learning on Accident Theory which repays study (see, in particular, the work of academics such as James Reason, Charles Perrow, Scott Sagan, Diane Vaughan, and Karl Weick).
3. There are two main Accident Theories: *Normal Accident Theory* and *High Reliability Theory*. Their proponents share the same goal, *i.e.* effective safety management at both an individual and an organisational level.[2]
4. The *'Swiss Cheese'* and *'Bow Tie'* models can be combined to form a composite 3-D model which may prove a useful tool in illustrating how the various layers of defences (the 'hierarchy' of preventative and ameliorating measures) may be logically placed.
5. The 'organisational theory' analytical framework model is a valuable aid to the proactive analysis of safety in high-technology systems.
6. The importance of investigating and understanding the organisational causes of accidents cannot be overstated.

[1] See Scott D Sagan, *The Limits of Safety*, 1993, pages 28-45. (Princeton publishing).
[2] 18th Century Philosopher (1724-1804).

Introduction

18.1 There has been a growing body of academic research and writing in the last 20 years into Accident Theory by distinguished academics such as James Reason, Charles Perrow, Scott Sagan, Diane Vaughan, and Karl Weick. A study of their material pays dividends because it contains useful insights into the nature and management risk and how best to control hazardous technologies. I have had the benefit of discussing some of their thinking and theories with James Reason.

18.2 In order to have a true understanding of Accident Theory, it is important in my view to bear in mind the following points.

18.3 *First, there are limits to safety.* Life is, by its very nature, unsafe. The activities that bind the human condition and go to make up 'living' carry with them residual or irreducible risks. Some activities, however, are more unsafe than others, for instance, defying the laws of gravity by flying in heavier-than-air machines.

18.4 *Secondly, simply knowing how accidents have happened in the past does not, of itself, prevent future ones.* Nevertheless, as James Reason has pointed out, by a careful study of earlier cases and accident theory we can begin to assemble a body of principles which, when applied to the design, maintenance and operation of high-risk technological systems, can reasonably be expected to help reduce either the occurrence of errors or their damaging consequences.[3]

18.5 *Thirdly, it is important to guard against 'hindsight bias'*. There is a danger in exaggerating what we think people should have been able to anticipate in foresight, or allowing knowledge which we have gained as to the outcome of a particular event to influence perceptions as they would have appeared at the time. Unless the potency of these retroactive distortions are appreciated, we will never truly understand the realities of the past, nor learn the appropriate remedial lessons.[4]

18.6 *Fourthly, to err is human.* Error is a normal characteristic of human behaviour.[5] So long as human fallibility remains a fact of life, it will be important to investigate serious accidents in detail in order to seek to learn the relevant preventative lessons.[6] Further, whilst it may not possible to change human nature very much, it is possible to change the conditions under which people work and think in order to make errors less likely and more easily recoverable.[7]

18.7 *Fifthly, chance or 'bad luck' often plays a significant role in accidents.* In all cases, an adverse event requires some assistance from chance in order to create a path of accident opportunity through the various barriers, safeguards and controls.[8] Moreover, *"Chance does not make moral judgements. Bad luck can afflict those who deserve better."*[9] It is said that accidents happen because 'latent' factors, *i.e.* that collectively produce defensive weaknesses, are created (called *"conditions"*) which then permit the *chance* conjunctions of local triggers and active failures to breach all the barriers and safeguards (called *"causes"*).[10]

18.8 *Sixthly, lessons are not always learned the first time.* Lessons and worthy sentiments are easy to espouse but not always easy to put into practice. This is particularly true when fundamental organisational and cultural changes are called for. NASA found this to be the case following the *Challenger* disaster. As Diane Vaughan said when giving evidence to the CAIB: *"What we find out from [a] comparison between Columbia and Challenger is that NASA as an organisation did not properly address all of the factors that the Presidential Commission* [in … on the Challenger disaster] *identified."*

[3] James Reason, *Human Error*, 1990, page 17. (Cambridge publishing).

[4] Ibid, pages 214-216.

[5] Reason, 1990; Senders and Moray, 1991.

[6] See Daniel E Maurino, James Reason, Neil Johnston and Rob B Lee, *Beyond Aviation Human Factors*, 1995, page 34. (Ashgate publishing).

[7] James Reason, *The Human Contribution*, 2008, page 34.

[8] Ibid, page 73.

[9] Daniel E Maurino, James Reason, Neil Johnston and Rob B Lee, *Beyond Aviation Human Factors*, 1995, page 86.

10 See James Reason, *The Human Contribution*, 2008, page 138.

18.9 *Seventhly, do not simply blame individuals whilst ignoring more fundamental organisational causes.* Human error does not take place in a vacuum. Investigators of accidents often fall prey to the temptation to focus simply on performance of individuals whilst ignoring the organisational deficiencies which may have caused or contributed to the individuals' ignorance or sub-optimal performance. Such flawed attribution sometimes arises because of the relative ease with which it is possible to point to individual human failures and the relative difficulty in identifying and analysing the more complex 'task', 'situational', 'institutional' and/or 'organisational' factors that shape human performance. Most people involved in serious accidents are neither stupid nor reckless, although they may have been blind to the consequences of their actions.[11] Key to any accident investigation is understanding why they acted as they did and the organisational factors that shaped their approach and behaviour.

The importance of investigating organisational causes

18.10 The importance of looking at organisational causes was recognised by International Civil Aviation Organisation (ICAO) in the 1990s when the following passage was added to its Annex 13 regarding the standards and recommended practices for air accident investigators throughout the world:

> *"1.17. Organisational and Management information [that accident reports should include]. Pertinent information concerning the organisations and their management involved in influencing the operation of the aircraft. The organisations include, for example, the operator, the air traffic services, airway, aerodrome and weather service agencies, and the regulatory authority. The information should include, but not be limited to, organisational structures and functions, resources, economic status, management policies and practices, and regulatory framework."*[12]

18.11 In their book *Beyond Aviation Human Factors*,[13] Maurino, Reason, Johnston and Lee examined how the scope of accident analysis had been extended from the individual to the collective, *i.e.* managerial and organisational. The authors emphasised that human error does not take place in vacuum, but within the context of organisations which either resist or foster it. The central contention of their book (with which I concur) is succinctly put as follows:

> *"[N]o matter how well equipment is designed, no matter how sensible regulations are, no matter how much humans excel in their individual or small team's performance, they can never be better than the system that bounds them."*[14]

The Dryden Report (1992)

18.12 The central case study considered by the authors of Beyond Aviation Human Factors is the inquiry by the Honourable Mr Justice Virgil P Moshansky into the crash at Dryden, Ontario, on 10 March 1989.[15] The cause of the accident was pilot error: Captain Morwood failed to de-ice the wings of his Air Ontario F-28 jet causing Flight 1363 to crash shortly after take off. The authors said the investigation might have been closed within a few weeks of the crash, had conventional wisdom been applied. In 'The Dryden Report', however, Moshansky *"tore apart"* the Canadian aviation system, and adopted a system-analysis approach, with emphasis on an examination of human performance. Commenting on his report Commissioner Moshansky later said:

> *"Whenever human beings are involved in a complex system, there will be failures both active and latent. The concept of human factors contributing to aviation accidents has been around since the 1930's, when it was first advanced by Dr Robert McFarland, a renowned American Psychologist. However, cynicism and a lack of understanding of the concept prevailed, with the result that accident investigations generally ignored it or regarded it with scepticism, until Dryden.*

[11] See James Reason, *Human Error*, 1990, page 216.

[12] See Ninth Edition of ICAO Annex 13 (Aircraft Accident and Incident Investigation), July 2001.

[13] Daniel E Maurino, James Reason, Neil Johnston and Rob B Lee, *Beyond Aviation Human Factors*, 1995.

[14] Ibid, pages x-xi.

[15] *Final Report of the Commission of Inquiry into the Air Ontario Crash at Dryden, Ontario* by Honourable Mr Justice Virgil P Moshansky (1992).

The three year Dryden Inquiry presented a rare opportunity for an independent body to examine the entire Canadian aviation system for organisational failures, both latent and active, which might have contributed to the Captain's faulty decision, and to make recommendations for necessary change. It was an opportunity not to be squandered."[16]

18.13 The authors of *Beyond Aviation Human Factors* point that, even if pilot error had not occurred on this occasion and the crash of Flight 1363 had not taken place, *"…the flawed organisational processes and the latent failures would still remain. Dryden would take place elsewhere, given the degree of sickness, the numerous pathogens hidden in the system*[17].

Accident Theories

18.14 There are two main accident theories:

18.14.1 *Normal Accident Theory*: 'Normal Accident Theory' holds that, when technologies become very complex and 'tightly coupled', accidents become inevitable and therefore, in a sense, 'normal'.[18] This theory takes a pessimistic, but not defeatist, view of the ability of organisations and individuals to manage high risk technologies.

18.14.2 *High Reliability Theory*: 'High Reliability Theory' argues that organisations responsible for operating high risk technologies can successfully compensate for inevitable human shortcomings which would normally lead to catastrophic failures. Proper design, management and training are seen as important requisites for being a highly reliable organisation.

Normal Accident Theory

18.15 Normal Accident theorists recognise that high-risk technologies are prone to accidents and catastrophes when the right combination of circumstances come together to defeat safety devices and/or the efforts of those responsible for coping with such events. The theory recognises the possibility of such events, rather than being a statement of despair or "learned helplessness".[19] However, Charles Perrow's basic pessimism is unmistakable:

"No matter how hard we try, no matter how much training, how many safety devices, planning redundancies buffers, alarms, bells and whistles we build into our systems, those that are complexly interactive will find an occasion where the unexpected interaction of two or more failures defeats the training, the planning, and the design of safety devices."[20]

"If interactive complexity and tight coupling – system characteristics – inevitably will produce an accident, I believe we are justified in calling it a normal accident, or a system accident. The odd term 'normal accident' is meant to signal that, given the system characteristics, multiple and unexpected interactions of failures are inevitable. This is an expression of an integral characteristic of the system, not a statement of frequency… System accidents are uncommon, even rare; yet this is not all that reassuring, if they can produce catastrophes."[21]

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[16] See Address by The Honourable Virgil P Moshansky, CM QC – The Halifax 5 – Canadian Health Care Safety Symposium At Calgary, Alberta, Saturday 22 October 2005.

[17] Ibid, page 81.

[18] See the work of Charles Perrow, a leading proponent of the 'Normal Accident Theory'.

[19] James Reason.

[20] Cited by Scott D Sagan in *The Limits of Safety*, 1993, page 45.

[21] Charles Perrow, *Normal Accidents – Living With High-Risk Technologies*, 1984, page 4. (Princeton publishing).

High Reliability Theory

18.16 High Reliability theorists take a slightly more optimistic view of the world. Proponents argue that organisations operating high-risk technologies, if properly designed and managed, can compensate for inevitable human shortcomings.[22] In other words, extremely safe operations are possible, even with extremely hazardous technologies, if appropriate organisational design and management techniques are followed.[23] A multi-disciplinary group of scholars at the University of California at Berkeley has conducted useful empirical research focused on three hazardous organisations that it argues are 'high reliability' organisations which have achieved *"nearly error free operations"*: the Federal Aviation Administration's (FAA) air-traffic control system, the Pacific Gas & Electrical Company's electric power system (which includes the Diablo Canyon Nuclear Power Plant), and the peacetime flight operations of two US Navy Aircraft Carriers. The researchers have (in their words) *"…begun to discover the degree and character of effort necessary to overcome the inherent limitations to securing consistent, failure free operations in complex social organisations."*[24]

18.17 In their book *'Managing the Unexpected'*,[25] Weick and Sutcliffe refer to High Reliability organisations. i.e. which operate under very trying conditions all of the time, as practising a form of organising that reduces the brutality of audits (major incidents) and speeds up the process of recovering.[26] Their view is that the hallmark of a High Reliability organisation is not that it is error-free but that errors do not disable it,[27] such a state of affairs being brought about by 'mindful management' i.e. good management of the unexpected.[28] They are also of the view that people in High Reliability organisations try to guide themselves towards 'troublesome' perceptions and away from 'soothing' ones in order that they can see more, make better sense of what they see, and remain more attuned to their current situation; and that they achieve this through a combination of being pre-occupied with failure; being reluctant to simplify; having sensitivity towards operations; having a commitment to resilience, and having a deference to expertise. Collectively, the authors state that these principles can influence the design of processes and move the system toward a state of 'mindfulness':

> *"[M]indfulness is different from situational awareness in the sense that it involves the combination of ongoing scrutiny of existing expectations, continuous refinement, and differentiation of expectations based on newer experiences, willingness and capability to invent new expectations that make sense of unprecedented events, a more nuanced appreciation of context and ways to deal with it, and identification of new dimensions of context that improve foresight and current functioning.*[29]

Contrasting the two schools of thought

18.18 Both sets of theorists share the same goal, *i.e.* effective safety management at both an individual and an organisational level, but differ about the degree to which it is ultimately possible to avoid errors, incidents, accidents, and catastrophes. Both strive to achieve the 'dynamic non-event' that represents 'reliability' in high-risk technologies. It is 'dynamic' because processes remain within acceptable limits due to moment-to-moment adjustments and compensations by the human operators. It is a 'non-event' because safe outcomes claim little or no attention. The paradox is rooted in the fact that accidents are salient, while 'normalcy' is not.[30]

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[22] See Columbia Accident Investigation Board Report, Volume 1, page 180, paragraph 7.2.

[23] See Scott D Sagan, *The Limits of Safety*, 1993, page 13.

[24] Ibid, page 15.

[25] Karl Weick and Kathleen Sutcliffe, *Managing the Unexpected*, 2007. (Jossey-Bass publishing).

[26] Ibid, page 1.

[27] Ibid, page 21.

[28] Ibid, page 17.

[29] Ibid, page 32.

[30] James Reason, The Human Contribution, 2008, pp239-240. Commenting on Weick K.E. (1987) 'Organisational culture as a source of high reliability.' *California Management Review*, 29: 112-127.

18.19 High Reliability theorists believe that properly designed and well-managed organisations can safely operate the most hazardous technologies[31] through: (i) the prioritisation of safety and reliability as a goal by political elites and the organisation's leadership; (ii) high levels of redundancy in personnel and technical safety measures (permitting back up or overlap to compensate for failures); (iii) the development of a *"high reliability culture"* in de-centralised and continually practised operations; and (iv) sophisticated forms of trial-and-error learning.[32]

18.20 Normal Accident theorists, however, consider much of the above to be an illusion. They regard serious accidents in organisations managing hazardous technologies as inevitable over time[33] because: (i) they have no faith that the 'goals' of leaders of elites and organisations can permeate complex organisations entirely; (ii) they place little faith in 'redundancies' which often add to the complexity of a system; (iii) they believe that, in a complex system, neither strict centralisation nor de-centralisation of authority can ensure safety; and (iv) they argue that significant restrictions are placed on 'organisational learning', not least because 'secrecy', both inside complex organisations and between linked organisations, limits the overall organisation's ability to learn and implement lessons from others and also from historical experience.[34]

18.21 In my view, there is value in both philosophies, but neither has a monopoly on veracity. The pessimism of Normal Accident theory must give way to rigorous and pro-active safety management during one's tenure of responsibility. The optimism of High Reliability must yield to human fallibility and the truth that *"…the one hazard for which there is no technological remedy: the insidious concatenation of latent human failures that are an inevitable part of any large organisation."*[35]

18.22 We cannot expect to eliminate human error, technical failures and organisational pathogens altogether, but we can hope to create systems so that they are more resistant to their adverse effects. Greater resilience (unlike zero defects) is an achievable goal.[36] To achieve the goal of greater resilience, however, it is necessary for safety to be an essential part of an organisation's core business and not simply an add-on.[37] It is an essential long term fitness plan.

Models

'Swiss Cheese' model

18.23 James Reason's well-known 'Swiss Cheese' model is a simple, but clever, illustration of how accidents happen (see Figure 18.1 below). The slices of Emmental represent various defences, barrier and safeguards and the holes and weakness that can develop through which an accident trajectory is able to pass. The holes are in continual motion, moving from place to place, opening and shutting. When a series of holes line up, an accident trajectory can pass all the way through and cause an accident event.

[31] Scott D Sagan, *The Limits of Safety*, 1993, page 28.

[32] Ibid, page 17.

[33] Ibid, page 28.

[34] Ibid, pages 37-43.

[35] See James Reason, *Human Error*, 1990, page 250.

[36] James Reason, *The Human Contribution*, 2008, page 261.

[37] James Reason, *Managing The Risks of Organisational Accidents*, 1997, page 114.

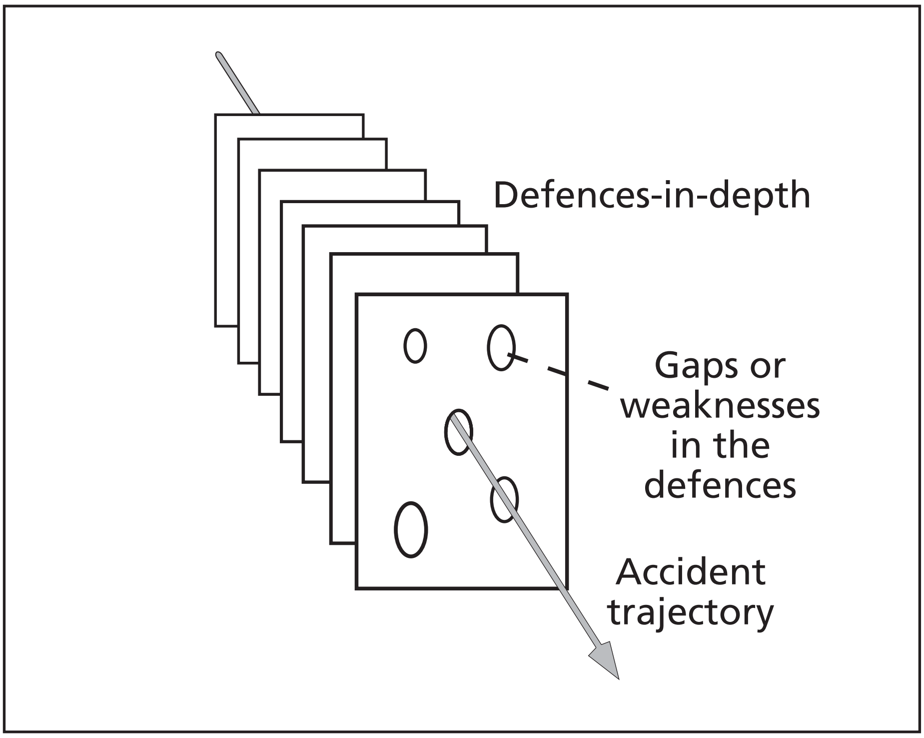

Figure 18.1: Classic 'Swiss Cheese' Model from Beyond Aviation Human Factors (Ashgate Publishing)

18.24 The 'defence, barriers and safeguards' are there to remove, mitigate or protect against operational hazards.[38] A safety system can be made up of different elements which may consist of little more than personal safety equipment or much more sophisticated 'defences-in-depth' which will comprise layers of people and engineered-safety features.

18.25 The *'Swiss Cheese'* model shows a trajectory of accident opportunity penetrating several defensive systems to produce an accident event. This results from a complex interaction between latent failures and a variety of local triggering events and random variations. The probability of a trajectory of opportunity finding a series of holes precisely lined up in all the defensive layers at any one time is normally very small. Indeed, very few unsafe acts result in actual damage or injury, even in relatively unprotected systems. Potential accident trajectories may penetrate one or two layers of the defensive layers and then vanish, often unnoticed and unrecorded. The event level is highly dynamic with gaps of different sizes appearing and disappearing and changing their locations within the defensive layer.[39] In highly protected systems, the various layers of defence can only be breached by the adverse conjunction of several different causal factors. Some of these are likely to be latent failures of pathogenic origin, others will be local triggering events such as the commission of a set of unsafe acts in a highly specific set of circumstances, for example, the unusually low temperature preceeding the *Challenger* launch, and the nose down trim of *The Herald of Free Enterprise* due to a combination of high tide and unsuitable docking facilities.[40] These were organisational accidents where the origin of the unsafe acts could be traced back to latent conditions within the workplace and within the organisation as a whole. What is clear, however, is that where errors are allowed to be present in a system over a long period of time, the probability of coincidence of multiple faults necessary for an accident is drastically increased.[41]

18.26 In Figure 18.2 below I have used the 'Swiss Cheese' model to illustrate how the various defences were penetrated over the period 1969-2006 and led to the loss of XV230. The drawing uses a zig-zag arrow trajectory in order to emphasise the eccentric and unexpected nature of accident paths over lengthy periods:

[38] Daniel E Maurino, James Reason, Neil Johnston and Rob B Lee, *Beyond Aviation Human Factors*, 1995, page 10.

[39] See Daniel E Maurino, James Reason, Neil Johnston and Rob B Lee, *Beyond Aviation Human Factors*, 1995, pages 23-28.

[40] See James Reason, *Human Error*,1990, pages 207-209.

[41] See James Reason, *Human Error*,1990, page 179 – referring to Rasmussen (1988, pages 3-4) and 'defence-in-depth'.

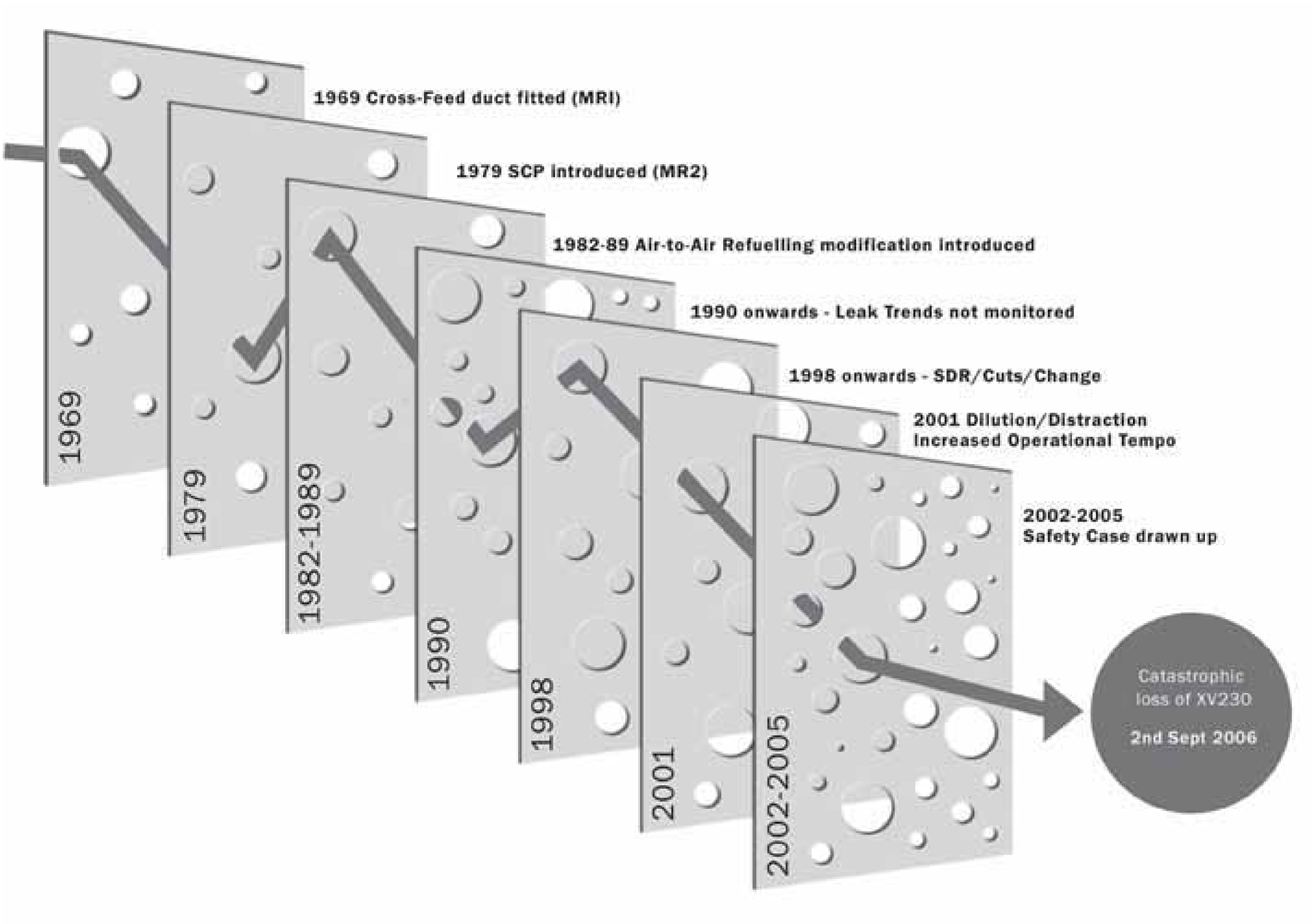

Figure 18.2: 'Swiss Cheese' Model as applied to XV230

'Bow Tie' model

18.27 Another illustrative model is the 'Bow Tie' model (see below) which usefully separates out the elements of 'defence-in-depth' into two categories: (A) those which prevent hazards from coming into being at all or provide primary barriers to them and (B) those which ameliorate the consequences of hazards which have not been caught by (A). Category (A) defences/barriers include a combination of factors and engineered mechanisms such as design, inspection and maintenance, quality assurance, and training prior to the initiating event. Category (B) effect-reducing defences/ameliorations include subsequent warning, control, back-up and evacuation mechanisms. XV230 is an example of a case in which there were insufficient effect-reducing (Category (B)) defences because, once a fire initiated in the No. 7 Tank Dry Bay, there was little to prevent it propagating and no evacuation option for the crew.

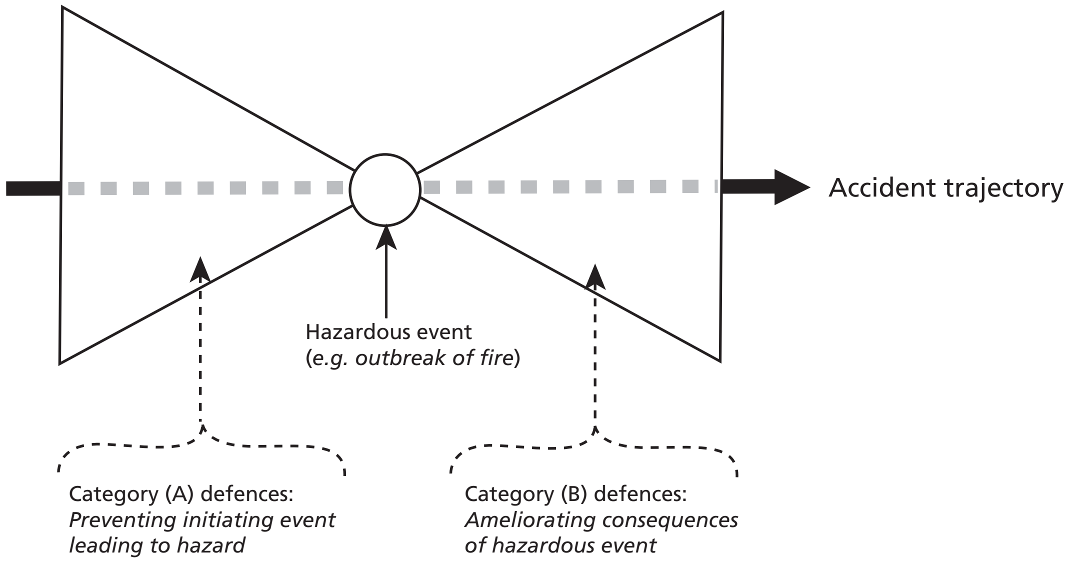

Figure 18.3: Classic 'Bow Tie' Model

Composite model

18.28 I have combined the 'Swiss Cheese' and the 'Bow Tie' models to form a composite 3-D model which may prove a useful tool in illustrating how the various layers of defences and the 'hierarchy' of preventative and ameliorating measures may be logically placed.

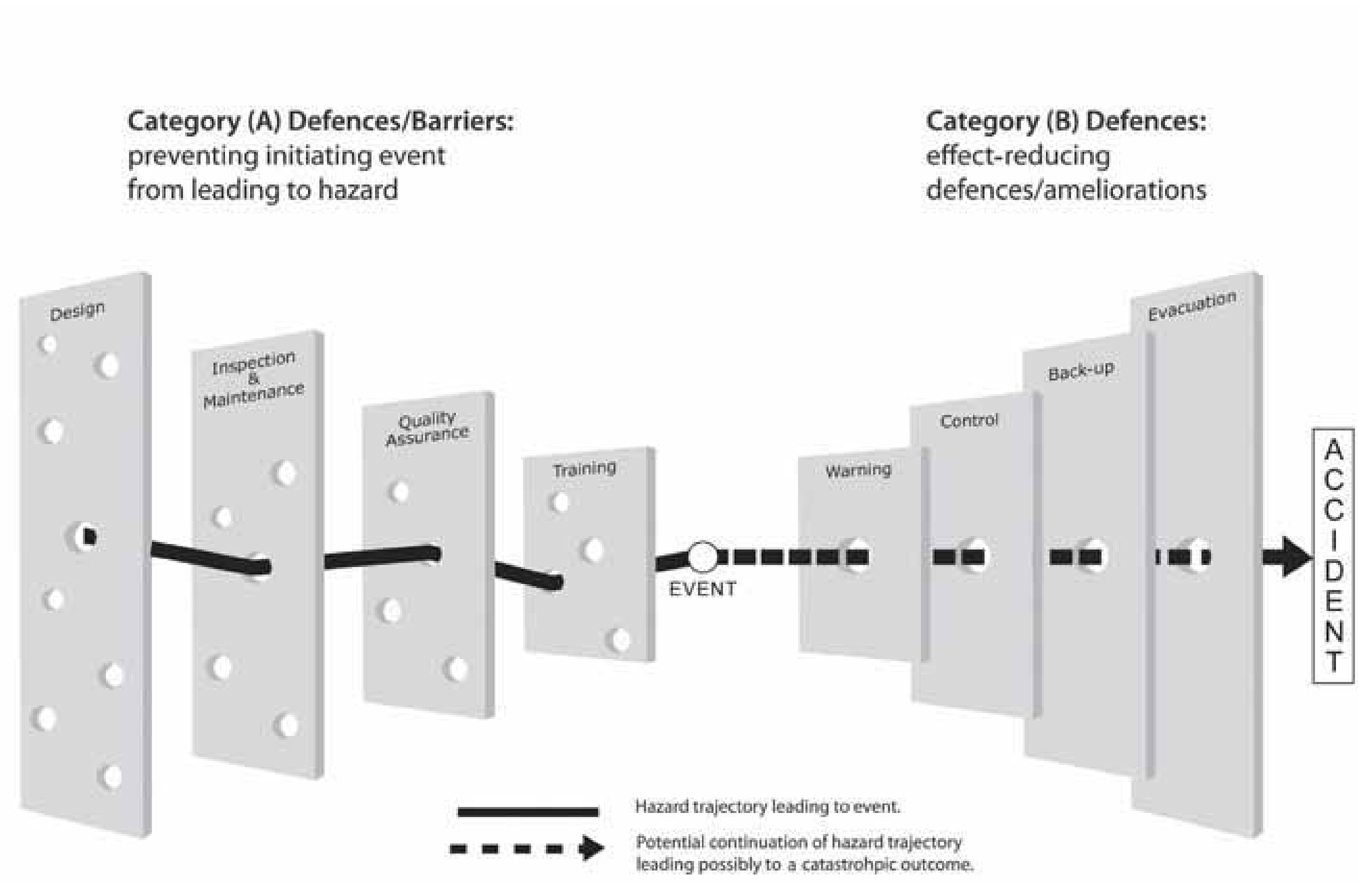

Figure 18.4: 'Composite Model'

The 'organisational theory' analytical framework model

18.29 Since it is impossible to guarantee the elimination of all human error, it is necessary to devise more effective ways of mitigating the consequences of human error in unforgiving situations.[42] The 'organisational theory' analytical framework model pioneered by James Reason is a 'self-monitoring' process which works in two ways. First, it works in the traditional way of allowing causal failures to be identified by accident investigators and tracked back to their organisational roots in order to prevent recurrence. Second, since the same precise mixture of causes is unlikely to recur,[43] the 'causal pathways' model enables 'pathogen' auditing of both 'active' and 'latent' failures within an organisation since this is considered to be the most effective way of managing safety.[44] Analysis of major accidents typically show that the basic safety of a system has eroded due to 'latent' errors, and that a more significant contribution to safety can often be expected from, *e.g.*, efforts to decrease the duration of latent errors then from measures to decrease their basic frequency.[45] In terms of remedial implications, therefore, by specifying the organisational and situational factors involved in the causal pathways, it is possible to identify potentially dangerous latent failures before they combine to cause an accident.[46] These conceptual tools can be applied to any event, no matter how trivial.

18.30 The 'organisational theory' analytical framework approach asserts that the starting point for any analysis is the decisions taken in the higher echelons of the system. These decisions, shaped by economic and political factors such as inadequate budgets, deficient planning, and operational pressures, seed organisational pathogens into the system at large. These resident 'pathogens' take many forms including ill-defined policies, lack of control over contractors, blurred responsibilities, poor design, specification and construction, lack of foresight or awareness of risks, excessive cost-cutting, managerial oversights, deficient maintenance arrangements, and missing or flawed defences. The negative effects or adverse consequences of these pathogens are transported along two principal pathways to the various workplaces, where they act upon the 'defences, barriers and safeguards' to create 'latent' failures and upon 'local working conditions' to promote 'active' failures, *i.e.* errors, violations and component failures.[47] 'Local working conditions' are the factors that influence the efficiency and reliability of human performance in a particular work context. These can conveniently be divided into factors relating to the task and its immediate environment, and those relating to people's mental and physical states. The authors point out that many such unsafe acts will be committed, but only very few of them will penetrate the defences to bring about damaging outcomes.[48]

18.31 Major disasters in defended systems are rarely, if ever, caused by one factor, either mechanical or human. Rather, they arise from unforeseen and usually unforeseeable concatenation of several diverse events, each one necessary but singly insufficient.[49] These observations suggested to James Reason an analogy between the breakdown of complex technological systems and the aetiology of multiple-cause illnesses such as cancer and cardiovascular disease. More specifically, there appeared to him to be similarities between latent failures in complex technological systems and resident pathogens in the human body. This metaphor provides useful elucidation in relation to the application of organisational theory and the existence of failures and local triggering events.[50]

18.32 The authors of *Beyond Aviation Human Factors* draw attention to a very important feature of the 'causal pathways' model, namely, that there is a clear separation between the 'active' and 'latent' failure pathways, though both have a common origin in the strategic organisational processes. The reason highlighted for distinguishing the pathways is in order to reflect the differing character of past (and potential) accidents. Accidents such as *Challenger, Piper Alpha and The King's Cross Underground Fire* involved little or no 'active' failures as proximal causes. In these cases the accident trajectory passed through longstanding 'latent' failures

[42] See James Reason, *Human Error*, 1990, page148.

[43] Ibid, page 174

[44] Ibid, page 210.

[45] Ibid, page 180.

[46] Daniel E Maurino, James Reason, Neil Johnston and Rob B Lee, *Beyond Aviation Human Factors*, 1995, page 28.

[47] Ibid, See page 82 for an example of the organisational theory analytical framework/causal pathways model, in relation to the Air Ontario Crash at Dryden, Ontario (referred to at paragraph 18.12 above).

[48] Ibid, page 9.

[49] See James Reason, Human Error, 1990, page 179.

[50] Ibid, pages 197-198.

in the defences. A large proportion of accidents, however, require the timely concatenation of both active and latent failures to achieve a complete trajectory of accident opportunity. This was true of a number of disasters including *The Herald of Free Enterprise* and the Dryden crash.[51]

18.33 'Defences, barriers and safeguards' stand between hazards and damaging losses. In some instances, these defences are undermined from within the system *via* the active failure pathway. In other cases, the gradual accretion of latent failures reaches a point where the hazard can invade the system from the outside.[52]

18.34 'Latent' errors pose just as great a threat to the safety of complex systems as 'active' errors. 'Latent' errors are those whose adverse consequences may lie dormant within the system for a long time. 'Active' errors are associated with 'front line' operators of a complex system, such as pilots, whose effects are felt almost immediately. Operators tend to be the inheritors of system defects created by poor design, incorrect installation, faulty maintenance and bad management decisions. These are all examples of 'latent' errors spawned by those whose activities are removed in both time and space from the direct control interface. In James Reasons' colourful description: "[the operator's] *part is usually that of adding the final garnish to the lethal brew whose ingredients have been long in the cooking*."[53]

18.35 The 'organisational theory' analytical framework has been adopted by the International Civil Aviation Organisation ('ICAO'), the International Air Transport Association ('IATA'), the International Federation of Air Traffic Controllers Associations (IFATCA), the National Transportation Safety Board ('NTSB') of the United States, the Bureau of Air Safety Investigations (BASI) of Australia, the Transportation Safety Board (TSB) of Canada, and British Airways.[54] It is a valuable aid to the pro-active analysis of safety in high-technology systems.

The age of the organisational accident

18.36 In the words of James Reason, we are in the age of the organisational accident. The operation of complex technologies such as aviation necessarily involves organisational processes and cultures which affect human behaviour. In my view it is increasingly important to focus on those organisational processes and cultures in order to raise standards of safety in an increasingly technological world.

Trend Analysis - Heinrich's Triangle

18.37 As Professor John McDermid has pointed out,[55] there are many 'low-level' errors which are precursors of, and hence warnings of, impending accidents. He emphasises, *"Good safety management identifies these low-level issues and feeds them back to reduce risk"*. Analysis of 1920s industrial accidents led to the development of *"Heinrich's Triangle"* showing the relationship between low-level deviations and accidents. Ratios of 600:1 are often reported. The example below illustrates data reported from air traffic management about the number of low level Operational Errors (OE) and Operational Deviations (OD). Whatever the precise ratio in any given field, the key point is to capture and understand these low level errors and deviations before they conspire to cause an incident or accident.

[51] See Daniel E Maurino, James Reason, Neil Johnston and Rob B Lee, *Beyond Aviation Human Factors*, 1995, pages 26-27.

[52] Ibid.

[53] See James Reason, Human Error, 1990, page 173.

[54] Daniel E Maurino, James Reason, Neil Johnston and Rob B Lee, *Beyond Aviation Human Factors*, 1995, page xi.

[55] JA McDermid, PHD, FREng, University of York, *Through Life Safety Management: Some Concepts and Issues, 2007.*

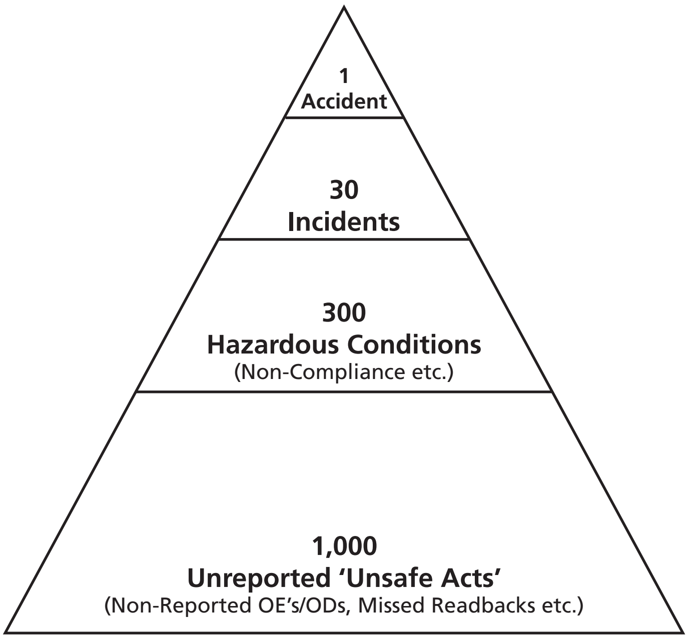

Figure 18.5: Examples of Heinrich's Triangle

18.38 This is why the Human Factors Maintenance Error Management Systems (HF (M)EMS) initiative of Wing Commander Jeanne Paul (XO Progs, COS SPP) and Air Commodore Julian Young (ACOS A4) is so valuable (see **Chapter 21**). Using the 'Iceberg Analogy', HF(M)EMS focuses on 'below the water line' near-misses and trends which help provide forewarning *before* an incident or accident occurs. This changes fundamentally the approach of hazard management from reactive to pro-active.

CHAPTER 19 – SHORTCOMINGS OF CURRENT SYSTEM

"Airworthiness should focus on product rather than process."
(Group Captain Nick Sharpe, former President of Nimrod XV230 Board of Inquiry, 2008)

Contents

Chapter 19 deals with the shortcomings of the current MOD Airworthiness system.

Summary

1. There are numerous shortcomings in the current MOD Airworthiness system:

(1) The current MOD Airworthiness system is of Byzantine complexity;

(2) There is a fundamental lack of 'ownership' of Airworthiness;

(3) The meaning of "Airworthiness" is not sufficiently understood;

(4) The meaning of ALARP[1] is not sufficiently understood;

(5) Airworthiness is mistakenly viewed as solely a DE&S responsibility;

(6) There is a bias towards Equipment risks;

(7) Airworthiness is diluted as a discipline;

(8) Airworthiness risks are managed separately by the equipment and operational domains;

(9) Risk is poorly assessed across the various Defence organisations;

(10) There are too many different Hazard Risk Matrices;

(11) There is a lack of independence and transparency;

(12) There is a lack of consistency across all three Services;

(13) The interface between the MOD and Industry is not working as it should;

(14) The MOD Regulators lack oversight of Airworthiness management at the Front Line;

(15) There is no training in airworthiness regulation;

(16) Regulations are too complex, prolix, and obscure;

(17) The system of "Letters of Delegation" is imperfect;

(18) There is a lack of alignment of duty, responsibility, resources, and expertise;

(19) Operators have not taken charge of Airworthiness;

(20) There is a lack of corporate memory;

(21) Reviews and inspections focus on process rather than product;

(22) There is a lack of clarity in the type-certification;

(23) A process-dependent, paper-reliant, and 'box-ticking' safety culture has developed;

[1] *i.e.* Risks shall be reduced to a level that is As Low As Reasonably Practicable.

(24) There is too much change and not enough stability;

(25) There is insufficient leadership; and

(26) A *plethora* of different safety and airworthiness-related bodies exist.

2. A new set of Principles (**Chapter 20**) is required and a new Military Airworthiness Regime is called for (**Chapter 21**).

3. There are the following further major shortcomings which need to be addressed:

- an inadequate and wasteful Safety Case regime (**Chapter 22**);
- an inadequate appreciation of the needs of Aged Aircraft (**Chapter 23**);
- weaknesses in the area of Personnel (**Chapter 24**);
- an unsatisfactory relationship between the MOD and Industry (**Chapter 25**);
- an unacceptable Procurement process (**Chapter 26**); and
- a Safety Culture that does not work (**Chapter 27**).

Current position

19.1 The Airworthiness system used by the MOD covers: (a) the procurement and support of equipment; (b) aircraft operation; (c) training; and (d) airspace management. Although there is a single 2-Star Regulator for MOD Airworthiness, the regulatory function is in practice delegated to three dispersed 1-Star appointments responsible for: (a) equipment; (b) flight operations; and (c) airspace management, respectively, supported by lower-level regulators for Military Airworthiness and Flight Test.

19.2 Each of the Services also has its own Airworthiness Release Authority, which undertakes an independent assessment of the Airworthiness of their respective aircraft types and approves them for use by their front line Aircraft Operating Authorities (AOA), setting the bounds for their use. There are also several senior appointments in the Equipment Authority with delegated Airworthiness responsibility for each platform type. Although the MOD's Airworthiness Regulator issues approvals for industry design and maintenance support, and vets candidates for Airworthiness appointments, the equipment and operating authorities across the three Services are otherwise largely self-regulating.

Differences between civil and military aviation worlds

19.3 It is important to bear in mind the fundamental differences between civil and military aviation. Civil aviation comprises many different operators, support organisations, and nationalities, with some operators operating several different platform[2] types. Carriage by air of passengers and freight is offered to the public on a commercial basis; services are normally of high volume and frequency on well-established routes to and from ICAO-standard[3] international airports; carriers compete for business on price and quality, frequency, and regularity of service; and the daily numbers of aircraft movements and passengers carried to and from high-density population centres around the world are enormous. Military aviation, on the other hand, is largely made up of multi-platform owner/operators engaged directly or indirectly in a wide variety of military operations, including combat, surveillance, carriage of combat personnel and supplies, support, rescue, and humanitarian aid. Aircraft may be deployed at short notice on operations or in theatre[4] in a wide variety of challenging environments and aerodromes. The fast-moving nature of modern war operations means that AOAs need flexibility to be able to make rapid military and engineering judgments in relation to the

[2] *i.e.* aircraft.

[3] International Civil Aviation Organisation – established by the Chicago Convention on International Civil Aviation of 1944.

[4] *i.e.* war zones.

risks faced in challenging combat and operational environments. Accordingly, AOAs employ and authorise equipment specialists and engineering officers to make Airworthiness decisions when and where they are needed, without having to refer to a central regulator. This is an entirely different construct to the civil sector and reflects the differing requirements of the military world.

Shortcomings of current MOD Airworthiness system

19.4 I set out below the main shortcomings of the current MOD Airworthiness system which, in my view, need to be addressed.

(1) The current MOD Airworthiness system is of Byzantine complexity.

19.5 Despite the recent laudable advances under the leadership of the Assistant Chief of the Air Staff (ACAS), Air Vice-Marshal Timo Anderson, in my view the MOD's current Airworthiness system lacks sufficient clarity, simplicity, and transparency. Roles and responsibilities are diffuse, diluted, and opaque. Lines of authority are often attenuated, conflicting, and unclear, even to those in them, and not widely appreciated by others in the organisation as a whole. The collection of so many disparate regulators, each responsible for different aspects of Airworthiness, and each having different levels of authority, is an arrangement that is neither effective nor, frankly, understood by the majority of practitioners in the Services.

(2) There is a fundamental lack of 'ownership' of Airworthiness.

19.6 The identity of Duty Holders is not clear. The ownership of 'risk' is fragmented and dispersed across platforms, operating, and equipment authorities. There is a lack of clear understanding or guidance as to what levels of risk can be owned/managed/mitigated and by whom, and no clear process for transferring ownership of risk from one organisation to another. There is also no recognised process for transferring risk upwards through the Airworthiness governance structure, or between those responsible for Airworthiness.

(3) The meaning of "Airworthiness" is not sufficiently understood.

19.7 'Airworthiness' is defined by the relevant Joint Service Publication as: *"The ability of an aircraft, or other airborne equipment, to operate without significant hazard to the aircrew, groundcrew, passengers or to the general public over which such airborne systems are flown"*.[5] Airworthiness, therefore, expressly covers equipment *and* its operation. This does not seem to be widely appreciated or understood by all concerned. Within the UK MOD, Airworthiness regulation, management, and focus remains largely equipment-centric and Defence Equipment & Support (DE&S)-centric. Those elements within the AOA's sphere of responsibility that contribute to Airworthiness are not considered to have as significant or important a role. As stated below, Airworthiness is generally assumed to be solely a DE&S responsibility and to relate to equipment. Neither assumption is correct.

(4) The meaning of ALARP[6] is not sufficiently understood.

19.8 The ALARP rule is one of the fundamental tenets of safety and a basic concept; and yet there is confusion in some (senior) quarters as to the relationship between ALARP and the 'tolerability' of risk, and also a lack of appreciation in others as to the temporal and financial flexibility inherent in the 'R' in ALARP.

(5) Airworthiness is mistakenly viewed as solely a DE&S responsibility.

19.9 Airworthiness covers both the provision and maintenance of Airworthiness equipment. This is a responsibility which spans both DE&S and the AOAs. Airworthiness is, however, widely viewed as solely a DE&S responsibility, both by those within DE&S and by the AOAs.

[5] Joint Service Publication (JSP) 553.

[6] *i.e.* Risks shall be reduced As Low As Reasonably Practicable.

(6) There is a bias towards Equipment risks.

19.10 Airworthiness is seen as an Equipment problem. Management focus and financial resources are often channelled specifically to mitigate equipment risks, even though the highest Risk to Life for an aircraft is likely to be Operational, *i.e.* to stem from its flying operations or its operating environments. Indeed, none of the current top eight aviation safety risks on the Defence Aviation Strategic Safety Risk Register (DASSRR) are platform airworthiness risks. They are: (1) aircraft availability; (2) operational commitments – structure and manning levels; (3) operational accommodation; (4) risk of aerial collision against commercial air traffic/ general air traffic; (5) 'brownout';[7] (6) mid-air collision on Operation Herrick; (7) helicopter wire strikes; and (8) risk of aerial collision – rotary wing.

(7) Airworthiness is diluted as a discipline.

19.11 Airworthiness is treated as a sub-set of the 'Safety' disciplines covered by the DE&S Safety Management System. DE&S' approach to 'safety' governance mixes Airworthiness risks with those related to 'business' or 'environmental' concerns. This dilutes the management of the more focused discipline of Airworthiness, which is necessarily technical and concerned only with reducing Risk to Life. Regulations for Safety and Airworthiness management overlap and duplicate each other in many areas. They are each written by different sponsors yet are managed by the same Safety Managers on the Integrated Project Teams (IPTs), and operating Airworthiness risks are left to the AOAs to consider separately. Without a standard set of criteria for risk assessment there are inconsistencies in the way equipment risks are assessed on different platforms and which are taken in isolation. Differences also exist across the boundary between the equipment and operating authorities, which together make it impossible to identify what the actual Risk to Life is for any platform. In terms of behaviour, the authorities have tended simply to 'log', *i.e.* record risks rather than proactively manage them. Risk assessments which are made are often done in isolation and lack relative context. As the equipment and operating authorities each manage their own risks, it is also not possible to identify what the composite top Risks to Life are for a platform. As the Airworthiness hazard and risk criteria is not directed by a single Regulator, discrepancies in the assessment have emerged which means that a 'Category A' for one platform does not compare with a 'Category A' for another platform in terms of the net Risk to Life. This means that relative assessments cannot be made between technical and operational risks, or across platforms so that resources can be apportioned effectively to reduce the net Risk to Life, and to ensure that risk is owned at the right level. Risk is now managed in DE&S under the subject of general 'safety and environmental' management. All types of risks, including those that do, and do not, have a Risk to Life component, occupy the same Risk Register. The management of Airworthiness is thereby diluted.

(8) Airworthiness risks are managed separately by the equipment and operational domains.

19.12 Both equipment and operational risks are part of the operation of military air platforms. Equipment and operational risks often overlap. Pro-active management of both together is a fundamental element of the Airworthiness regulatory framework. Equipment and operational risks are, however, managed separately by the Equipment and Operational domains as 'equipment' or 'operational' risks, with hazards logged (rather than managed) separately, each with their own mitigation. Currently most risks captured by Integrated Project Teams (IPTs) are related to equipment risks; and AOAs have their own separate risk databases which are related to operational risks.

(9) Risk is poorly assessed across the various Defence organisations.

19.13 'Equipment' and 'Operational' risks are considered in isolation and under different criteria for each platform. It is not possible to identify the top 'Risks to Life' for any one platform, or to compare risks associated with one platform with another so that resources can be marshalled and directed appropriately. There is no broad assessment of Risk to Life and appropriate allocation of resources. There is no evidence that the MOD takes, or is able to take, a measured, broad, pan-MOD view on risk across all platforms, operations and lines of development to ensures that limited resources are used to best effect to reduce the net Risk to Life. Instead,

[7] Dust clouds reducing helicopter pilots visibility on take-off and landing.

the MOD tends to focus and spend its money in making individual pieces of equipment (*e.g.* aero-engines) extremely safe, which means that it does not have the resources to spend on other measures which might significantly reduce the overall net Risk to Life (*e.g.* collision avoidance systems such as TCAS[8] or additional spares). This imbalance is caused by myopia and a poor appreciation of the total risk picture. The result is that resources are not targeted as effectively as they might be. Further, the difficulty in comparing like-with-like and making relative assessments of risk across domains and platforms, means that the higher level governance boards which manage Airworthiness across Defence (*e.g.* MARSB) lack appropriate information to manage aviation risks or direct resources appropriately. The US Air Force Safety Center told me of a striking example of the advantages of being able to address Risk to Life across all platforms and operations: the US Navy, which assesses Risk to Life across all lines of development, came to realise that most aircrew deaths and injuries at various aircraft bases were attributable to motorbike accidents and, as a result, it instigated a successful advanced motorbike training programme, which substantially reduced road accident deaths for aircrew, thereby preserving one of its most precious assets.

(10) There are too many different Hazard Risk Matrices.

19.14 There are a myriad of different Hazard Risk Matrices used to determine risk categorisations. This is confusing, potentially dangerous, and makes it more difficult to compare risks across platforms.

(11) There is a lack of independence and transparency.

19.15 The Assistant Service Chiefs have each had bestowed on them the conflicting roles of Duty Holder and Release to Service Authority. This runs entirely counter to the principle of independent regulation and assessment which is a key tenet of proper Airworthiness regulation as practiced by *e.g.* the UK Civil Aviation Authority. These are pivotal regulatory functions that the Assistant Chiefs are expected to undertake in addition to their (very demanding) primary duties.

(12) There is a lack of consistency across all three Services.

19.16 Each of the three Services executes the Release to Service Authority function differently. The Navy and Army carry out this regulatory function from within their operating authorities. The RAF relies on the expertise of experienced air operators; the Navy relies on aircraft engineers; and the Army relies on a mixture. In effect, there are three quite different arrangements for what is the same regulatory function, whilst none, in my view, provides an example of best practice.

(13) The interface between the MOD and Industry is not working as it should.

19.17 The Regulator has initiated a move towards a more 'civil' Airworthiness regulatory model in order to seek to improve the interface between Industry (who manufacture and support the MOD's aircraft) and the Front Line military. The transition to a 'hybrid' model has, however, proved difficult. This is due in part to the fundamental differences between civil and military operations and to the difficulties of meshing different regulatory systems. The Military Approved Organisation Scheme (MAOS) was devised to align with the approval system used by the civil sector and to make it easier and less expensive for the MOD to contract with Industry. Those Industry support organisations that have been approved under the MAOS system have been permitted to devise their own systems for maintenance management. Unfortunately, these do not necessarily correlate with those used by the Forward environment who operate and support the aircraft, which has *e.g.* made the tracking of life critical components difficult. Most importantly, Industry MAOS support organisations will not recognise engineering decisions made by the Front Line engineering officers taken *e.g.* to defer corrective maintenance or accept capability limitations, even though these decisions are a fundamental requirement for military air operations. Rather, Industry MAOS support organisations typically demand corrective action *before* aircraft are handed over to Industry for routine maintenance. At RAF Marham, for instance, where MAOS is in place, Industry has on occasion even been unwilling to recognise component life data issued

[8] Traffic Collision Avoidance System.

by the IPT and has refused to let their people fly in those aircraft. This fundamentally undermines the basic construct of the scheme which is for an 'approved' organisation, such as an IPT, to issue 'approved' data. Regulator-issued MAOS approvals are based on evidence that processes exist rather than the effectiveness of their processes or the output standard of the aircraft post-Depth maintenance. Further, under the MAOS arrangements, the IPTs act as the Continued Airworthiness Management Organisation (CAMO) and the IPT Leader (IPTL) is the Continued Airworthiness Manager (CAM). The IPTs and the IPTL are thus the type-specific Regulator, the Engineering Authority, and the Airworthiness Authority, with control over in-year finance and support contracts. This is a range of roles that would be deemed unacceptable for one organisation to hold in civil aviation.

(14) The MOD Regulators lack oversight of Airworthiness management at the Front-Line.

19.18 Unlike EASA[9] and the CAA who govern civil aviation, the MOD's Regulators lack direct authority over the operating authorities (AOAs). The MOD Regulators are also dispersed both functionally and geographically. Crucially, they have very little oversight of Airworthiness management where it most matters, *i.e.* at the point of use.

(15) There is no training in airworthiness regulation.

19.19 Those charged with complying with airworthiness regulations are neither taught, nor examined, on the subject, nor schooled in what are acceptable means of compliance.

(16) Regulations are too complex, prolix and obscure.

19.20 The current complexity, prolixity, and obscurity of the structure, content and language of the regulations makes them virtually impenetrable and, frankly, a closed book to the majority of the congregation governed by them. Much of the language is obscure, difficult to read, and repetitive. The sheer volume of regulations with which officers are expected, or presumed to be familiar, is neither sensible nor realistic. This has all led to the gradual marginalisation, misunderstanding, and mistrust of much of Defence regulations. The Review has over 60 lever arch files of Defence regulations stretching back several decades. Such is the *plethora* and disparate nature of the current regulatory documentation set, and the cloudy overlap between Safety, Airworthiness and Environmental regulations, it is unrealistic to expect those charged with compliance to assimilate, let alone implement, many of the regulations that now exist. The regulatory document set has grown into a veritable *pot pourri* of guidance, policy, and regulation, lurching from the highly prescriptive to the overly-relaxed, with regulations permitting all manner of local interpretation. This has encouraged divergence in the way Airworthiness has been applied by individual IPTs and by Industry. The verbose Airworthiness and Safety regulatory set is neither well understood nor applied. Nor does it provide the clarity, purpose, or authority needed by those in Airworthiness positions. There is a need to cut away much of this undergrowth. By way of comparison, the equivalent regulation document set used to govern Defence Nuclear is concise and unambiguous and can readily be assimilated by users. Regulations should be succinct, structured, coherent, consistent, comprehensive, and, above all, written in plain English. Good regulation is axiomatic to any organisation. The more complex the organisation and product, the more important it is to strive to keep regulations as simple as possible. Good simple regulation is key to providing the framework and guidelines for the safe, efficient, and productive carrying out of Defence activities.

(17) The system of "Letters of Delegation" is imperfect.

19.21 Specific responsibility for safety and airworthiness is the subject of letters of authority called "Letters of Delegation" (LOD). The LOD system purports to 'cascade' instructions and authority regarding safety and to form a 'chain' of responsibility. In practice, however, LOD have operated to transfer ownership of safety and airworthiness from the desks of higher ranks to lower ranks, *i.e.* pass-the-parcel, with little oversight or monitoring. I have recommended that "Letters of Delegation" are rewritten to make them simpler and

[9] European Aviation Safety Agency.

renamed "Letters of Authority" to make it crystal clear that responsibility for safety remains at, and is driven from, the very top, and what is being given is authority to act. Delegation is a two-way street, with reciprocal duties and responsibilities between the delegator and delegatee

(18) There is a lack of alignment of duty, responsibility, resources and expertise.

19.22 The current safety system operating in the MOD is illogical and dysfunctional because duty, responsibility, resources and expertise are not aligned or in the same hands:

19.22.1 AOAs, namely Group and Base Commanders and Force HQ have: (a) the relevant knowledge of operational requirements, problems, and priorities; (b) immediate and daily access to the views and expertise of Front Line air and engineering crews; (c) the most direct interest in ensuring the safety and airworthiness of their aircraft; and (d) overriding responsibility for the safety of the personnel under their command. However, Base Commanders and Force HQ have: (i) no budget; (ii) no direct access to the Design Authority; and (iii) no responsibility for platform safety and airworthiness.

19.22.2 The Design Authority (BAE Systems) has: (a) the relevant design knowledge and expertise; (b) ownership of the intellectual property; (c) increasing knowledge of and responsibility for maintenance; and (d) substantial manpower and resources. But the Design Authority has: (i) no funds save those negotiated on a piece-work rate with the IPT; and (ii) no overall responsibility for the safety and airworthiness of aircraft which they manufactured and (increasingly) maintain.

19.22.3 The platform IPT has: (a) neither the operational nor the design knowledge or expertise nor the manpower, in-house, to be able to deliver safety and airworthiness themselves; (b) no option but to outsource much of the Safety Case work; (c) to meet the requirements and views of the Operator; (d) conflicting roles as both regulator and provider of capability; and (e) a myriad of other competing tasks. However, the IPT has delegated responsibility for platform safety and Airworthiness on a day-to-day basis. IPTs are sometimes considered merely another layer of bureaucracy.

(19) Operators have not taken charge of Airworthiness.

19.23 AOAs and Front Line operators should own airworthiness. They are most directly affected by the absence of it. As emphasised by the Chairman and Managing Director of Conoco, however, *"By and large, safety has to be organized by those who are directly affected by the implications of failure"*.[10] It is for this reason that Lord Cullen said that the operators themselves needed to be involved in drafting their own Safety Cases. Currently, everyone has been tending to look in the wrong direction *i.e.* towards DE&S and Industry for this task.

(20) There is a lack of corporate memory.

19.24 The diffuse Airworthiness structure, and absence of requirements for single, centrally-owned Databases, Safety Cases, and Risk Registers, means that there is a lack of corporate memory. This is particularly worrying in relation to legacy platforms. The older a platform becomes, the more important it is to gather and study data on it.

(21) Reviews and inspections focus on process rather than product.

19.25 Airworthiness reviews and inspections tend to focus on confirming whether relevant processes are in place, rather than investigating whether there is compliance and whether the processes are, in fact, having the desired effect. There has been a lack of penetration in audits. Auditors have tended to chase 'paper

[10] Cited in the Cullen Report, paragraph 21.4.

trails' rather than check what is actually taking place on the ground.[11] Unlike in the Civil Sector, there is no requirement for the AOAs to undertake annual Airworthiness reviews to confirm the Airworthiness of their aircraft (although the Army have their own annual review process). The absence of any general formal annual review process is one of the reasons why husbandry problems in relation to legacy aircraft have been allowed to develop. Recent investigations have identified failings in the way aircraft husbandry of legacy aircraft has been managed and carried out.[12] These shortcomings highlight the absence of any formal annual review process to confirm the Airworthiness of individual aircraft where scheduled maintenance has not identified the problem. There is, therefore, a need to review and align the re-certification processes used by each of the Services, and to consider the benefits of adopting a military version of the Civil Type Certificate, Certificate of Airworthiness, and the ARC.[13]

(22) There is a lack of clarity in the type certification

19.26 Whilst the certification process used in the civil sector to approve type designs and the Airworthiness of individual platforms clearly defines designer/manufacturer/operator responsibilities for Airworthiness, there is not the same clarity with respect to military aircraft, where responsibility for design/manufacture/maintenance is often shared between Industry and the IPTs and is confused.

(23) A process-dependent, paper-reliant, 'box-ticking' safety culture has developed in the MOD.

19.27 Any large, complex, hierarchical 'top-down' organisation which measures itself by strict adherence to procedures can become a slave to process and paperwork, and find false comfort in compliance and complexity. The MOD has not been immune from these pathogens. A process-dependent and paper-reliant culture has developed, particularly within DE&S and IPTs, which led to a shift away from proper risk analysis and ownership towards a 'box-ticking' approach to the management of safety and Airworthiness. Compliance with process and form-filling has taken the place of sound judgment.

(24) There is too much change and not enough stability.

19.28 There has been too much organisational 'change' generally in the MOD in the past decade in the wake of the impact of the Strategic Defence Review in 1998 and subsequent Logistic Transformations. The years of 'change upon change' have had a baleful effect on Airworthiness systems and structures. 'Change-weariness' has been the most common feature of evidence given by MOD witnesses in interviews conducted by the Review. As set out below, an internal RAF survey conducted in August 2008[14] found: *"Near-continuous change initiatives over recent years have created a climate of deep uncertainty, mistrust of enterprise and a sense of 'constant turbulence'; moreover continuous change does not permit the establishment of a baseline to measure logistical and personnel support required to conduct operations".* Any Airworthiness system requires time, stability, and continuity to enable it to bed down, take hold, gain strength and to become generally understood, accepted and effective across its whole reach.

(25) There is insufficient leadership.

19.29 With rank comes responsibility. With responsibility comes the need to exercise judgment and to make decisions. Airworthiness judgments and decisions can often be difficult and worrying. They also can have serious consequences. Airworthiness penumbra can also be viewed as less glamorous and pressing than other matters. For these reasons, there has been a discernable inclination by (admittedly busy) officers at all ranks to deflect, downgrade, avoid or slough off Airworthiness responsibility, judgments, and decisions either: (a) by means of wholesale delegations; and/or (b) by the outsourcing of airworthiness thinking to Industry; and/or (c) by the creation of further elaborate processes, procedures, or regulations to stand between them and the

[11] Similar disquiet was voiced, for instance, in the *Ladbroke Grove Rail Inquiry Report, Part 2*, paragraph 7.35.

[12] See further **Chapter 23**.

[13] Airworthiness Review Certificates.

[14] RAF "Capability Health Check" Survey, 18 August 2008, page A-8 (see further below).

problem. Indeed, one gets the impression that much of the process currently in place is designed not so much to improve safety, but to act as a bulwark against criticism in the event that things go wrong. These essentially defensive avoidance mechanisms are perceived to have a number of short-term advantages: first, they get the problem off one's desk; second, they shift the heavy burden on to other shoulders; and third, they provide handy protection against any against future criticism which might be made. Responsibility for airworthiness, however, is and should always be regarded as a non-delegable duty. Leadership should be shown from the top by those of rank taking personal control and responsibility for all critical decisions.

(26) Plethora of different safety and airworthiness-related bodies

19.30 The culture of change and complexity fed the MOD safety and Airworthiness structure. The Review carried out a historical analysis of the number and layers of safety and Airworthiness 'boards', 'meeting groups', 'committees', 'sub-committees' and 'working groups' *etc*. which were already in existence or have come into existence in the past decade or so. As far as the Review was able to ascertain these numbered at least 37 in total and formed the 'patchwork' shown below for the period 1996-2009 (see Figure 19.1). It is obviously highly unsatisfactory and confusing to have such a myriad of different safety and airworthiness-related bodies, leaving aside the major question marks over cost, their ability (where necessary) to communicate with each other properly, and their overall effectiveness. Many are the result of the growth of 'bolted-on' process in reaction to problems, rather than any strategic foresight or planning.

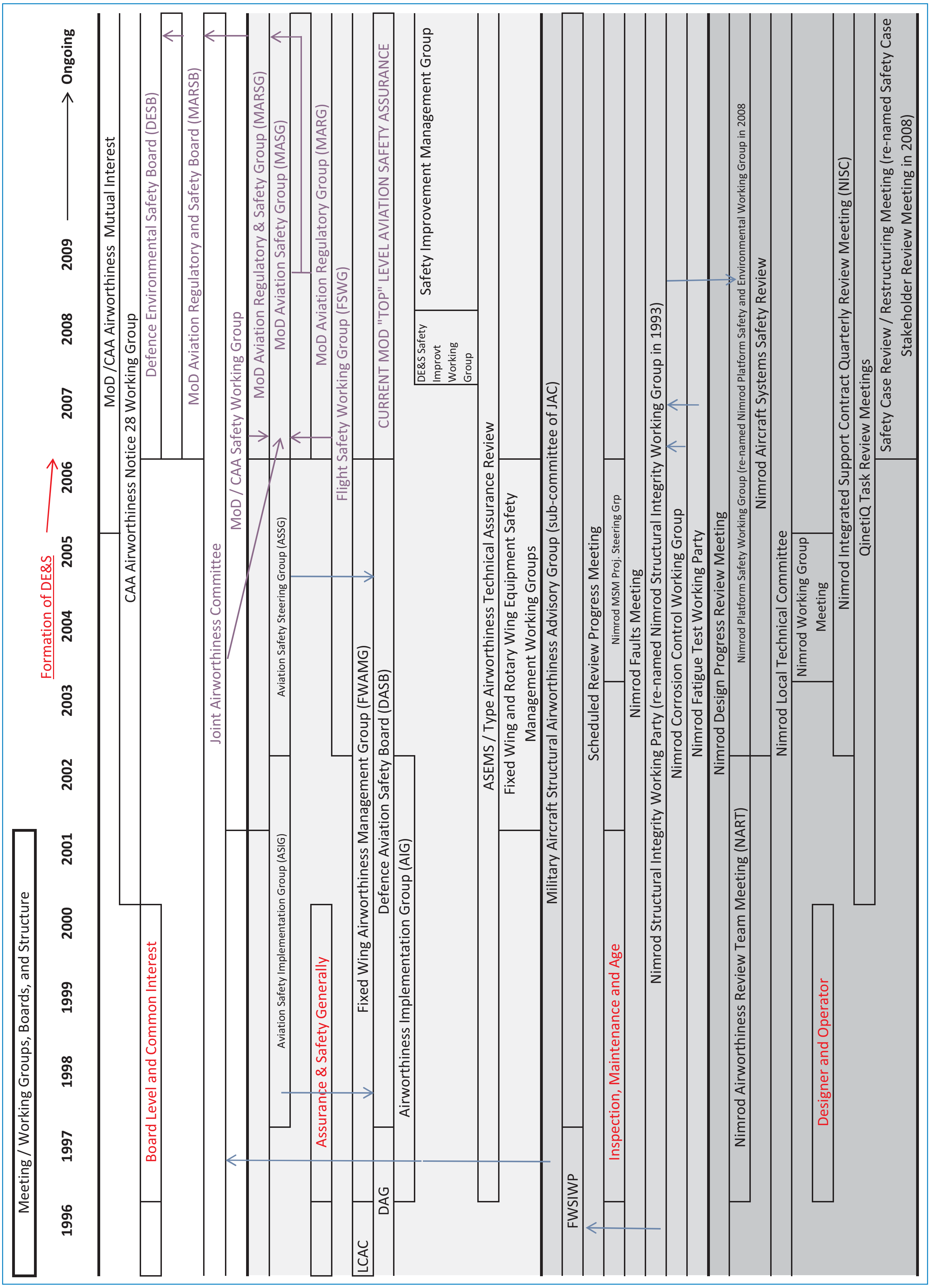

Figure 19.1: MOD Safety and Airworthiness committees etc (1996-2009)

The Future

19.31 A new set of Principles (**Chapter 20**) is required and a new Military Airworthiness Regime is called for (**Chapter 21**).

Shortcomings in Safety Case regime, Aged Aircraft, Personnel, Industry, Procurement, and Culture

19.32 There are also the following further major shortcomings which need to be addressed:

- an inadequate and wasteful Safety Case regime (**Chapter 22**);
- an inadequate appreciation of the needs of Aged Aircraft (**Chapter 23**);
- weaknesses in the area of Personnel (**Chapter 24**);
- an unsatisfactory relationship between the MOD and Industry (**Chapter 25**);
- an unacceptable Procurement process (**Chapter 26**); and
- a Safety Culture that does not work (**Chapter 27**).

RAF "Capability Health Check" (August 2008)

19.33 I am fortified in my above findings and my Recommendations[15] by having recently seen the results of a detailed survey carried out by the RAF on itself. The survey was commissioned by the Assistant Chief of the Air Staff (ACAS). The results of the survey are contained in a document entitled *"Capability Health Check"*,[16] dated 18 August 2008. Upon recently becoming aware of the survey I asked to see the report. It is a remarkably candid document with a stark assessment of the current state of certain aspects of the RAF. It deserves extensive citation in this Report because it highlights some of the major issues which most concern me.

19.34 I set out below the most important and pertinent passages in the *"Capability Health Check"* survey which confirm or support many of the finding which I have made in this Report (and also my own impressions having conducted numerous interviews of, and discussions with, personnel of all ranks, including a large number at RAF Kinloss at all levels, over many days), and reinforces the necessity for many of the Recommendations which I make in subsequent Chapters:

19.34.1 *". .... Officers and airmen at all levels convey the feeling they lack the guidance, prioritisation of task and resources to accomplish their jobs. Near continuous structural and functional change at [Command], Group and Station level has resulted in a perceived lack of clarity, structure and purpose."* (Executive Summary, paragraph 2).

19.34.2 *" ... The findings of the [Capability Health Check] lead to the conclusion that the RAF is able to execute the missions it is required to carry out but is eroding across a range of capabilities due to lack of sufficient resources and organisational complexities."* (Executive Summary, paragraph 3).

19.34.3 *"**Preamble** ...the implications of lack of manpower and resources, change-weariness and failing industrial support were universal."* (paragraph 1).

19.34.4 *"**Control of Resources.** Commanders feel less empowered than in the past to control manning, logistical support, infrastructure, In respect of manpower and logistical support, they felt they did not directly control many of the levers that deliver operational output, such as manpower levels and skills mix, stockholding levels of components, degrees of external tasking, the contractual delivery of airframes and contractor compliance. Part of the disempowerment is a result of 15 years of initiatives and structural changes across the RAF and Defence, combined with unprecedented*

[15] See **Chapters 20 to 27.**

[16] 20080818-CHX EXECSUM-RSM

operational tempo. In addition, Commanders felt constrained by contractual base support over which they have little or no control." (paragraph 3).

19.34.5 *"**HQ/Gp/Station Relationships.** The roles and responsibilities of [Group/Joint Helicopter Command, [Force Head Quarters] Station/Squadron Executives and STANEVALs] are unclear to many across the [Force Elements] and the rustication of some [Group] functions has exacerbated the problem. In addition, this lack of clear understanding has resulted in units developing non-standardised processes even within the same Force Elements. The end result of the rustication of HQ and Group functions has been viewed as a general increase in station workloads without any appreciable increase in manpower.*" (paragraph 4).

19.34.6 *"**Impact of Engineering Force Cuts.** ...Progressive cuts in engineering unit manning had an increasingly detrimental effect on engineering capability to the point of failure; this was especially true in cuts made to depth engineering. Some of the fleets interviewed were using two shifts worth of technicians and mechanics spread over a three-shift pattern with an attendant risk of errors and omissions being made validated by increases in the number of snags reported during walk-rounds. Engineering personnel on all sites also reported, albeit cautiously, that maintenance often follows the 'quick way' rather than the 'right way' (ie not in accordance with the Maintenance Instructions) in an effort to get the job completed in time. Although there are many safe systems of work in place across the engineering and related trades, it is clear that short cuts continue to be taken in order to meet the task. Whereas the depth of experience in the past would have allowed considered risk-based judgements to be made, risk aversion coupled with less experienced crew paradoxically could raise the probability of failure or unnecessary delays. Coupled with [......] ageing platforms and high rates of tasking, considerable risk is being accumulated, increasing the likelihood – and severity – of major failure.*" (paragraph 6).

19.34.7 *"**Operations and Engineering.** Several of the stations used ad-hoc organisational structures to interface operations and engineering. This translated into a generally poor interaction and lack of understanding of both operational needs and engineering capacity. Some of the units visited were limited in the development of near or long term flying programmes as the engineers could barely generate enough aircraft to meet bare minimum flying rates, compounding the planning problem. [...]*" (paragraph 7).

19.34.8 *"**IPT and Industry Support.** Many of the stations reported that for varied reasons industrial support was, at times, not achieving headline or contracted rates of delivery of airframes or equipment. ... Engineering officers also reported confusing relationships with their IPTs and Group interfaces in being able to manage the force."* (paragraph 8).

19.34.9 *"**Delivery of qualified personnel.** Each of the units sampled relayed problems with getting adequate numbers of qualified personnel in the right positions. This stemmed from a range of issues, including a lack of qualified personnel, training backlogs in OCUs and formal courses, new training systems, and poor management of personnel. There was the sense that the numbers of personnel, rather than their skills and experience, determined placement. The typical practice of posting personnel on promotion, often to a different platform, can result in substantial loss of skills and experience... The net result is a growing experience gap [......] .... Some Forces are already facing the prospect of not having enough experience personnel to man their OCU and STANEVAL functions. ...*" (paragraph 9).

19.34.10 *"**Training Standards.** ... the sparse availability of platforms, coupled with a shortage of qualified instructors means that aircrew conversion training is sporadic and characterised by cancelled sorties and lack of opportunity to consolidate skills... Changes in engineering training structures such as multiskilling technicians are reported to have made little changes in rates of delivery, as most would feel uncomfortable in their second trade and they do not have time to consolidate their training. This problem is aggravated by the absence of a 'Training Margin' to provide staff/manning cover when personnel undertake additional training. ...*" (paragraph 11).

19.34.11 *"**The 'more with less' culture.** The general feeling at Station level is the multitude of changes made to organisations, coupled with cuts in support functions, lead to more work with fewer resources. This leads to the oft-quoted perception of 'having to fight for everything'. This leads to feelings of being overburdened where many – if not most – look forward to serving on operations as a chance for respite. The continual (over-)tasking results in losing the benefits of military life... and leads to a perception of the RAF being 'civilianised' in thought, speech and deed. .... The culture of 'change for change sake' has permeated the RAF and it is viewed with weary cynicism by so many of our personnel as a covert means to reduce manpower. Continuous change had created confusion as well as denying a stable baseline against which manning for operations and peacetime training can be scaled."* (paragraph 12).

19.34.12 *"**Additional Duties.** Our personnel reported being 'more busy than ever' dealing with the myriad of management overheads (eg Sapphire Reporting), guarding, EAW training, staff visits, surveys and external audits."* (paragraph 13).

"CONCLUSIONS"

19.34.13 *"**Are we [as] good as we think we are?** The RAF is under-resourced. Low aircraft availability coupled with a lack of training opportunities, training resources and equipment issues, is causing the forces that we examined to struggle to maintain currency and competency across all skill sets. ...it is clear that compared with skills sets and [Crew Flying Task] hours that we had, say, 10 years ago, there has been demonstrable fade ... The parlous manpower situation compounded by the strain of enduring operations is slowly bleeding the mission capability of many of our fleets, possibly leading in the worst case to mission failure. ... "* (paragraph 14).

19.34.14 *"**The People Component.** ... Most officers and airmen have had recent experience of high tempo expeditionary operations, producing a level of operational experience not seen since WWII. ... Our strength (and weakness) lies not with capabilities but with our personnel. Our people remain very 'can do' and although this is an admirable quality that we must continue to foster, it also serves to mask systemic problems and resource shortfalls."* (paragraph 15).

19.34.15 *"**Impacts of Engineering Force Cuts.***

– [...]

– *The 'Can do' attitude of our personnel, built on pride and goodwill has been the RAF's own worst enemy: it has masked the shortfalls and fissures of manpower and logistical support that have developed since the early 1990s.*

– *Some SNCOs feel that they are now carrying greater risk and liability within a culture of blame; in one instance an SNCO claimed that he [retired early] because he was not prepared to 'carry the can any longer' due to systemic shortages in his trade and role.*

– *...[M]any SNCOs feel that depleted experience and supervisory levels increase risk of failure through inexperienced judgement. Senior [flight] engineers report finding many snags and omissions when taking over [aircraft] from line personnel, due to, they believe a lack of experience and lack of supervision.*

– *Net reduction of suitably qualified and experienced personnel through efficiency drives and redundancy programmes has depleted any reserve capacity to improve individual deployment harmony (as opposed to unit harmony), as well as increasing time to rectify increasingly frail aircraft..."* (pages A-2 to A-3).

19.34.16 *"Additional Duties and Diversions.*

- *Even with low sortie rates as a function of aircraft availability, [station] personnel report being 'more busy than ever' dealing with the myriad of management overheads... In addition to being cynical about change programmes, weary cynicism surrounded the good that surveys/ audits such as the Continuous Attitude Survey and the [Capability Health Check] can do.*

- *... Devolved duties and responsibilities from [Group] also increase the non-operational work load."* (page A-3).

19.34.17 *"Reliance on Industry*

- *[...]*

- *... At Kinloss, there was grave concern over the time it took for the Design Authority to approve relatively simple repair schemes and components that had to return to BAES were reportedly taking 'many months' to be returned. Similarly there were 'insufficient' brake and tyre spares for the NIMROD; it was claimed that one heavy landing would have used [station] stockholdings. It was alleged that there was no real plan for 'spares support' for the MR4 after it is introduced, and concern was expressed about the level of support for the remaining MR2 fleet until OSD. Engineering staffs at Kinloss expressed concern about ongoing industry commitment to support the MR2 until OSD, as airframe numbers are reduced and MR4 progressively enters service."* (page A-4).

- *[...]*

- *... 'Dead on Ground' aircraft are routinely robbed of spares that are otherwise in the [Central Maintenance Unit/BAES-Marham loop, doubling the workload to return these platforms to the line.*

- *[...]*

- *... More [aircraft]* were being robbed of spares to keep the rest of the fleet airborne, doubling the maintenance requirement to get these aircraft returned to service."

19.34.18 *"Delivery of Qualified Personnel*

- *... The key issue raised in all discussion groups and interviews was the lack of suitably qualified and experienced people. ...[M]anpower shortages resulting in NCOs increasingly being 'hands on' and delivering output, rather than supervising it. ..."* (page A-5).

- *...Additional personnel have been promised in some areas as a result of reviews, eg an additional 18 technicians on Nimrod Line Sqn, but they have yet to arrive and experience has shown that the trades and qualifications may not necessarily cover the gap. ..."* (page A-5).

- *"Shortage of trained manpower meant that relatively straightforward jobs, such as an engine change on a NIMROD, had doubled in time, compounding aircraft availability problems. ... Skills fade was also a concern raised on several occasions as there were fewer opportunities now for airmen to do depot level maintenance (Depth) and have the broader knowledge and experience to support aircraft on operations, especially at austere locations. ..."* (page A-6).

19.34.19 "*Training Standards*

- *Sparse availability of platforms, coupled with shortage of qualified instructors (Nimrod QFIs in particular) means that aircraft conversion training is sporadic and characterised by cancelled sorties and the lack of opportunity to consolidate skills. ...*

- *... Falling levels of broad spectrum experience coupled with 'parking' of some skills raises safety concerns amongst aircrew and ground crew.*

- *...Across the fleets, conversion courses run months behind schedule due to aircraft un-availability, leaving large gaps in the flying programme and little opportunity for crews to reinforce training. Moreover, at RAF Kinloss the loss of most of the QFIs on the OCU (to local operator) jeopardises future trained output, and thus the viability of the MR2 fleet. ..."* (page A-7).

19.34.20 "*Moral and Motivation*

- *It was singularly clear to the [Capability Health Check] team the commitment and the pride in their work – to see aircraft get airborne – remains paramount amongst maintenance and other support personnel. Much of this is down to inspired leadership at the SNCO level....*

- *Personal and professional pride means that personnel claim to be staying for increasingly longer hours to turn aircraft around or to carry out other support tasks, but there is a palpable sense, expressed by a significant number interviewed, that the RAF was 'letting them down' by agreeing to the culture of continuous change – with no obvious end in sight.*

- *Near-continuous change initiatives over recent years have created a climate of deep uncertainty, mistrust of enterprise and a sense of 'constant turbulence'; moreover continuous change does not permit the establishment of a baseline to measure logistical and personnel support required to conduct operations. Additionally, the presumptive language of 'management speak' and 'JPA civvie-speak' is alienating our personnel – at all levels interviewed. ..."* (page A-8).

Summary

19.35 In summary, in my view, the MOD has nurtured and endured an Airworthiness regulatory system that lacks coherence, clarity, ownership, and authority, which rates poorly against the other Airworthiness models used by other military forces (such as the US Air Force and the Australian Defence Force), and by the Civil Sector; and which lacks the clarity of expression and ownership afforded by *e.g.* Defence Nuclear regulation. There are, moreover, major problems in the areas of Safety Cases, Aged Aircraft, Personnel, relations with Industry, Procurement and, most importantly, Culture, which need to be addressed.

19.36 The case for substantial reform of the Airworthiness regime in the MOD is overwhelming and urgent.

Recommendations

19.37 I make detailed Recommendations for a New Military Airworthiness Regime (**Chapter 21**), together with Recommendations to address the problems with Safety Cases (**Chapter 22**), Aged Aircraft (**Chapter 23**), Personnel (**Chapter 24**), relations with Industry (**Chapter 25**), Procurement (**Chapter 26**) and, most importantly, Safety Culture (**Chapter 27**). I also make a number of final Recommendations (**Chapter 28**).

19.38 I turn first, however, to make Recommendations regarding the key Principles for an effective airworthiness system (**Chapter 20**).

CHAPTER 20 – NEW PRINCIPLES

"Rules are not necessarily sacred, principles are."
(Franklin D. Roosevelt, 1882-1945)

Contents

Chapter 20 identifies the key principles for an effective airworthiness system.

Summary

1. It is important to identify the right principles and always to be guided by them.
2. In my view, the key principles for helping assure and ensure an effective safety and airworthiness regime in the future are four-fold:
   - ✓ Leadership
   - ✓ Independence
   - ✓ People (not just Process and Paper).
   - ✓ Simplicity

Four Key Principles

> *"Perfect wisdom has four parts, viz. wisdom, the principle of doing things aright; justice, the principle of doing things equally in public and private; fortitude, the principle of not flying danger, but meeting it; and temperance, the principle of subduing desires and living moderately."*
>
> (Plato, 428 BC-348 BC).

Introduction

20.1 It is important, in any sphere of life, to identify the right principles and then to be guided by them.

20.2 In the complex world of high-risk technologies, there are a myriad of forces competing for time, attention and resources. This is nowhere more true than in the world of modern Military Aviation. Designing, maintaining and operating heavier-than-air machines remains one of man's most complex technological achievements. The boundaries of aviation technology continue to be pushed. In the Military Aviation context, the overriding imperatives of achieving the military mission, the need to be able to operate towards the edges of the safety 'envelope', and the vicissitudes of modern warfare, add layers of complexity to an already difficult equation.

20.3 Most aviation organisations worth their salt espouse safety and airworthiness as their 'highest priority' and enunciate 'principles' to which they profess adherence. Translating these laudable aspirations into a practical reality, however, is easier said than done.

Current policy, principles and definitions

20.4 The Safety Management Policy of the Secretary of State for Defence is expressed as follows:

> *"I expect the Ministry of Defence and the Armed Forces, in their organisation and processes, to ensure that in the acquisition of material and equipments of all kinds, safely and environmental management begins at the requirement definition stage and is carried forward through service to disposal. This includes all aspects of maintenance and operation."*[1]

20.5 The Secretary of State requires: *"that the airworthiness arrangements for military aircraft should be at least as effective as those for civil aircraft contained in the [Air Navigation Orders], and should comply with the [Health & Safety at Work Act 1974] where relevant. This is particularly important in roles that are paralleled in civil operations, such as where passengers are carried."*[2]

20.6 The current Military definition of Airworthiness is: *"The ability of an aircraft or other airborne equipment or system to operate without significant hazard to aircrew, ground crew, passengers (where relevant) or to the general public over which such airborne systems are flown."*[3]

20.7 In the MOD, those in receipt of Type Airworthiness Authority delegated authority are required to: *"Ensure that airworthiness-related processes, functions and activities are: completed to accepted standards, performed by competent individuals, accomplished by approved organisations [and] undertaken using accepted procedures".*[4]

20.8 The 'Four Pillars' of Airworthiness in the MOD[5] are expressed as:[6]

- *Use of Competent People* (by means of the Design Approved Organisation Scheme (DAOS), the Maintenance Approved Organisation Scheme (MAOS) and assessment of MOD staff to whom Letters

[1] JSP815.

[2] JSP553, paragraph 1.15.

[3] Military definition of 'airworthiness', JSP553, Change 5, Notes to Users, paragraph 2.

[4] AD(Air Systems), D&MSD. Presentation to the Nimrod Review, April 2008.

[5] DE&S.

[6] AD(Air Systems), D&MSD. Presentation to the Nimrod Review, April 2008.

of Delegation (LOD) are issued);

- *Use of Recognised Standards* (by application of Defence Standard 00-970);
- *Independent Assessment* (by the use of independent and competent Third Parties); and
- *Safety Management System* (by 'cradle to grave' safety management including feedback).

20.9 These are all admirable aims and aspirations in themselves; and they represent key steps in any safety journey. As **Chapters 10** and **11** have shown, however, statements of good practice counted for little during the drawing up of the Nimrod Safety Case. As **Chapter 13** has shown, these pillars were vulnerable to being obscured or diminished or re-arranged by the powerful organisational forces prevalent at the time. And as **Chapter 19** explains, there is much that has gone wrong with the Airworthiness Management system in the MOD in the past decade to put it in its current, weakened state.

20.10 In order to make good such aims and aspirations regarding Airworthiness, it is necessary to identify, and adhere to, the correct overriding principles which are most likely to drive the behaviours necessary to ensure the required steps are taken and the right Safety Culture is established. Currently, a sense of clearly identified overriding principles in the arena of MOD Airworthiness is lacking. In order to re-build Airworthiness and restore confidence in the MOD, it is necessary to identify some core principles and to stick to them throughout the process of designing, establishing and operating any new Airworthiness Management System in the future.

Discussions in the context of 'Process Safety' Management

20.11 There are many well-known principles in the 'safety' field from which to choose. They tend to coalesce around some common themes.[7] In the context of 'Process Safety', which is the term used to describe the blend of general management and engineering skills aimed at preventing catastrophic accidents, particularly explosions, fires and toxic releases,[8] the Health & Safety Executive recommends that major hazard organisations should focus on 'Process Safety leadership' built around seven key elements:[9]

(1) Leadership.

(2) Process management taking place at all business levels.

(3) Real and dynamic risk assessments.

(4) Robust management of change approaches.

(5) Sustainability.

(6) Well trained and competent people.

(7) A learning organisation.

[7] *e.g.* 'Leadership', 'Communication', 'Audit', *etc.*

[8] A 'Process Safety Management' regulation was promulgated by the U.S. Occupational Safety & Health Administration (OSHA) in the wake of the *Bhopal Disaster.*

[9] I had the benefit of being invited to attend a seminal conference organised by the Health & Safety Executive entitled *"Leading from the Top – Avoiding Major Incidents",* London, 29 April 2008.

20.12 In the Baker Report[10] into the BP U.S. Texas City Oil Refinery Incident, recommendations were made in 10 areas:

(1) Process safety leadership.

(2) Process safety management.

(3) Process safety knowledge and expertise.

(4) Process safety culture.

(5) Clearly defined expectations and accountability for Process Safety.

(6) Support for line management.

(7) Leading and lagging process safety performance indicators.

(8) Process safety auditing.

(9) Board monitoring.

(10) Industry leader.

20.13 The phrase 'Process Safety' is used in contra-distinction to 'Personal Safety'. The former is aimed at wider organisational issues. I prefer, however, to avoid using the word 'Process' so generically because of the dangers of emphasising the 'processes' of safety at the expense of the end product and of encouraging 'comfort in compliance' with process.

Recommendation: Adoption of FOUR KEY PRINCIPLES

In the light of the lessons learned from previous Chapters, I recommend that the MOD should promulgate and adhere to the following **Four Key Principles**, in order to help assure and ensure an effective Safety and Airworthiness regime in the future:

✓ Leadership

✓ Independence

✓ People (not just Process and Paper).

✓ Simplicity

20.14 I outline these **Four Key Principles** in further detail below.

✓ *Leadership*

20.15 **Principle of *Leadership*: There must be strong leadership from the very top, demanding and demonstrating by example active and constant commitment to safety and Airworthiness as overriding priorities.**

20.16 Leadership is the most common principle emphasised time-and-time again in reports into major incidents and other materials:

- *"[T]he first priority for a successful safety culture is leadership"* (Lord Cullen, Ladbroke Grove Rail Inquiry, 2001)[11]
- *"Leaders create culture. It is their responsibility to change it."* (Columbia Accident Investigation Board, 2003).[12]

[10] The Report of the BP U.S. Refineries Independent Safety Review Panel, January 2007, headed by former US Secretary of State, James A. Baker III. The Panel focused on the wider picture of 'Process Safety' rather than what it referred to as merely 'Personal Safety'.

[11] Ladbroke Grove Rail Inquiry Part 2 Report (2001), Chapter 1, paragraph 1.11.

[12] Columbia Accident Investigation Board Report, 2003, page 203.

- *"If reliability and safety are preached as "organizational bumper stickers", but leaders constantly emphasize keeping on schedule and saving money, workers will soon realize what is deemed important and change accordingly. Such was the case with shuttle program."* (Brigadier General Duane W. Deal, USAF, 2004)[13]
- *"In hindsight, the Panel believes that if [the Chief Executive] had demonstrated a comparable leadership and commitment to process safety, that leadership and commitment would likely to have resulted in a higher level of process safety performance in BP's U.S. refineries."* (Report of BP U.S. Refineries Independent Safety Review Panel, January 2007).
- *"[T]he real fault lies, as Shakespeare noted, in ourselves, the leaders of the business. Businesses are the product and the extension of the personal characteristics of its leaders - the lengthened shadows of the men and women who run them."* (Donald Keough, former Chief Executive of Coca-Cola, *Ten Commandments of Business Failure*, pages 8-9).
- *"Generally speaking, organisations behave and teams behave in the way that their management, immediate boss, does, this dictates culture. So if you have a boss in a bank who likes to take risks, his staff will take risks. ...And you end up with a culture of risk."* (Witness L [QinetiQ], Safety Engineer, 2009)

20.17 The present case of Nimrod XV230 is no different. The fundamental failure was a failure of Leadership. As preceding Chapters have shown, lack of Leadership manifested itself in relation to the way in which the Nimrod Safety Case was handled, in the way in which warning signs and trends were not spotted, and in relation to inexorable weakening of the Airworthiness system and pervading Safety Culture generally. For these reasons, Leadership is a key principle for the future.

✓ *Independence*

20.18 **<u>Principle of *Independence*</u>: There must be thorough independence throughout the regulatory regime, in particular in the setting of safety and airworthiness policy, regulation, auditing and enforcement.**

20.19 A fundamental weakness of the MOD Airworthiness and regulatory system in the past decade has been the lack of independence. This lack of regulatory independence is manifest in two major respects. First, the lack of truly independent regulatory oversight. Second, the number of people throughout the Support and Front Line organisations who are dual-hatted, having to combine and reconcile conflicting Airworthiness and Output duties. This is manifestly unsatisfactory.

20.20 The notion of the independent Regulator, setting policy and regulations, carrying out audits and enforcement, is key to ensuring that the orthogonal values of Safety and Airworthiness are preserved. This is all the more required in the military context where the pressures and conflicts on time, attention and resources are often so acute.

20.21 As has been pointed out:

- *"It is important that that regulation is truly independent of operation."* (Rupert Britton, Legal Advisor to CAA,[14] 2008)

✓ *People (not just Process and Paper)*

20.22 **<u>Principle of *People*</u>: There must be much greater focus on People in the delivery of high standards of Safety and Airworthiness (and not just on *Process* and *Paper*).**

20.23 The MOD Airworthiness and regulatory system has become increasingly process-driven and process-reliant. The amount of process has burgeoned exponentially. Compliance with Process and Paper has been at the expense of People.

[13] Member of Columbia Accident Investigation Board, ASPI article *'Beyond the Widget'*, 2004.

[14] Civil Aviation Authority.

20.24 Safety and Airworthiness ultimately depends on People. Whatever elaborate Processes and Paper requirements are in place, it is People who ultimately have to ensure they take care, pay attention, think things through and carry out the right tasks and procedures at the right time and exercise caution where necessary.

20.25 As has been pointed out:

- *"Safety is delivered by people, not paper"* (Commodore Andrew McFarlane, Defence Nuclear Safety Regulator, 2008)
- *"It is important to value the individual and ensure that they are familiar with the aircraft and the process"* (Garry Copeland, Director of Engineering, British Airways, 2008).

✓ *Simplicity*

20.26 **Principle of *Simplicity*: Regulatory structures, processes and rules must be as simple and straightforward as possible so that everyone can understand them.**

20.27 As explained in **Chapters 12** and **19**, the Byzantine complexity of the MOD Airworthiness system, the fragmentation of Airworthiness duties and responsibilities, and the prolixity and obscurity of much of the regulations is a major source of concern.

20.28 Complexity is normally the enemy of Safety and the friend of Danger. A safe system is generally a simple system.

20.29 As has been pointed out:

- *"There is false comfort in complexity".* (Darren Beck, Secretary to the Nimrod Review, 2008).
- *"We believe hugely in simplicity and stability".* (Garry Copeland, Director of Engineering, British Airways, 2008)
- *"NASA was so complex it could not describe itself to others."* (Martin Anderson, HSE, 2008).

Conclusion

20.30 These are the four Principles that have most informed the Recommendations that I have made in following Chapters regarding a New Airworthiness Management System (**Chapter 21**) and a New Safety Case Regime (**Chapter 22**).

CHAPTER 21 – NEW MILITARY AIRWORTHINESS REGIME

"Safety is a 24/7 business."
(William C. Redmond, Executive Director of the US Air Force Safety Centre, 2008)

"By and large, safety has to be organised by those who are directly affected by the implications of failure."
(Mr R E McKee, Chairman and Managing Director of Conoco (UK) Ltd, 1990)[1]

Contents

Chapter 21 makes Recommendations for A New Military Airworthiness Regime.

Summary

1. The purpose of these Recommendations is to provide a detailed blueprint to enable the MOD to build a New Military Airworthiness Regime which is effective, relevant and understood, which properly addresses Risk to Life, and which drives new attitudes, behaviours and a new Safety Culture.

2. I make Recommendations for the creation of a New Military Airworthiness Regime under ten headings:

   A. New Military Airworthiness Authority.

   B. Clearly identified Airworthiness 'Duty Holders'.

   C. Proper training in Airworthiness Management and Regulatory skills.

   D. Proper system of Mandatory Reporting and Analysis.

   E. Single Safety Case and single Risk Management System.

   F. New joint independent Accident Investigation process.

   G. Readable and concise Airworthiness Regulations.

   H. Coherent Flight Safety management across the three Services.

   I. Clarification of Integrated Project Team Responsibilities.

   J. Restoration of the Chief Engineer.

3. The aims of the particular Recommendations include:

   (1) The Military Airworthiness Authority will bring coherence and governance to the current fragmented regulatory structure.

   (2) Airworthiness regulation will no longer be a part time job, or lack top-level leadership.

   (3) There will be clarity as to who holds ultimate Airworthiness responsibility.

   (4) Airworthiness Duty Holders will be properly supported.

   (5) There will be proper training in Airworthiness regulation.

   (6) The concept of 'Airworthiness' will be properly understood.

   (7) Regulations will be readable and usable.

[1] Giving evidence to Cullen Inquiry, 1990, *Piper Alpha* Report, paragraph 21.4.

(8) Mandatory reporting will be properly managed and overseen.

(9) Accident investigations will be independent, competent and effective.

(10) Important Airworthiness roles and disciplines previously lost will be restored: Chief Engineer, Flight Safety Inspectorate and rigorous compliance Audits.

4. I recommend that, in two years time from the publication of this Report, an independent auditor be appointed to report to the Secretary of State for Defence and 2nd Permanent Under-Secretary on progress in implementing these Recommendations for a New Military Airworthiness Regime. The independent auditor should preferably be from the Civil Aviation Authority or the Health & Safety Executive (and, for the avoidance of doubt, should not be a serving or past member of the RAF or Services, nor anyone connected with the Nimrod Review).

Purpose of the Recommendations

21.1 The purpose of the Recommendations in this Chapter is to provide a blueprint to enable the MOD to develop a clear, coherent, comprehensive and comprehensible pan-MOD Military Airworthiness Regime to which everyone in the organisation can subscribe, which adopts elements of the Civil Model where there is self-evident benefit, and which demonstrably addresses Risk to Life without compromising capability, and which drives new attitudes, behaviours and a new Safety Culture. In both peacetime and in military operations, the military need to operate, in a safe manner, aircraft which are available, capable and safe. An effective Airworthiness Regime which demonstrably assures and ensures this will take several years to mature. I recognise that implementation will be a major undertaking. The structural, substantive, cultural and behavioural changes required are significant. A sea-change in attitudes will be required. I am confident that the effort will be worthwhile in terms of Availability, Capability and Risk to Life.

Haddon-Cave Review Implementation Team (HCIT)

21.2 Success in implementation will depend upon effective leadership, collective will, sufficient resources and sustained effort over several years. I welcome the decision by the Chief of Defence Materiel (CDM), General Sir Kevin O'Donoghue, to set up and staff in advance of publication of my Report, the Haddon-Cave Review Implementation Team (HCIT) headed by my Technical Adviser, Air Vice-Marshal Charles Ness, so that work on implementing the Recommendations can begin immediately. The HCIT will report direct to the 2nd Permanent Under-Secretary (2nd PUS) in the MOD and it is important that it should do so on a regular basis.

Summary of Recommendations for Military Airworthiness Regime

21.3 My recommendations for a Military Airworthiness Regime are, in summary, as follows:

A. **New Military Airworthiness Authority**: The establishment of a new independent Military Airworthiness Authority (MAA) and Regulator to govern all aspects of military aviation, including authority for issuing a Release to Service (RTS). The MAA will be a self-standing, separate and independent entity reporting directly to the 2nd PUS at the MOD. The Head of the MAA will be a 3-Star (the Regulator) supported by two 2-Stars for Technical and Operating Airworthiness. The Equipment and Aircraft Operating Authorities (EAs and AOAs) will retain their responsibility to make Airworthiness decisions and to manage their own Airworthiness activity, but under the governance and watchful eye of the MAA which will have the authority, duty and resources to provide proper direction, oversight and assurance.

B. **Clearly identified Airworthiness Duty Holders**: The nomination of clearly identified accountable Duty Holders in each of the Services, at three senior levels, Service Chief, AOA and Unit Commander, who have legal responsibility for: (a) the safety of their people; (b) the equipment they provide them with; (c) the environments in which they work; and (d) the tasks they give them. The current AOAs are: in the Air Force AOC 1 Group, AOC 2 Group and AOC 22 Group; in the Royal Navy, COS Aviation/Rear Admiral Fleet Air Arm; and, in the Army, Commander Royal Artillery (for Unmanned Air Vehicles (UAVs)) and Commander Joint Helicopter Command (JHC).

C. Proper training in Airworthiness Management and Regulatory skills: The establishment of a regulatory system staffed with professional-status engineers and experienced operators, trained and examined in Airworthiness regulation. Specific Airworthiness responsibilities will be disseminated, where appropriate, through Letters of Airworthiness Authority (LOAA) to authorised, qualified, professional engineers who will thereby be authorised to make Airworthiness decisions in both DE&S and in support of the Duty Holder chains in the AOAs. All LOAA holders will have direct access to the Regulator.

D. Proper system of Mandatory Reporting and Analysis: The MAA Regulator will oversee a system of mandatory reporting and data analysis that provides accurate and timely feedback on Airworthiness across the air domain. The Operating Centre Directors[2] and AOAs will be responsible for collecting, assimilating and analysing data. AOAs will take the lead in the day-to-day management of Flight Safety.

E. Single Safety Case and Single Risk Management System: There will be a single Safety Case for each platform, formatted to an agreed standard directed by the Regulator and owned by the Regulator and kept current by Integrated Project Teams (IPTs),[3] which will be sufficiently clear and succinct that it can actually be used: (a) to inform and influence the daily management of a platform's Airworthiness; and (b) to underpin the aircraft's Release to Service. There will be a single Risk Register for all equipment and operating Airworthiness risks which will support the Safety Case and Release to Service. The Risk Register will articulate, to a common standard across the various platforms laid down by the Regulator, the net Risk to Life. The Risk Register will be owned by the Duty Holder in the relevant AOA who will ensure: (a) it is actively managed; and (b) a far clearer distinction is made between Airworthiness and Safety management generally.

F. New joint independent Accident Investigation process: There will be a new joint military air accident investigation process. The establishment of a Military Air Accident Investigation Branch (MAAIB) comprising permanent joint teams of technical specialists which will provide rapid investigation into the immediate causes of military accidents to assist Service Inquiries (SI). The Regulator will be the Convening Authority for all MOD SI accident investigations involving either military aircraft and/or air personnel. The Regulator will have the authority to appoint more senior or specialist presidents where the nature of the accident requires it or where a protracted legal analysis is likely post inquiry. There will be specialist training for the investigation presidents, and the provision of legal support.

G. Readable Airworthiness Regulations to inform and guide those charged with ensuring regulatory compliance: A concise set of Airworthiness regulations will be developed to govern Airworthiness as a discreet element of safety management, to replace the verbose, confusing and overlapping set of Airworthiness regulations which duplicate in many areas procedures and process set out in safety management regulations, and which dilutes Airworthiness management as a consequence. Airworthiness needs to be managed as an activity discrete from Safety in order to ensure that processes, resources and attention are firmly focused on Airworthiness over business and environmental risks.

H. Coherent Flight Safety management across the three Services: The establishment of three single-Service Flight Safety Organisations, with responsibility for the management and delivery of Flight Safety and a Flight Safety Inspectorate role, will rest within the AOAs.[4] Each AOA will appoint a Senior Operator working within the AOA responsible for the pro-active management of Flight Safety. The Regulator will maintain oversight of Flight Safety data/processes to inform his strategic management of Military Airworthiness. (This is closely linked, but wider in its remit, than the Mandatory Reporting which has been detailed in Recommendation D, above).

[2] The recently renamed DE&S 2-Star Directors who command the IPTs (now known simply as 'Project Teams: for consistency, their former title of 'Integrated Project Teams' is used throughout this Chapter).

[3] See footnote 2 above.

[4] For the avoidance of doubt the RAF Flight Safety Organisation is to be under the command of the CinC Air Command.

I. **Clarification of Integrated Project Team Responsibilities.** IPTs are responsible for setting the technical/regulatory/contractual boundaries within which the AOAs are permitted to operate their respective platforms (and the AOAs are responsible for ensuring the platforms are operated within those boundaries). The responsibility, at local unit level for managing continued Airworthiness within these bounds, is to be vested in the Continued Airworthiness Management Organisation (CAMO) overseen and directed by the Senior Engineer (OC Engineering Wing/CAM) at the unit concerned.

J. **Chief Engineer.** Each AOA will appoint a Chief Engineer to ensure support to the AOA Duty Holder and to ensure the Airworthiness of platforms and Airworthiness regulatory compliance in the fleets.

Aim of Recommendations

21.4 The aim[5] of my Recommendations is, in summary, as follows:

21.4.1 *The MAA will bring coherence and governance to the current fragmented regulatory structure.* The MAA will encompass all of the Equipment, Flight Operations, Air Space Management and Release to Service Authority (RTSA) regulatory functions, subsuming the role of the MARSB and relieving the Deputy Service Chiefs of the RTSA role.

21.4.2 *Airworthiness regulation will no longer be a part time job, or lack top-level leadership.* The MAA will be headed by the Regulator who will be a full time 3-Star appointment, and who will be supported by two, full time, 2-Star officers, and appropriately resourced permanent staffs.

21.4.3 *There will be clarity as to who holds ultimate Airworthiness responsibility.* This will rest where it properly should: with the AOAs at senior levels. The Airworthiness Duty Holders will be properly identified and accountable.

21.4.4 *The Airworthiness Duty Holders will be properly supported.* DE&S will face the Duty Holders in order to provide them with the Airworthiness support they need for the platforms. IPTs and IPT Leaders (IPTLs) will be responsible for providing safe equipment, but will not be Duty Holders. IPTs will have a true support role, with CAMOs at the Units established under the authority of an OC Engineering Wing to manage Airworthiness maintenance activity and taskings.

21.4.5 *There will be proper training in Airworthiness regulation.* Those required to interpret, apply, implement and administer Airworthiness regulation will be properly trained and examined so that they are in no doubt what their regulatory responsibilities are, and what are, and are not, acceptable means of compliance.

21.4.6 *The concept of 'Airworthiness' will be properly understood.* It is a discrete discipline focused on 'Risk to Life' which encompasses both the equipment and operating aspects of Airworthiness , *i.e.* IPTs', RTSAs' and the AOAs' areas of responsibilities.

21.4.7 *Regulations will be readable and usable.* A readable and usable Regulatory document set will be drawn up, which can be readily assimilated by those who are required to comply with Airworthiness regulations, and which is clear, concise, coherent and comprehensive.

21.4.8 *Mandatory reporting will be properly managed and overseen.* There will be a nominated senior person in each AOA responsible for ensuring that all mandatory reporting is properly compiled, assimilated and analysed, and with the MAA providing appropriate oversight and authority. IPTs will be required to undertake detailed maintenance data analysis in order to maintain the Airworthiness of their fleet.

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5 "Kentucky windage" allowed.

21.4.9 *Accident investigations will be independent, competent and effective.* There will be a permanent cadre of technical experts, proper training and resources for those carrying out investigations and the means to extract, retain and disseminate the lessons to be learned across all domains.

21.4.10 *There will be a restoration of important Airworthiness roles and disciplines previously lost*: Chief Engineer, Flight Safety Inspectorate and rigorous compliance Audits.

Necessary Change

21.5 I am conscious that, having criticised too much change in the past, I am advocating substantial change in the future. This is because I believe that change is absolutely necessary and the Recommendations I make in this and other Chapters will bring real long-term benefits and will strengthen and stabilise the Safety and Airworthiness regime in the MOD in the future. I have no doubt that the HCIT will implement the Recommendation in a sensible and measured manner.

A. New Military Airworthiness Authority

Current position

21.6 The person currently designated as Lead Officer within the MOD with responsibility for MOD Aviation and Safety Regulation is the 2-Star Assistant Chief of the Air Staff (ACAS). ACAS exercises this responsibility through delegation to three 1-Star specialists responsible for: (i) Air Equipment; (ii) Flight Operations; and (iii) Airspace Management for the three Services. These three 'pillars' form what has been called a 'virtual' military airworthiness authority, each headed by the 1-Star 'Regulator', but the constituent parts of which are dispersed geographically and organisationally across the MOD (see further below). ACAS is also the authority for approving aircraft for use by the RAF's Front Line commands, *i.e.* the RTSA. The Navy and Army have corresponding RTSA bodies.

21.7 The current position represents a marked improvement on the 2005 position, which the Defence Aviation Safety Centre (DASC) categorised as *"convoluted"* and *"seemingly dysfunctional"* in its January 2005 report. The improvement owes much to the leadership and drive of the current ACAS, Air Vice-Marshal Timo Anderson, and the work of the current Director Aviation Regulation & Safety, Air Commodore Ian Dugmore, in implementing the *2005 Military Aviation Authority Study*.[6] The 2005 Study determined that a standing military airworthiness authority mirroring the CAA was not appropriate because the responsibilities, authorities, structures and processes of the MOD as a Department of State in its own right were significantly different from those of the CAA; and insofar as there were similarities between the two organisations, these tended to lie within the area of the CAA's Safety Regulation Group (SRG). Accordingly, the Study focussed on comparative improvements in this latter area.

21.8 The implementation of the recommendations of the 2005 Study has now led to the following: (a) the appointment of ACAS as the designated Lead Officer for MOD Aviation Safety & Regulation; (b) the reconfiguration of the Defence Aviation Safety Board (DASB) as the MOD Aviation Regulatory & Safety Board (MARSB) chaired by ACAS to exercise line management of the subordinate MOD Aviation Safety Group (MASG) and MOD Aviation Regulatory Group (MARG);[7] (c) the co-location and combining of the MOD Aviation Regulation Team and DASC into the Directorate of Aviation Regulation & Safety (DARS) at RAF Northolt; (d) the establishment of the MOD Airworthiness & Flight Test Regulator (MAFTR) located at Wyton, Boscombe Down and Abbey Wood and comprising mainly experienced aircrew from the three Services; and (e) the establishment of the Directorate of Airspace & Air Traffic Management (DAATM) at HQ Air Command at High Wycombe. D MAFTR and D DAATM issue their own regulations for their respective areas of responsibility and undertake process-based audits of the equipment and operating authorities. The DARS, MAFTR and DAATM represent the 'three pillars' of the 'virtual' military airworthiness authority responsible for: (i) Equipment; (ii) Flight Operations; and (iii) Airspace Management respectively referred to above. ACAS

[6] CAS/02, dated 5 December 2005.

[7] Recommendations (1) and (2) were implemented in April 2007 and LOD issued to ACAS by the 2nd PUS on behalf of the Secretary of State.

issues personal LODs to: (i) the Director of DARS (dual-hatted as Director MARSG); (ii) the Director of MAFTR (dual-hatted as Director Air Systems) and (iii) to the Director of DAATM (dual-hatted as Dir Officer Battlespace Management).[8] Both D MAFTR and D DAATM report to the MARSB through D MARSG. A new reporting and analysis tool, the Aviation Safety Information Management System (ASIMS), is in the process of being trialled and implemented. In addition, ACAS tasked DARS to examine Flight Safety in Afghanistan and Iraq and as a result, a new post has been established for an in-theatre Flight Safety Officer to work across the various command and international boundaries, deployed on 1 July 2009.

Shortcomings of present system

21.9 The MOD's current Airworthiness system has largely evolved rather than been designed. Whilst the current three-pillared 'virtual' military airworthiness authority represents a significant step in the right direction, it is, in my view, too ethereal, disparate and weak for the job in hand. The function and identity of the three Regulators is neither coherent nor optimally suited to the respective governance roles. The separate Release to Service Authority (RTSA) edifice is an historical anomaly with little logic. Moreover, it is far from satisfactory that ACAS should have to juggle his bi-furcated Lead Officer Airworthiness roles, as head of the 'virtual' Military Airworthiness Authority and head of the RAF RTS, with his many other important functions. Further, it is both impractical and does not send out the right signals for the Head of Military Airworthiness to be part-time, with real responsibility devolved to three specialist regulators and three RTSAs, comprising many with dual-hats. Airworthiness is a full-time 24/7 job.

21.10 The current Regulators do not have the necessary oversight or authority over the AOAs or IPTs to govern Airworthiness effectively. Unlike his CAA equivalent, the Air Equipment Regulator does not have sight of occurrence reports, nor does he audit the Main, or Deployed, Operating Bases to assess either the standard of maintenance or the aircraft themselves. Whilst the Flight Operations Regulator checks for process compliance against the regulations that he issues, he does not undertake the 'inspectorate of flight operations' role at the Front Line units that used to be carried out by the Inspectorate of Flight Safety (IFS). This IFS role was lost in one of the more recent reorganisations. This was unfortunate because it had significant Airworthiness value. The lack of oversight and authority over the AOAs, and lack of 'presence' at Operating Units, significantly limits the ability of the Equipment and Flight Operations Regulators: (a) to shape policy and regulation on an informed basis; (b) to gauge the effectiveness of it direction or ability; and (c) to impose coherence or provide authoritative direction on Airworthiness matters.

21.11 The lack of efficacy and clarity of the current MOD Airworthiness system is in marked contrast, for example, to the MOD Nuclear management arrangements whereby a 3/4-Star equivalent level committee (DNSC) appointed by the Secretary of State defines, guides and issues Nuclear Safety policy, which is then 'delivered' via a 2-Star led DNSEB (effectively the Nuclear Regulator) via a limited 'cascade' of responsibility and inspected for compliance on a regular basis by an independent, competent team. The DNSC is the authority through which all related policy is written, issued and amended and through whom all occurrences/incidents are reported.

21.12 The current, separate and variegated, Release to Service (RTS) arrangements are unsatisfactory. Airworthiness should not be split into RTS and In-service. The three Services should not have materially different RTS systems, employing as they do different skill sets and arrangements to maintain RTS independence. Moreover, the arrangement whereby the Royal Navy and Army RTSAs are co-located with the respective AOAs casts doubt over the degree of independence that they can provide or be seen to provide.

21.13 The current DE&S equipment Safety Management System (SMS) does not sufficiently recognise Airworthiness as a discrete and separate field, requiring significant technical knowledge, expertise and experience. The DE&S SMS encompasses far broader 'Safety' issues and risks than simply aircraft Airworthiness. Airworthiness should not be rolled up with Safety generally. Further, the DE&S SMS is not recognised by Air AOAs who manage their own Airworthiness risk separately and against quite different criteria.

21.14 Care needs to be taken in embracing all aspects of the civil model. The Air Equipment Regulator issues approvals for industry design and maintenance support and interprets policy for the equipment and operating

[8] D DAATM also supports ACAS in relation to European air traffic and airspace policy.

authorities for the three Services. The Air Equipment Regulator is seeking to promote an initiative to implement a military version of the UK Civil Airworthiness model and is leading a European forum attempting to achieve similar convergence between European Armed Forces and Industry. The implementation of this model has been difficult, however, with inefficiencies manifesting themselves at the interface between Forward and Depth and roles and responsibilities not being widely understood. In my view, it is doubtful whether such arrangements meet the needs of the Military that operate the equipment and carry the risks.

Independent MAA but part of MOD

21.15 In my view, it is important that the MAA is independent but remains part of the MOD. There is a logical argument which can be made for the MAA to be entirely separate from the MOD so that it can provide a totally independent voice untrammelled by financial or political pressures. Given the failings identified in this Report, I see force in this argument.

21.16 However, the military element adds an entirely different dimension to the picture. The MOD has the responsibility for delivering a certain military capability and balancing risk with task. A military organisation must be 'risk sensible' but not too 'risk averse'. The MAA must understand and appreciate operational relevance and, importantly, be seen by military operators to understand and appreciate this, if it is to enjoy their confidence. In my view, it would not be sensible or practicable to position the MAA legally and physically outside the MOD. Sufficient independence will be assured by having: (a) the MAA working direct for 2nd PUS; (b) a high-ranking 3-Star officer as Head of the MAA; (c) full time MAA Regulators who do not have other potentially conflicting responsibilities, *i.e.* do not have responsibilities for delivery which give rise to potential conflicts of interest; (d) clear Regulations which spell out different roles and responsibilities and assure the MAA's independence and immunity; and (e) stronger links with the CAA and HSE, including non-executives from such organisations sitting on an MAA board with an express responsibility to watch for, and report annually, on the MAA's independence from financial, political and operational pressures.

Objective

21.17 The objective of Recommendations A is to establish as soon as practicable within the MOD a single, independent, self-standing, autonomous, fully-functioning, co-located, tangible MAA which shall draw together and regulate, on delegated authority from the Secretary of State for Defence, [9] all aspects of Military Airworthiness, including the current regulatory roles of: (i) Equipment; (ii) Flight Operations; and (iii) Airspace Management Regulators, and (iv) the three Service RTSAs. The mission of the MAA is to transform Airworthiness management, transactional behaviour and culture across Defence. Unless senior 3-Star and 2-Star personnel are appointed to the posts of the Regulator (3-Star) and Technical/Operating Airworthiness Regulators (2-Star) as recommended, the MAA will fail. Leadership is key.

Recommendations A

21.18 In order to achieve this objective, I make the following Recommendations:

<u>Recommendation 21.A.1</u>: A Military Airworthiness Authority (MAA) shall be established as soon as practicable which comprises the single regulator authority responsible for regulating all aspects of Airworthiness across the three Services and DE&S and reporting direct to 2nd PUS.[10] The MAA shall subsume all the roles and responsibilities currently undertaken by ACAS and by: (i) the Equipment (Dir Air Systems and the MAR); (ii) Flight Operations (DARS); and (ii) Airspace Management (DAATM) Regulators and the three Services RTSAs.

[9] Military Aviation is regulated by a mix of enabling statute and Crown or Defence Prerogative. Regulation of the Royal Navy and Army are entirely matters of prerogative with the power of the Defence Council to make Regulations set out in the Letters Patent. In the case of the Royal Air Force, the statutory basis for making regulations is section 2 of the Air Force (Constitution) Act 1917 with the role of the Air Council replaced by the Defence Council under the Defence Transfer of Functions Act 1964. The recommendations regarding the new airworthiness regime in this Report do not require statutory amendments. However, if in the course of implementation, the new Head of the MAA requires any statutory power I understand there is an opportunity to effect this in the Armed Forces Bill leading to the new 2011 Act.

[10] This would reflect current arrangements for the management of Nuclear Safety.

Recommendation 21.A.2: The Head of the MAA (the Regulator) shall be a full-time 3-Star appointment and someone who is highly experienced and respected in the military air environment (and ideally has a background in Airworthiness Regulation).

Recommendation 21.A.3: The Regulator shall be supported by co-located Technical and Operational Airworthiness Regulators at 2-Star level, supported by specialist staffs.

Recommendation 21.A.4: The current RTSAs shall be folded into the MAA as a distinct regulatory function with Service specialists employed to provide appropriate input on Service-specific environmental requirements. The MAA will employ senior engineers with professional status holding Letters of Airworthiness Authority (LOAA), and experienced operators, to undertake demonstrable independent assessment for the initial release and supplementary changes to all Release to Service (RTS) issued for specific platforms. ACAS and the other Service deputies will be relieved of this specialist regulatory role.

Recommendation 21.A.5: The MAA shall facilitate and ensure a comprehensive, coherent, consistent and meaningful assessment of Airworthiness in terms of Risk to Life across of all lines of development in Defence, *i.e. "to provide assurance that aircraft have been designed, constructed, maintained and expected to be operated to approved standards and limitations by competent individuals who are acting as members of an approved organisation and whose work is both certified as correct and accepted on behalf of the MOD".*[11]

Recommendation 21.A.6: The MAA shall have a status comparable to that afforded to the CAA, with *mutatis mutandis* similar functions, oversight and authority performed on behalf of the Secretary of State for Defence, and set appropriately in the military context.

Recommendation 21.A.7: The MAA shall have direct authority over the Equipment Authorities and AOAs and with respect to all Airworthiness regulatory policy and compliance.[12]

Recommendation 21.A.8: The MAA shall have authority to determine appropriate Defence Standards and contractual requirements regarding Airworthiness with Industry and be given all concomitant assurance and enforcement powers.

Recommendation 21.A.9: The MAA shall be given appropriate financial, manpower and estate resources which shall be ring-fenced.

Recommendation 21.A.10: The MAA shall be located in a single geographic location entirely separate from the Equipment and AOAs, in order to re-enforce its independent status and enable it to carry out its remit to govern Airworthiness for the three Services in an objective and even-handed manner.

Recommendation 21.A.11: The MAA shall be responsible for devising, drafting and promulgating a concise and logically structured regulatory documentation set based on the Australian Defence Force and Defence Nuclear Safety management regulatory sets.

[11] Operational Airworthiness in the Australian Defence Force – definition of Airworthiness.

[12] This is similar to the arrangement employed by the Australian Defence Force and removes the perceived weakness of the current self-regulation system by providing for independent and over-arching assessment and assurance by the MAA.

Recommendation 21.A.12: The MAA shall be the higher authority for all mandatory reporting, with the Operating Centre Directors and AOAs' action addressees responsible for coordinating all mandatory reporting. The MAA shall have the authority to provide specific direction in the form of an Airworthiness Directive (AD) requiring immediate or particular Airworthiness management action.

Recommendation 21.A.13: The MAA shall put in place appropriate arrangements which permit Duty Holders in the AOAs to go beyond the bounds of the RTS to meet specific operational requirements where time constraints preclude the issue of a change to the RTS. Such arrangements will need to encompass the need for engineering officers in the Forward domain and IPTs to make appropriate Airworthiness decisions without recourse to the MAA (in effect, such decisions will need to be deemed to be 'approved data' and be subsequently recognised by the approved maintenance organisations in Depth). This will be achieved by issuing Letters of Authority (LOA) to the engineering officers required to make such decisions.

Recommendation 21.A.14: The MAA shall have a team of skilled surveyors who shall undertake regular compliance audits similar to those undertaken by the CAA on civil operators, such MAA audits being over and above any self-regulation undertaken by the Equipment and AOAs operating authorities themselves.

Recommendation 21.A.15: The MAA shall undertake a specific 'flight safety inspectorate' role in furtherance of its Flight Operations regulatory (*i.e.* assurance) function, with the actual delivery and deployment of Flight Safety being the responsibility of the respective AOAs (*i.e.* ensurance).

Recommendation 21.A.16: The MAA shall be the Authority and sponsor for all Airworthiness regulatory training, tailored for the specific Airworthiness responsibilities and posts.

Recommendation 21.A.17: There shall be a direct two-way line of communication (by-passing the usual chain of command) between the responsible engineers employed in Airworthiness posts and the Regulator for all Airworthiness matters.[13]

Recommendation 21.A.18: The definition of "Airworthiness" in JSP553 should be clarified and the Australian model of the three tenets of "Airworthiness" should be adopted, *i.e.*: (a) Operational Airworthiness *("ensures that aircraft are operated in their approved roles, with the right equipment, by competent operators")*; (b) Technical Airworthiness *("ensures that the design, manufacture and maintenance processes provide platforms which can perform safely in their intended roles and environment")*; and (c) Flight Safety *("is concerned with the human performance and operation within acceptable levels of risk")*.[14]

Recommendation 21.A.19: "Letters of Delegation" shall be redrafted and renamed *"Letters of Airworthiness Authority"* (LOAA) in a simple form to make it clear that: (a) Airworthiness is a separate and discrete area of responsibility; and (b) the grant of Airworthiness authority is not an abrogation of responsibility for Airworthiness by the delegator.

Recommendation 21.A.20: Non-executives from the CAA and HSE shall be appointed to the MAA Board and shall have express responsibility to watch for and report, annually, on the MAA's independence from financial, political and operational pressures.

Recommendation 21.A.21: Suitable forums and mechanisms shall be established whereby the MAA can regularly discuss common issues with the CAA and the HSE, and use the good offices of the CAA and HSE to help develop and monitor the MAA's Regulatory and Airworthiness policy, implementation, skills and knowledge.

[13] A similar arrangement is used in the management of Defence Nuclear safety.

[14] 'Operational Airworthiness in the ADF', September 2007 Air Vice Marshal J.N Blackburn, AO, ADF Operational Airworthiness Regulator.

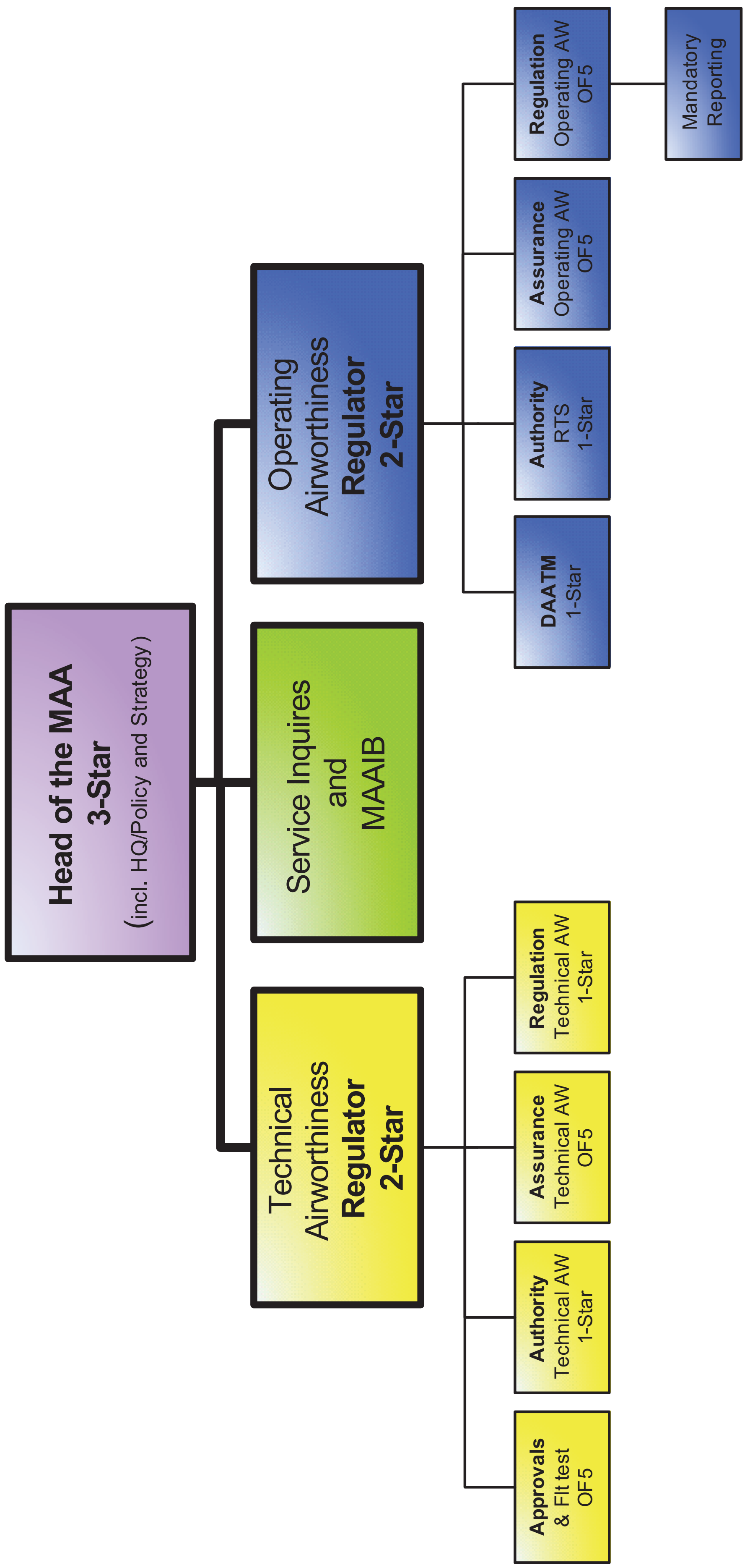


Fig. 21.1 MAA Organogram

Commentary on the Military Airworthiness Authority (MAA) Organogram

1. The MAA

- The MAA shall be the independent Airworthiness Authority and Regulator for Defence Aviation.[15]
- The MAA shall be answerable directly to 2nd PUS.
- The MAA shall comprise operations and engineering specialists with appropriate experience from all three Services.
- The MAA shall comprise three divisions: (i) the Operating[16] Airworthiness Authority (which shall include the Airspace/Air Traffic Management Authority and the RTSA); (ii) the Technical Airworthiness Authority; and (iii) the MAAIB and Service Inquiry Support Team.
- The MAA shall provide independent, expert regulatory authority for Airworthiness across the whole of Defence.
- The MAA shall provide the Defence Aviation environment with non type-specific Airworthiness policy and regulations, independent regulation, certification and approvals.
- The MAA shall provide external, independent assurance by undertaking audits[17] to validate AOA and DE&S assurances on Airworthiness.

2. The Head of the MAA

- The Head of the MAA shall be 'The Regulator'.
- The Head of the MAA shall be a 3-Star Senior Officer, with a comprehensive background in the air environment, approved for the appointment by the three Services.[18]

3. The Operating Airworthiness and Technical Airworthiness Regulators

- Two full-time, functional Regulators of 2-Star rank shall support the Head of the MAA.
- Both shall have a comprehensive and appropriate background in aviation.[19]

4. Operating Airworthiness: The following entities shall form the Operating Airworthiness Regulator's Area of Responsibility and report direct to him/her:

- **Regulation Department:** The Regulation Department (Operating Airworthiness) shall be OF5-led. It shall be responsible for:
  - developing and issuing all policy and regulation for Operating Airworthiness across the Defence environment (including the Operating industry environments).
  - providing independent oversight of all operating mandatory reporting, in order to effect a 'closed loop' for policy and regulation.
  - providing independent cross-department oversight of all mandatory reporting, with the authority to intervene or mandate as it sees fit (a similar function to that performed by the CAA).[20]
- **Assurance Department:** The Assurance Department (Operating Airworthiness) shall be OF5-led. It shall be responsible for:
  - assuring Operating Airworthiness regulatory compliance across Defence.[21]
  - the independent assessment of units, ships, operational bases and contractors to determine whether individual platform operations are compliant and airworthy.
  - examining the entire spectrum of operating regulations (that govern how equipment is used) in order to: assure compliance therewith; and to consider relevant support, training and airmanship issues that have a bearing on Airworthiness.

[15] The formation of an MAA will, finally, give effect to the recommendation in the Man S(Org) Report of 1994 that there should be a central safety office and safety management board.

[16] "Operating", *i.e.* those aspects concerned with the actual operation of the equipment and its operating environment as opposed to the technical aspects of the equipment.

[17] These shall be both compliance and evidence based.

[18] Ideally, the appointed individual should have some background in Airworthiness Regulation.

[19] Ideally, the appointed individuals should have some background in Airworthiness Regulation.

[20] AOAs will still be required to provide a focal point for mandatory reports originated within their organisation; they will be required to monitor and analyse trends, taking action to correct unwanted trends when required.

[21] The AOAs shall remain responsible for assuring their own Operating Airworthiness assurance using the services of such bodies as aircraft STANEVALS (Standards and Evaluations Units).

- **Defence Airspace and Air Traffic Management (DAATM):** DAATM, which is already a well established department (albeit under the part-time lead of a 1-Star), shall be headed by a full time 1-Star officer with appropriate experience in this specialised field of airworthiness.
- **Release To Service Authority (RTSA)**: The 2-Star Operating Airworthiness Regulator shall have RTS sign-off powers for all Defence Aviation platforms. The RTSA shall be led by an experienced 1-Star whose department shall provide independent operating and engineering scrutiny of Safety Cases, for the initial RTS and all subsequent amendments. The RTSA will also be responsible for assuring Air System Equipment airworthiness throughout its in-service life.

5. **Technical Airworthiness:** The following entities shall form the Technical Airworthiness Regulator's Area of Responsibility and report direct to him/her:

- **Regulation Department**: The Regulation Department (Technical Airworthiness) shall be a 1-Star-led department responsible for developing and issuing all policy and regulation for Technical Airworthiness across the Defence environment (from the AOA reaching back through to Defence Industry).
- **Assurance Department:** The Assurance Department (Technical Airworthiness) shall be an OF5-led department. It shall have responsibility for:
  - assuring technical airworthiness regulatory compliance across Defence.[22]
  - providing the necessary independent assessment of units, ships, operational bases and contractors to determine whether individual type technical operations are compliant and airworthy.
  - examining the spectrum of technical regulation to assure compliance (as well as considering support issues, training and behavioural/cultural aspects).[23]
- **Technical Airworthiness Authority:** The Technical Airworthiness Authority shall be led by a 1-Star officer. It shall have responsibility for:
  - decisions regarding the implementation of regulations for type.
  - providing direction and approval for all non type-specific Airworthiness issues.
- **Approvals & Flight Test:** The Approvals,[24] Flight Test and Certification Department shall be an OF5-led department. It shall be responsible for:
  - Approvals for Flight Test (including approvals for contractor flying of military platforms).
  - Regulatory oversight of the approval of individuals who are required to hold Airworthiness Letters of Authority (LOAs).
  - Certification approval (once requirements have been properly defined).

6. **Accident Investigation:** There will be a new Military Accident Investigation regime under the direct control of the Regulator:

- **Military Air Accident Investigation Branch:** A Military Air Accident Investigation Branch (MAAIB) shall be established, led at OF5 level. It shall comprise a team of full-time, trained, specialised and experienced operators and technicians built upon the well-established Royal Navy (RN) Flight Safety Accident and Investigation Team. The MAAIB shall provide a function similar to that of the Air Accident Investigation Board (AAIB) in the Civil Aviation sector and shall work closely with the AAIB. The MAAIB shall be configured to investigate all UK and deployed military air accidents. The MAAIB will assist the Service Inquiry (SI) in the technical investigation of the cause of the accident, under the direction of the SI President. The MAAIB will also provide specialist advice to the SI as necessary throughout its broader investigation. As soon as the SI/MAAIB team has determined the immediate cause of the accident it shall produce an interim report and (if necessary) interim recommendations. This report shall be without prejudice to the final SI report which will incorporate any interim report, consider the accident in its wider context and make further recommendations as necessary.
- **Service Inquiries and Support:** All future SIs will be convened by the Regulator, who will appoint appropriate Presidents to lead them, taking into account the nature and circumstances of the accident. There shall be a SI Support Team which shall provide specialist advice, administration, management and legal services to SIs throughout their investigation and beyond.[25]. The SI Support Team shall be required to ensure the training of sufficient candidates at SO1 level or above to ensure the Services have sufficient trained SO1 Presidents to call upon to conduct SIs into fatal or non-fatal air accidents.[26]

[22] The AOAs shall retain responsibility for assuring their own Technical Airworthiness, calling on the services of their Chief Engineer and his/her staffs.

[23] This role is commensurate with that undertaken by the CAA Surveyor's department in the civil sector.

[24] *i.e.* DAOS, MAOS approvals (*e.g.* Mil Part 145, Mil Part M, Mil Part 147, *etc*).

[25] The SI members may be required to attend civil, criminal or coroner's courts as a result of their SI duties.

[26] The students attending each year's Advanced Staff Course (ASC) will contain many of those eligible to undertake such training and arranging for the training to follow the ASC would ensure minimum disruption to posting patterns. However, the ASC should not be seen as a prerequisite to be a SI President. The course could also be attended by some of those likely to be nominated as aircrew or engineering members.

B. Clearly Identified Airworthiness 'Duty Holders'

Current position

21.19 Whilst the term 'Duty Holder' is liberally accorded to many in senior positions across the three Services and in the Support domain, there is little clarity as to its precise meaning or who is ultimately accountable for Airworthiness[27] across the MOD.

21.20 The command chain often masks true Airworthiness accountability in AOAs. The chain of command is used to manage the delivery of Capability throughout the ranks, from senior staff down to delivery at Unit level. There is a complex set of interfaces within, and across, command chains which manage support arrangements and undertake self-regulation activity. In the Maintenance domain, Quality Assurance is the means by which self-regulation is carried out. In the Operational domain, Standards and Evaluation teams (STANEVAL) check aircrew flying competencies. Neither mechanism provides comprehensive assurance, independent or otherwise. Delegation of Airworthiness responsibility is clearly identifiable in the Acquisition environment. The same is not true, however, in the AOAs, who use the equipment and who own the majority of risks pertinent to maintaining the Airworthiness of the platform. It should be noted that, in the Nuclear environment, specific safety responsibilities are identified with specific individuals.

Problems with the current position

21.21 *The first major problem is a lack of clarity*: most people within the three Services would not be able to identify the Duty Holders for Airworthiness, nor articulate their responsibilities. Even those that believe they are Duty Holders disagree as to their respective Airworthiness responsibilities and degree of accountability. There is, moreover, confusion with holders of Letters of Delegation.

21.22 *The second major problem is lack of alignment*: responsibility, authority and financial control are not in the same hands. Whilst Unit Commanders are responsible for: (a) the delivery of Capability; (b) the safe operation of equipment; and (c) the safety of people on their Unit, they have little in the way of authority over the Support infrastructure that serves them. Real power and authority lies, unsurprisingly, with those who have and exert financial leverage elsewhere in the organisation. It is a fact of life that those who control the money wield authority over those who depend on it.

21.23 *The third major problem is a lack of a focal point*: there is no chief Airworthiness engineer, or senior engineers or operators, who are the focal point and directly accountable for ensuring Airworthiness regulatory compliance in the Operating domains.

21.24 *The fourth major problem is that DE&S faces the wrong way*: DE&S Support organisations such as IPTs do not face and serve those who are in fact responsible for Airworthiness, namely the Operators, but are inclined rather to face towards those that hold the financial purse-strings. For instance, IPTs negotiate maintenance contractual arrangements with approved organisations on behalf of the staff in the Commands who have the money to pay for the service, rather than for the Duty Holders at the Operating bases who use the equipment and who have a duty of care to their people.

21.25 *The fifth major problem is the apparent schism in the consideration of airworthiness*. The DE&S focus is, quite logically, very much on the airworthiness of equipment. The first Nimrod Safety Case was explicitly an 'Equipment' Safety Case, aimed at ensuring that the equipment presented to the Operators was airworthy. The minutes of the Platform Safety Case Meetings focus very much on this aspect. The RAF, on the other hand, has a long established and comprehensive system of ensuring that its aircrew operate an aircraft safely and within defined limits (the key element of operational airworthiness). As an example, each year the majority of aircrew are subject to a STANEVAL examination of their practical skills and theoretical knowledge. However, what is missing to date is an all-encompassing system that acknowledges the inextricable links between the many facets that contribute to Airworthiness. The best people to organise that system are

[27] Airworthiness, JSP553 definition: *"The ability of an aircraft or other airborne equipment or system to operate without significant hazard to aircrew, ground crew, passengers (where relevant) or to the general public over which such airborne systems are flown."*

those who are most directly affected by the implications of system failure: the Operators. Nonetheless, if the Operators are to assume this responsibility, they must also be able to exert due influence on the funding used to support their aircraft.

21.26 *The sixth major problem is that the DE&S is introspective and self-regarding to a degree*: DE&S organisations which have Airworthiness and Safety roles are inclined to serve their own needs, based on what they perceive to be their own accountability as (self-appointed) Duty Holders. Operating authorities are increasingly regarded as no more than an incidental part of the overall process. Authority as to the operation of platforms properly lies with those charged with operating them on a daily basis. Operators are the true Duty Holders. They own the risks. They suffer the consequences. Support organisations are there to support Operators, not *vice-versa*.

21.27 The net result of all of the above is confusion and distortion in the provision of support services and the potential jeopardising of the management of Airworthiness. The simple aim is the safe maintenance and operation of equipment. The *raison d'etre* of DE&S IPTs is supporting those who carry this out at the Units. A fundamental shift in focus is required to ensure the needs of the AOAs and Duty Holders are properly met by the IPTs in DE&S. Such a construct would require a switch in the direction faced by the Support organisations towards the Operators who are the Duty Holders. This poses a significant challenge to the current culture, behaviour and remit of DE&S.

21.28 In summary, therefore, the current position is manifestly unsatisfactory. There is no clearly recognisable Duty Holder structure within which those that hold responsibility understand their responsibilities and the risks that they hold. Those who are accountable do not necessarily have the authority they need properly to exercise their duties and to mitigate the risks that they own. Support organisations are not actually facing the Duty Holders at Unit level, who are actually responsible for the safe operation and maintenance of the equipment in question and the lives of their people.

Identity of Duty Holders

21.29 It is self-evident that the Operators are the proper Duty Holders with respect to the safe operation of the military equipment in question.

21.30 Although the Secretary of State owes the overall legal duty of care, useful guidance as to the identity of Duty Holders, and the nature of their duties, is to be found in relevant Health & Safety statutory provisions, such as the Health & Safety at Work Act 1974 and the COMAH Regulations.

Health & Safety at Work Act

21.31 The Health & Safety at Work Act 1974[28] (H&SWA) lays down duties which employers owe to employees. Section 2 provides:

> *"2. (1) It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his employees.*

21.32 Sub-section 2(2) goes on to articulate the nature and scope of the general duty:

> *"(2) Without prejudice to the generality of an employer's duty under the preceding subsection, the matters to which that duty extends include in particular*
> *(A) the provision and maintenance of plant and systems of work that are, so far as is reasonably practicable, safe and without risks to health;*
> *(B) arrangements for ensuring, so far as is reasonably practicable, safety and absence of risks to health in connection with the use, handling, storage and transport of articles and substances;*

[28] The Health & Safety at Work Act 1974 applies to the MOD as to any other employer.

(C) the provision of such information, instruction, training and supervision as is necessary to ensure, so far as is reasonably practicable, the health and safety at work of his employees;
(D) so far as is reasonably practicable as regards any place of work under the employer's control, the maintenance of it in a condition that is safe and without risks to health and the provision and maintenance of means of access to and egress from it that are safe and without such risks;
(E) the provision and maintenance of a working environment for his employees that is, so far as is reasonably practicable, safe, without risks to health, and adequate as regards facilities and arrangements for their welfare at work.

21.33 Sub-section 2(3) of H&SWA imposes a duty on employers:

"(3).....to prepare and as often as may be appropriate revise a written statement of his general policy with respect to the health and safety at work of his employees and the organisation and arrangements for the time being in force for carrying out that policy, and to bring the statement and any revision of it to the notice of all of his employees."

21.34 The standard of care which the H&SWA requires is, therefore, to ensure health and safety *"so far as is reasonably practicable"* (SFAIRP). The Health & Safety Executive regard SFAIRP as the same test as the duty to reduce risks to *"as low as reasonably practical"* (ALARP).

COMAH Regulations

21.35 The Control of Major Accident Hazards Regulations 1999 (COMAH Regulations)[29] impose statutory duties on operators with regard to *"major accidents"*. An *"operator"* is defined by the COMAH Regulations as *"a person who is in control of the operation of an establishment or installation"*.[30] For the purpose of the COMAH Regulations, the reference to *"control"* by a person means *"control in the course of a trade or business or other undertaking carried on by him"*.[31] In Airworthiness, *"control"* bears its ordinary meaning.

21.36 The COMAH Regulations define *"major accidents"* as *"an occurrence (including in particular, a major emission, fire or explosion) resulting from uncontrolled developments in the course of the operation of any establishment and leading to serious danger to human health or the environment, immediate or delayed, inside or outside the establishment, and involving one or more dangerous substances"*.[32] Paragraph 4 imposes a general duty on every operator to *"take all measures necessary to prevent major accidents and limit their consequences to persons and the environment."* Paragraph 5 imposes a duty on operators to prepare a *"major accident prevention policy document"* which is designed *"to guarantee a high level of protection for persons and the environment by appropriate means, structures and management systems"* and must demonstrate the operator has a *"safety management system"* which takes account of the following principles:

"2. The major accident prevention policy should be established in writing and should include the operator's overall aims and principles of action with respect to the control of major accident hazards.
3. The safety management system should include the part of the general management system which includes the organisational structure, responsibilities, practices, procedures, processes and resources for determining and implementing the major accident prevention policy."[33]

29 The Control of Major Accident Hazards Regulations 1999 (SI 1999 No. 743).
30 COMAH Regulations, paragraph 2(2).
31 Ibid.
32 Ibid.
33 COMAH Regulations, Schedule 2.

21.37 Paragraph 6 requires the operator to notify the *"competent authority"* of relevant information about himself and the operation. Paragraphs 7 and 8 require the operator to send to the *"competent authority"* a *"safety report"* of relevant information about himself and the operation which is regularly updated:

> ***"1.** demonstrating that a major accident prevention policy and a safety management system for implementing it have been put into effect in accordance with the information set out in Schedule 2;*
> ***2.** demonstrating that major accident hazards have been identified and that the necessary measures have been taken to prevent such accidents and to limit their consequences for persons and the environment;*
> ***3.** demonstrating that adequate safety and reliability have been incorporated into the - (a) design and construction, and (b) operation and maintenance, of any installation and equipment and infrastructure connected with its operation which are linked to major accident hazards within the establishment;*
> ***4.** demonstrating that on-site emergency plans have been drawn up and supplying information to enable the off-site plan to be drawn up in order to take the necessary measures in the event of a major accident;*
> ***5.** providing sufficient information to the competent authority to enable decisions to be made in terms of the siting of new activities or developments around establishments."*

21.38 Paragraphs 9 and 10 require the operator to send to the competent authority an *"on-site emergency plan"* and an *"off-site emergency plan"*, which are to be regularly reviewed and updated pursuant to paragraph 11 and implemented without delay pursuant to paragraph 12.

Objective

21.39 There is a need clearly to identify, and mark out, the senior Duty Holders that have both the authority and the legal responsibility, with respect to the operation of military equipment. It is the Operators who bear the immediate responsibility for ensuring: (a) the safe operation of the equipment; (b) the safety of (their) personnel operating or using the equipment; and (c) the safety of the tasks which such personnel are required to undertake using the equipment. Such immediate duties do not lie with those who supply or support the equipment. By reason of their legal duty, Operators as Duty Holders are responsible for the management and mitigation of risks and hazards arising from the operation of the platform. By contrast, although senior personnel in the Support domain have Airworthiness responsibilities (as detailed in their Letters of Delegation), they are not themselves Duty Holders, but are (merely) responsible for providing safe equipment and support to the Duty Holders in the Operating domain. Duty Holders are required, in general, to work within the parameters set by the RTS for their platform. Duty Holders may, however, go beyond the RTS where the circumstances require them to do so.

21.40 The following Recommendations B are intended to establish primary Duty Holders and to ensure the alignment of: (a) responsibility; (b) accountability; and (c) budgetary power and place them in the same Duty Holder hands, such that three, key, senior personnel in each AOA are clearly identified, and marked out, as exercising (on behalf of the Secretary of State) the legal duty of care for the safe operation of equipment in their domain and the concomitant duties to their people and the wider public who might be affected by their operations to ensure risks are reduced to ALARP, and that they have the financial resources, logistical support and specialist advice to be able properly to discharge their responsibilities.

21.41 The objective is for the MOD to establish a clear Duty Holder chain on senior Operators who bear legal responsibilities for the safe and airworthy operation of platforms, and establish senior posts to lead proper engineering and flight safety self-regulation.

Recommendations B

21.42 In order to achieve this objective, I make the following Recommendations:

<u>Recommendation 21.B.1</u>: The MOD shall clearly identify the three Duty Holders in each Air domain as follows:

- *Top Level:* The single Service Chiefs (CNS,[34] CGS,[35] and CAS) shall be appointed the senior (corporate) Duty Holders for the respective aircraft and personnel within their domain.
- *AOA Level:* The heads of the AOAs (the three AOCs for the RAF) shall be appointed the (operational) Duty Holders for their respective personnel and platforms who are responsible for the safe employment of the equipment usage.
- *Unit Level:* Unit Commanders shall be appointed the (delivery) Duty Holders with operating Airworthiness responsibility for personnel and platforms under their command, and who will report directly to their Aircraft Operating Authority for all 'Duty Holder' matters.

<u>Recommendation 21.B.2</u>: Each Service shall appoint (a) a Chief Air Engineer to head the self-regulation of Technical Airworthiness in each of the operating authorities and (b) a Senior Operator to head the self-regulation of Operational Airworthiness and Flight Safety.

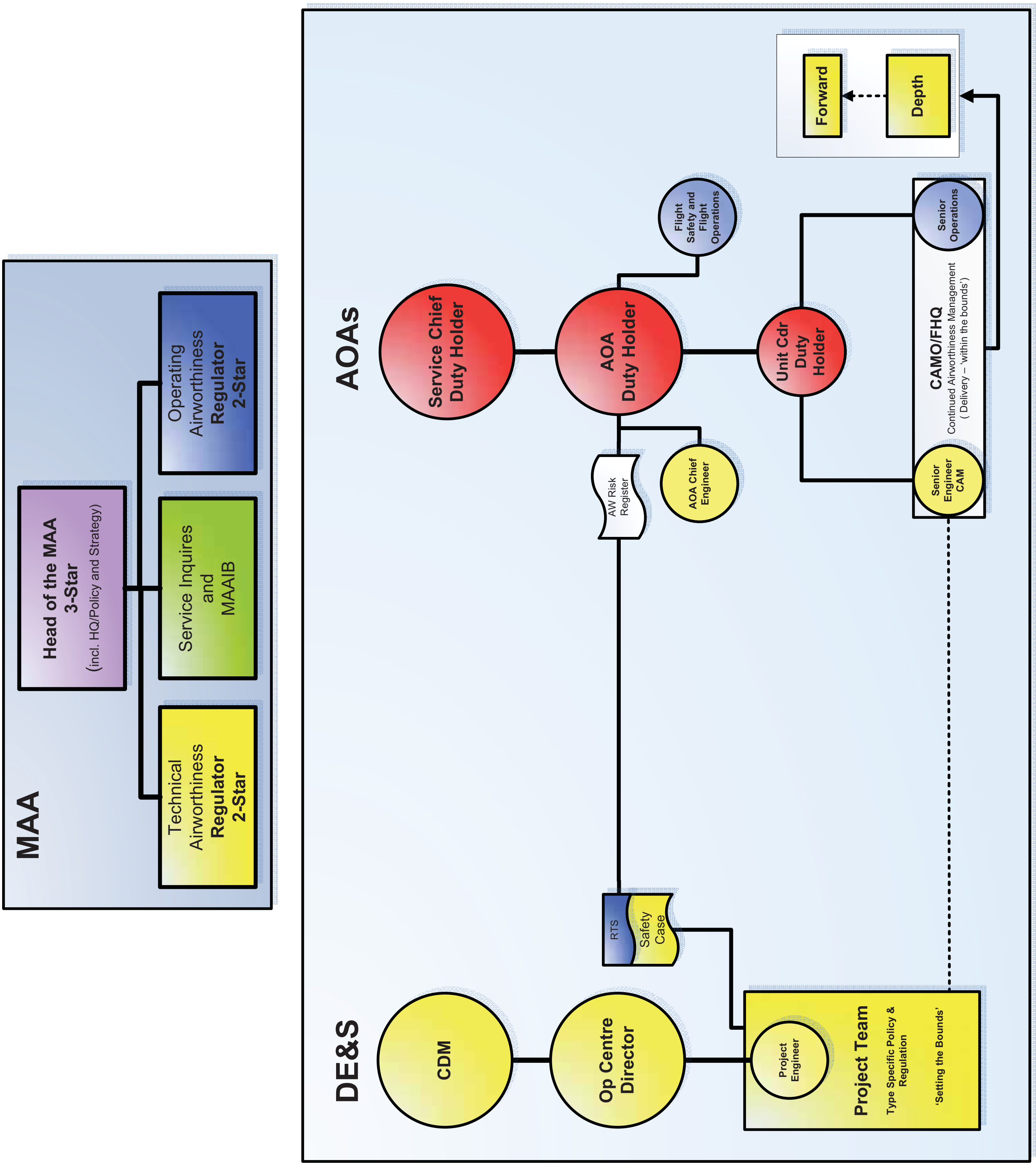
21.43 For the avoidance of doubt, for Recommendation 21.B.2: As regards (a), the Duty Holder, as the senior operator, will manage operational regulation with his Command and Group Staff, but will necessarily rely on a Chief Air Engineer to govern the self-regulation activity in the Engineering domain, including standards and practices and strategic engineering and support issues that cross platforms. Further, there will be no requirement for the Chief Air Engineer appointed by the AOA to be an Airworthiness Authority as this latter function will be undertaken by the Senior Engineers or their equivalents at Unit/base level, who will be responsible to their duty holder Unit/Base Commanders, and to the Regulator heading the MAA for Airworthiness compliance. Senior Engineers would be given a LOA from the Duty Holder. As regards (b), the Flight Operations/Flight Safety Service Lead will be equivalent to the Chief Air Engineer and will be responsible to the AOA for ensuring the self-regulation of the Operational Airworthiness within the AOA in addition to being the lead for the management/delivery/inspectorate of Flight Safety.

<u>Recommendation 21.B.3</u>: Those in Duty Holder posts (Service Chief, AOA and Unit Commanders) shall have Airworthiness responsibility and authority issued by decree by the MAA. When personnel and/or aircraft are deployed on Operations in Theatre, Service Chief, AOA and Unit Commanders shall retain their Duty Holder responsibilities (only) for those Airworthiness issues which remain under their control.

21.44 For the avoidance of doubt, for Recommendation 21.B.3: (1) When Unit Commanders' personnel and/or aircraft are deployed on Operations in Theatre, such Unit Commanders shall retain their particular Duty Holder responsibilities, *e.g.*: (a) to ensure the aircraft are Airworthy to deploy; (b) to ensure the personnel being deployed are sufficiently competent and trained; and (c) for continued airworthiness management (CAMO function); (2) When personnel or aircraft are deployed, the Commander Joint Operations (CJO) and Theatre Commanders will not become designated Duty Holders, but will acquire a Duty of Care for the personnel and aircraft under their command for the time being similar to that of any other commander. Theatre Commanders will also acquire a responsibility for the time being for regulatory compliance exercised through their nominated deployed Operations and Engineering Specialists; (3) The MAA shall provide adequate guidance/direction on the Airworthiness aspects associated with Airworthiness decisions during Operations in Theatre, including setting the broad rules/requirements, e.g. regarding demonstration of having sought specialist In-Theatre Type Airworthiness advice. Such guidance must recognise that Operational Commanders may be required to make operational decisions at short notice in a highly dynamic and intense environment; and (4) The MAA shall also provide adequate guidance/policy on specific Airworthiness responsibilities where UK assets/personnel are commanded by Non-UK Operational Commanders.

[34] Chief of Naval Staff.

[35] Chief of General Staff.


MAA
Head of the MAA
3-Star
(incl. HQ/Policy and Strategy)
Technical Airworthiness Regulator 2-Star
Service Inquires and MAAIB
Operating Airworthiness Regulator 2-Star
DE&S
CDM
Op Centre Director
Project Engineer
Project Team
Type Specific Policy & Regulation
'Setting the Bounds'
RTS
Safety Case
AW Risk Register
AOAs
Service Chief Duty Holder
AOA Duty Holder
AOA Chief Engineer
Flight Safety and Flight Operations
Unit Cdr Duty Holder
CAMO/FHQ
Continued Airworthiness Management
(Delivery – 'within the bounds')
Senior Engineer CAM
Senior Operations
Forward
Depth

Commentary on the MAA/Duty Holder Organogram

1. **MAA – The Regulator:** The MAA is the independent Airworthiness Authority and Regulator for Defence Aviation drawing together all the main regulatory functions: RTSA, Technical Airworthiness, Operating Airworthiness and Airspace/Air Traffic Management Regulators. It will be led at a very senior level by a 3-Star officer supported by functional specialist Regulators who will be of 2-Star rank. The MAA will provide the Defence Aviation environment with non-type specific Airworthiness policy and regulations, independent regulation, certification and approvals. The MAA will provide assurance by undertaking compliance and evidence-based audits to validate AOA and DE&S assurances on Airworthiness. The RTSA within the MAA will comprise staff from all three Services, with RTS sign-off powers maintained at 2-Star level for all Defence Aviation.

2. **The 'Duty Holder' chain – The 'Compliance' aspect of the Defence Organisation:-** Airworthiness Duty Holders will be those occupying the Service Chief, AOA and Unit Commander posts. These are the key senior operating commanders that control the conditions of work in terms of equipment, resources and task. The Duty Holder's authority and responsibility for Airworthiness will be provided by decree by the MAA. Whilst senior commanders responsible for Theatre Operations (*e.g.* CJO) will have a duty of care for the people under their command, Airworthiness responsibility for the deployed platforms will remain with the AOA duty holders as they will continue to own the platform risk register and the CAMOs, with the direct support of the IPTs and the RTSA. The Unit Commander will retain responsibility for maintaining the Airworthiness of the aircraft which he will exercise through the CAM/CAMO, and through the operations and engineering specialists that are deployed. Airworthiness responsibility will remain with the parent unit even though the aircraft are under the tasking authority of another commander as the CAMO function will not deploy. It will be for the AOA Duty holder to ensure the aircraft are airworthy for their deployed role, for the Unit Commander to ensure the aircraft are airworthy to deploy, that they have the necessary support to keep them airworthy in theatre and that the personnel deploying are sufficiently competent and trained to keep the aircraft airworthy. Theatre Commanders will have a duty of care for their people and a responsibility for regulatory compliance exercised through the deployed Operations and Engineering specialists. Responsibility, budget and authority will reside together with the AOA Duty Holders who finance In-Service Support. AOA Duty Holders need to attend Decision Conferences (Joint Capability Boards) for new platforms and for modification to existing platforms to ensure the equipment being procured or modified on their behalf is acceptable in Airworthiness terms from a Duty Holder's perspective. The AOA Duty Holders will call upon the support of a single Service 2-Star/1-Star Flight Safety/Flight Operations Lead and Chief Engineer for the end-to-end governance of their Operational and Technical Arms respectively in order to assure Airworthiness regulatory compliance and safe operation. The AOAs must establish and manage a single Airworthiness Risk Register for the people and platforms in their AOR, seeking appropriate input from the PTs, their Chief Engineer, their Flight Safety/Flight Ops Lead and the Unit Duty Holders to ensure all of the Defence lines of development that contribute to Airworthiness are considered. So that the Unit Commander Duty Holders can fulfil their responsibilities they will give 'authority' for maintaining Airworthiness and for making limited Airworthiness decisions for individual platforms, to their Senior Operator (invariably the aircraft squadron commander) and their Senior Engineer. There will be just one Senior Engineer per unit, referred to as the OC Engineering Wing or Principle Engineer. Current OC Depth posts will become contract management posts in the CAMO working for the AOA/Unit Commander. The Senior Engineer at a Unit will be the Continued Air Worthiness Manager (CAM) with responsibility for the CAMO. The CAMO will task Forward and Depth as necessary to ensure regulatory compliance, utilising the 'approved data' provided by the IPT to deliver capability. Where there is a requirement to operate outside the approved data, the Senior Engineer will have the authority to approve individual aircraft for flight, defer corrective maintenance and accept capability limitations in line with current practice. Appointed engineering officers at the Unit will exercise the Senior Engineer's authority through the existing 'authority' system that is already in use on Army/RN/RAF Units. The CAMO will be responsible for requesting 'solutions' from the IPT where the approved data is insufficient, although the decision on whether to fly an individual platform will remain with the Senor Engineer. The CAMOs will comprise those staff needed to undertake the management of continued Airworthiness. Personnel will come from existing ILOC/FHQ and Industry staffs as well as the reallocation of IPT posts currently involved in the delivery aspects of Airworthiness to become part of the AOA's CAMO. The CAMO/HQ will subsume all type specific Role Office Functions and responsibilities from Group staffs in order to serve the needs of the Unit Duty Holder. A Depth Contract Manager within the CAMO (also employed by the AOA) will be responsible for ensuring the Depth output and delivery met Forward's requirements within the contract bounds provided by the PT. Financial resources will be programmed by the AOA Duty Holder, with in-year Management devolved to DE&S to manage on their behalf to meet the Unit Commander's Duty Holder and capability requirements.

3. **DE&S – The Type-Specific 'Policy and Regulation' aspect of the Defence Organisation:–** DE&S will be a service provider to the Duty Holders (*i.e.* an approved organisation). Within DE&S, CDM (as the Chief Executive equivalent) will retain overall corporate responsibility for the output and for Airworthiness of the equipment his IPTs procure and support, but will not be a Duty Holder or have Airworthiness authority. Each 2-Star Director in the Air Operating Centres will need to be an air specialist and be given Airworthiness Authority by the MAA; the 2-Star Air Operating Centre Directors will be the most senior Airworthiness positions within DE&S. The 2-Star Directors will appoint their own Project Engineers, give them specific Airworthiness responsibilities for their platform and the authority to make Airworthiness decisions. The IPT will be responsible for setting the technical/regulatory/commercial boundaries within which the Duty Holder then operates the platform. The IPT

will also maintain the Safety Case and make RTS recommendations to the RTSA for endorsement/sign-off. Whilst the RTS and the Safety Case will be owned by the RTSA, a copy would be 'presented' to the AOA Duty Holder, together with any associated technical/operational risks. The PT will be responsible to the Duty Holders for ensuring that they were made aware of emerging Airworthiness risks and issues concerning the operation of a platform.

C. Proper training in Airworthiness Management and Regulatory skills

Current position

21.45 Responsibility for Airworthiness of Equipment is delegated from the Chief of Defence Material (CDM), through the Chief Operating Officer (COO) to three 2-Star Directors in DE&S responsible for Combat Air, Air Support and Helicopters. These individuals in turn delegate their platform specific responsibilities to their IPTLs or, in some cases, Project Engineers (PE). In the AOAs, Airworthiness responsibilities are assumed on appointment with authority for each rank clearly defined in Joint Airworthiness Publications (JAPs). The majority of junior personnel are individually assessed to determine their Airworthiness competence. Engineering officers are authorised to defer corrective maintenance and to authorise Capability limitations. However, increasingly, Industry (Depth) organisations will not recognise the RAF Engineering officer's decisions unless they are supported by approved data as they are deemed by Industry (Depth) not to have the authority to make such decisions.

21.46 Airworthiness in the Equipment and Operating authorities is governed by self-regulation, with Quality Assurance the main tool used to provide assurance that maintenance support is compliant. STANEVAL is the principal means by which assurance is provided in respect of aircrew regulatory and procedural compliance.

21.47 IPTs are funded through Front Line Commands to provide support to the Forward domain who operate the aircraft. IPTs undertake Airworthiness management and act as the Airworthiness authority for the platform. In this respect, each IPT is charged with ensuring continued Airworthiness for its platform. To undertake this role, each IPT has to have a range of specialists and Service experts. In addition, IPTs sub-contract Airworthiness functions to an Industry Design Authority (such as BAE Systems) and, increasingly contract specialist organisations (such as QinetiQ) to undertake independent assessment or to provide specialist advice on a wide range of matters including Airworthiness.

21.48 Candidates for senior Airworthiness appointments (*i.e.* those who are granted LOD) are currently reviewed by the Military Aircraft Release (MAR) which looks at past experience and competencies before recommending that the respective 2-Star Director issues an Airworthiness delegation. For those in Airworthiness management positions, training is provided in the form of an 'Airworthiness Awareness' course, with professional and type-specific training providing the foundation for those in the Forward domain.

Problems with the current position

21.49 There is a lack of regulatory training. Personnel in Airworthiness appointments do not undergo Airworthiness regulatory training; nor are they taught acceptable means of compliance for their particular responsibilities; nor are they examined or re-certified to ensure they remain current.

21.50 The process of accreditation is slow and unsatisfactory. The process for assessing an individual's competencies to undertake the role of an IPTL can take several months, with little or no value-added by the MAR which considers past experience and assesses its application against the competencies required for a particular appointment.

21.51 Professional status is not axiomatic. Under the current construct, engineers in DE&S and the AOAs who bear Airworthiness responsibilities are not required to hold professional status or to be authorised by the relevant Regulator. This is unsatisfactory and, in any event, makes their authority in, or with, an approval-based organisation untenable. This is a problem that will be compounded as the Services begin to operate aircraft which have to be maintained and operated by an approved maintenance organisation.

21.52 The current position in the Air domain is in stark contrast with the position in Nuclear Safety, where there is a clear chain of responsibility from the highest to the lowest level which does not simply follow the chain of command. This ensures that the number of delegations is kept to an absolute minimum and ensures the chain of responsibility is based on informed individual judgment and not merely bureaucracy. Each individual in the chain understands their responsibilities and with whom to raise issues. Each individual has a direct line into the DNSC if required.

21.53 The system needs to allow senior ranks to appoint and delegate Airworthiness responsibilities to sub-ordinates as they see fit given that: (a) they are best placed to assess an individual's suitability; and (b) they will remain accountable. Those with Airworthiness responsibilities should then undergo Airworthiness training, and be examined on their regulatory responsibilities to ensure that they know what the Regulator expects of them and that they understand their personal accountability. The Regulatory role should be to check that due process has been followed in making an appointment, including any regulatory training where necessary. What is lacking is an enterprise-wide framework to determine which appointments attract specific training and examination on Airworthiness regulation, to be sponsored by the Regulator, to ensure that the complete regulatory process is adhered to.

21.54 'Strategic' organisational changes in the acquisition domain over the past decade and a succession of recent manpower reduction initiatives have reduced the number of Service personal employed on the IPTs that support in-service platforms. Further, DE&S' manning strategy has failed to ensure that Service personnel posted to the IPTs are experts on type. As a result of this relentless downward pressure on the number of Service personnel in Acquisition and skills fade, IPTs no longer have the necessary skills or capacity either to undertake detailed technical analysis or to act as 'intelligent customers' on all occasions. The IPTs need people with practical experience of the airframe and the operational context; these are skill sets to which civilian staff are rarely exposed.

21.55 As a result of cuts in Service and civilian manpower, IPTs have increasingly delegated much of what has been asked of them to their Design Authority (such as BAE Systems) and to independent organisations (such as QinetiQ). This process of sub-contracting out by IPTs of large tracts of analysis, decision-making and thinking has had an increasingly deleterious effect on IPTs and their ability to do their job in the short, medium and long term. First, it has led to a significant reduction in the quantity and quality of active in-house hazard management and analysis of Airworthiness issues and risks. Second, it has led to an increase in disproportionately large, superficial, flawed paper analysis/assessment reports produced by Industry at enormous cost. Third, it has led to Operators, who can be expected to have a far better knowledge of the operation, maintenance idiosyncrasies *etc.* of the platform than Industry, have being increasingly marginalised in the hazard management and analysis process. Fourth, it has had a corrosive effect on the ability of IPTs to think for themselves and will increasingly do so as skills in this crucial area recede in the medium to long term.

21.56 The fact is that, in the past few years, IPTs have increasingly lacked the ability, capacity and, frankly inclination, to provide expert analysis and guidance, to pro-actively manage Airworthiness issues, consider trends and support issues, and have been forced instead into essentially: (a) reactive management of emerging issues; and/or (b) parcelling out work to Industry which would, in fact, be done 'better, faster and cheaper' in-house if the IPTs had appropriate manpower and the confidence to do so.

21.57 The net result is that IPTs have been hampered in the level of support they can provide to the Front Line users; and Units/Bases have seen deterioration in the quality of support provided by IPTs.

21.58 Self-regulation across the Services has largely comprised Quality Assurance Audits of the Forward maintenance organisations and STANEVAL assessments of the aircrew; although the aircrew STANEVAL assessments are comparable to those undertaken by the CAA of civilian flight decks, the other audits fall short of the CAA's Airworthiness regulatory compliance checks. Although there is an audit system within the Air Command AOA[36] which looks across all platforms at engineering policy, standards, practices and Quality Assurance, there is, surprisingly, no assurance system for technical Airworthiness. Airworthiness reviews associated

[36] Which works for COS Support.

with the operation of the aircraft are undertaken by STANEVAL who audit flying activity at the Units; their reports are copied to the Central Flying School. They do not, however, provide the AOAs with an operational assurance system.

21.59 By contrast, the CAA examine Airworthiness regulatory compliance by employing experienced and certified surveyors who look at the maintenance standards on the aircraft in question; and, in parallel, aircrew assessors fly with the commercial operator aircrew. In the Nuclear Safety Organisation, the 'inspectors' have experience of the roles which they are inspecting, have themselves been fully trained and deemed competent and assess the organisation and individual on compliance against the regulations.

21.60 In terms of best practice within the MOD, the Army have the lead, undertaking physical audits of Army Air Corps helicopters annually, an initiative that has recently been proposed for the RAF AOAs as part of its Quality Assurance processes.

Objective

21.61 The aim of the following Recommendations C is to enable the Services to build a cohort of Airworthiness appointees in both the Equipment and Operating authorities who will be suitably qualified and experienced to be able to ensure complete Airworthiness regulatory compliance across the domains. These Airworthiness appointees will need to be trained and examined on Airworthiness regulation and acceptable means of compliance, with Airworthiness responsibilities cascaded from senior to junior levels using Letters of Airworthiness Authority, without unnecessary interference from the Regulator.

21.62 Ownership of Airworthiness must be taken back in-house and no longer outsourced to Industry.

Recommendations C

21.63 In order to achieve this objective, I make the following Recommendations:

Recommendation 21.C.1: All holders of engineering Airworthiness posts (at SO2 equivalent and above) shall be required: (a) to have achieved professional status as Chartered Engineers; and (b) to have acquired appropriate experience in the Forward air domain.

Recommendation 21.C.2: All personnel with Airworthiness responsibilities shall be required to undergo formal Airworthiness regulatory training, examination and periodic reassessment.

21.64 For the avoidance of doubt, for Recommendation 21.C.2: (1) Training in the Regulation of Airworthiness should seek to ensure all personnel are fully conversant with: (a) Airworthiness Regulation generally; and (b) their specific regulatory responsibilities and compliance requirements; (2) The Regulator will need to sponsor and approve a suite of suitable courses in the Regulation of Airworthiness which include formal training and assessment in Airworthiness regulation and which are tailored appropriately for the various roles and rank levels; and (3) It is intended that this scheme should be comparable to the Nuclear Safety management structure whereby all personnel about to be employed in responsible positions receive formal and examined training followed by a period of further training and supervision before being signed-off as competent; there is then periodic (at least annual) re-assessment of competence by the Nuclear Regulator.

Recommendation 21.C.3: The Chief Engineer and Flight Safety/Operations specialists supporting the Duty Holders at each level shall be clearly identified and hold senior rank.

<u>Recommendation 21.C.4</u>: There shall be a review of manpower in the IPTs to ensure that they each have sufficient numbers of suitably skilled and qualified Service and civilian manpower, to undertake the tasks demanded of them without having to resort to the practice of routinely sub-contracting analysis and decision-making because of shortfalls in personnel and relevant experience.

21.65 For the avoidance of doubt, for Recommendation 21.C.4: (1) Gaps, skills-shortages and manpower-shortages must be rectified as soon as possible. The systemic practice of 'gapping' and 'dual-hatting' must stop; (2) IPTs need substantially and quickly to reduce their reliance on Industry and 'independent' outsourcing. In order to improve the quality and validity of the support given by IPTs to the Duty Holders on Airworthiness and other key issues, IPTs must undertake far more of the required dynamic analysis and decision-making themselves in-house, thereby re-invigorating their ability to understand, own and manage Airworthiness issues; (3) IPTLs need to be able to recruit appropriately experienced Service personnel from the Forward domain (as they once did) in order to grow the required experience needed by the IPTs; and (4) The acquisition domain needs to be able to provide a tailored and meaningful career structure for Officers, SNCOs[37] and Civil Servants to help retention, 'grow' experience and develop skill levels relevant to the acquisition domain.

<u>Recommendation 21.C.5</u>: The Regulator's role in the appointment of senior Airworthiness managers (*i.e.* IPTLs and PEs) shall be limited to ensuring compliance with the appointment/assessment process.

21.66 For the avoidance of doubt, for Recommendation 21.C.5: (1) The MAA shall grant to the respective 2-Star Directors in DE&S authority to appoint senior Airworthiness managers and issue Letters of Authority to them as they see fit giving them Airworthiness responsibilities; and (2) This Recommendation is based on the assumption that: (a) the 2-Star Directors will be themselves be Air domain engineering specialists; and (b) candidates will be suitably trained and examined in Airworthiness regulation and properly assessed and interviewed before appointment.

D. Proper System of Mandatory Reporting and Analysis

Current position

21.67 IPTs are mandated to collate and analyse data for continuing Airworthiness management purposes.[38] The methodology, quality, and depth of data collection and analysis across the air domain is, however, variable and inconsistent and, in some cases, inadequate. A number of IPTs have chosen to outsource this work, or significant elements of it, to industry 'partners'. Divergent solutions have resulted with significantly different levels of analysis undertaken.

21.68 A range of Mandatory Occurrence Reporting (MOR) systems is used across the Air domain to collect, in an 'open and honest manner', data on errors/issues/incidents. These tools are, however, not part of the regulatory framework and are, therefore, not monitored by the Airworthiness Regulator as they would be in the civil sector by the CAA/EASA.

21.69 Occurrence reports are mandated by DARS in its Flight Safety capacity. Although the Regulator for Flight Operations provides a degree of analysis of this information, the Airworthiness Regulator does not receive nor consider the reports either to highlight relevant Airworthiness issues to other operators, as the CAA would do for example, nor provide direction on specific issues or amend Airworthiness policy.

Maintenance Error Management Systems (MEMS)

21.70 There have been recent praiseworthy advances in pre-emptive Human Factors (HF) reporting using Human Factors Maintenance Error Management Systems ((M)EMS) due in large measure to the initiative of Wing

[37] Senior Non-Commissioned Officers.

[38] JSP553, Chapter 2.

Commander Jeanne Paul (XO Programmes, COS SPP) and the support of Air Commodore Julian Young (ACOS A4). The great advantage of HF M(EMS) is that it encourages a pro-active reporting and trend analysis culture. Using the 'Iceberg Analogy', HF (M)EMS focuses attention on the 'below the waterline' near-misses, which, if openly and honestly reported in sufficient numbers, provide valuable information and visibility of potential issues *before* an incident or accident occurs. This changes fundamentally the approach of hazard management from reactive to pro-active. (See Heinrich's Triangle, CHAPTER 18).

21.71 Following a rise in the RAF's HF-related maintenance incidents in 2007, early in 2008 Jeanne Paul analysed the last two years' Flight Safety Investigations (RAF F765Bs) in accordance with current Error Management theory.[39] Her review showed three things. First, an increase in repeat incidents, indicating that the root causes of the maintenance errors were not being addressed effectively in the first place. Second, the RAF had particular HF-related maintenance issues which stemmed from motivation-based, 'can do' cultural errors in the maintenance arena. Third, these problems resulted in part from the cumulative effect of recent significant 'change initiatives' (some of which were undertaken to meet Defence efficiency targets) compounded by an increase in operational tempo. Jeanne Paul then attended a Confidential Human Incident Reporting Programme (CHIRP) meeting where the civil community share best practice, at which she learnt of the work of Baines Simmons Ltd. (Baines Simmons) who have proven expertise in project-managing HF (M) EMS in the civil sphere and had recently had successfully helped the Army introduce HF (M)EMS in a military support environment at the Apache Helicopter Depth Support Unit at Wattisham. Jeanne Paul briefed Air Commodore Young and proposed the introduction and implementation of an RAF-wide HF (M)EMS using Baines Simmons. Julian Young supported the proposal, lobbied for the funding necessary and sponsored the Business Case for a four-year contract to introduce HF (M)EMS in the Forward environment on 12 of the RAF's Main Operating Bases (MOBs). Between April and October 2008, Jeanne Paul visited the majority of the MOBs and gained the support of all the Officer Commanding Forward Support Wings (OC FSWs – the senior Engineer Officer at an MOB). DE&S committed to supporting Air Command by ensuring that the PTs would be able to act intelligently on HF (M)EMS data as it flowed from Forward into the Support environment. A paper on HF (M)EMS implementation was submitted to HQ Air Command's 2-star Command Delivery Group in January 2009 and was endorsed. The Air Command HF (M)EMS programme is set to roll out in four phases over 42 months:

(1) *Phase 1 – Understanding*: assessing the current position using Error Management Diagnostic (EMD) and Safety Culture Surveys at the MOBs.

(2) *Phase 2 – Enabling*: developing 'Just Culture' policy, Fatigue Management policy, Shift/Task Handover defences, Roles and Responsibilities, Training Needs Analysis on MOBs.[40]

(3) *Phase 3 – Reporting*: training Maintenance Error Investigators (MEI) as part of a three-month trial for the civil industry standard investigative/reporting tool, Maintenance Error Decision Aid (MEDA), with the aim of training approximately 15-20 MEIs on each MOB.

(4) *Phase 4 – Learning*: continue skills and MEI training, quality assurance and sharing of best practice with industry.

21.72 The (M)EMS initiative is already paying substantial dividends in the RAF: to date five investigations have been carried out using the new techniques and there is a radical improvement in both (a) the quality of investigation, and (b) the effectiveness of the interventions and solutions recommended.

21.73 In early 2009, DE&S asked Jeanne Paul to brief both Joint Helicopter Command and Fleet (RN) about the Air Command project; both Commands have expressed significant interest in adopting HF (M)EMS, tailored to their own specific operating environments. This has led to a proposal that Air Command should take the lead for implementing HF (M)EMS across all four Top Level Budgets (TLBs) (Air Command, Land Command, Fleet and DE&S) to ensure consistency of approach and common processes across the Joint Defence environment. Funding to achieve this aim has, however, not been identified, and is expected to be an issue.

[39] Reason, J and Hobbs, A. (2003). MANAGING MAINTENANCE ERROR A Practical Guide. Aldershot: Ashgate.

[40] Baines Simmons Ltd Flowchart Analysis of Investigation Results (FAIR) System developed in April 2009, and adapted by Air Commodore Young, specifically to support the RAF HF (M)EMS introduction.

21.74 It should be noted that the word 'maintenance' in HF (M)EMS is in brackets because, whilst the programme is aimed initially at engineers, the technique of Error Management has a much wider applicability than just engineering. This has been recognised with the advent of the Air Command HF (M)EMS programme and particularly with visibility of the new Just Culture policy. If the RAF's Air Command-led HF (M)EMS programme is successful, there is potential to expand Error Management across the RAF, operations and engineering environs , and then lose the (M). Beyond this, there is scope for a pan-Defence solution.

21.75 In my view, the (M)EMS initiative is a model of its kind, with huge potential benefits for the improvement of Airworthiness management across the whole of Defence. I make Recommendations regarding it below.

Shortcomings of current position

21.76 Whilst the collection of data to maintain the continued Airworthiness of the platform is required by JSP553, there are no clear regulatory requirements for the format, content and compliance criteria for IPTs in the management of maintenance data. Furthermore, IPTs are not required to demonstrate compliance to any Regulator. This 'free for all' has encouraged divergent solutions, including outsourcing, and standards across the IPTs (see above). Further, evidence suggests that several IPTs do not, in fact, undertake the required pro-active analysis of maintenance data. Of those who have outsourced the task, several IPTs are still unable to provide evidence of detailed maintenance data analysis having been undertaken.

21.77 There is no overall role for the current Airworthiness Regulator in policing or co-ordinating mandatory reporting. The recent 'Can do Safely' campaign initiated by Air Command in response to concerns on engineering standards and practices at the operating bases was not initiated or governed by the MAR, who did not have sight of the occurrence reports or the standard of the maintenance. Whilst Air Command is attempting to tackle the symptoms of the problem in Forward, the strategic issues concerning the contractual arrangements with Industry for several platforms have not been addressed by the current Regulator. A key problem is that the contracts that have been implemented in Depth now mean that aircraft are not 'reconditioned' when they undergo scheduled maintenance with a repair-to-fault strategy being adopted in its place. Further, there is no longer the maintenance policy or resources to undertake 'reconditioning' maintenance in the Forward domain with a cumulative deterioration in husbandry as a consequence. This situation would not have occurred if the Airworthiness Regulator: (a) surveyed aircraft and maintenance at the operating bases; (b) co-ordinated mandatory reporting; and (c) had the authority to mandate strategic change to support arrangements for MOD aircraft. Further, several of the reporting systems for each of the Services differ in format and intent and overlap, such that the potential benefits associated with a single Defence-wide system are not realised. There are also numerous bodies involved in assimilating and processing data received who cannot between them effect a coherent reporting system that stimulates and coordinates action from the appropriate agency. Although the revised occurrence reporting system is now common across the Services, there is still no single accountable action addressee. This means that key issues and trends could be missed if they are not picked up by the appropriate addressee.

21.78 As set out above, HF (M)EMS has been recently been embraced by Air Command. Already used extensively by Industry, and proven by the Army's Apache Force, it provides a comprehensive, high volume reporting system designed to pre-empt issues before they manifest themselves, and provides a 'voice for all' in the organisation. (M)EMS aims to makes senior managers accountable whilst also ensuring that they have sight of emerging issues before they become a serious problem. (M)EMS is an example of a laudable individual initiative that one would expect the Regulator to be driving, but has been left to the Service operating authorities to implement with potentially different levels of take-up across the Services.

21.79 DARS plays a major role in overseeing flight safety issues. This is, however, no single authority above to: (a) provide comprehensive analysis and direction on the whole spectrum of Airworthiness issues; (b) interface with the IPTs or the platform Risk Registers; (c) drive behind new Airworthiness and 'best practice' initiatives gleaned from the civil sector and industry (such as (M)EMS above); and (d) provide the overall coherent, measured and informed development of Airworthiness policy in response to reported incidents and trends pan-Defence which is required. With no single authority responsible for monitoring mandatory reporting, the current system relies on many action addressees identifying issues that fall within their area of responsibility with the real risk that issues are not adequately considered and that some risks may be missed.

21.80 In the civil model, all occurrence reporting is sent to the CAA which then distributes follow-up directives to action addressees across the operating and equipment authorities and considers issuing guidance or policy changes; this represents a logical and effective system.

21.81 Whilst Airworthiness is a sub-set of Safety, it requires specific and discrete management which can be diluted by the more general 'H&S' approach, leading to a confusion of lines of accountability for Airworthiness and Safety and an undermining of the process and technical needed to assure and ensure Airworthiness.

Objectives

21.82 In order to underpin the authority and effectiveness of an MAA, four key objectives relating to data collection and analysis need to be achieved:

(1) The IPTs need to be able to predict maintenance failings by having in place systems for effective data analysis to inform their support activity, maintenance policy and decision-making.

(2) The MAA needs to have a 'closed loop' which allows it to assess the effectiveness and consequence of its regulations. The MAA needs to be the higher authority for a mandatory reporting system which would provide it with feedback on the 'health' of military aircraft and their use, a part of the Regulator's oversight responsibility for Flight Safety. Such a system must cover the spectrum of mandatory reporting topics. The Operating Centre Directors and the AOAs will be the action addressees.

(3) There needs to be a fundamental change to the current reporting philosophy, not only to make the MAA the higher authority for mandatory reporting, but also to stimulate the cultural change that is needed to make the user community accountable to the MAA.

(4) The focus needs to move away from the reliance on merely 'logging' data and 'fields of text', to a form which stimulates analysis and pro-active management to prevent the manifestation of Airworthiness failings. The HF (M)EMS is but one example of methods which stimulate *action* in preference to inert text or more regulation.

(5) Whilst there has been undoubted and commendable initial support for RAF HF (M)EMS, it is important to ensure the initiative has the opportunity to realise its full potential for Defence.

Recommendations D

21.83 In order to achieve these objectives, I make the following Recommendations:

Recommendation 21.D.1: All Maintenance Data Analysis shall be regulated.

21.84 For the avoidance of doubt, for Recommendation 21.D.1: (1) The Regulator shall devise, define and prescribe standardised formats and contents for reporting and analysis and give direction on data management processes to enable IPTs to meet their obligations for Continuing Airworthiness management; (2) The Regulator shall consider whether, and if so where, such data changes may require contract amendment and require all contractors to deliver data outputs which are 'fit for purpose' and which facilitate the pro-active management of the equipment to ensure it remains demonstrably 'safe for operation'; and (3) Each IPT shall be required regularly to demonstrate to the Regulator that it is pro-actively managing the Airworthiness of its platform by analysing maintenance data.

Recommendation 21.D.2: The Regulator shall provide independent analysis of maintenance data.

21.85 For the avoidance of doubt, for Recommendation 22.D.2: (1) This is an additional role for the Regulator, but an important one, which might have may have had a bearing on, for example, the loss of Nimrod XV230, had such a system been in place; and (2) It will only be possible for the Regulator to provide independent analysis if a standard format is used to record data for all of the IPTs.

Recommendation 21.D.3: A pan-Defence reporting system shall be established as part of the regulatory framework, which shall include HF, MEMS and MOR, with the MAA acting as the higher authority for mandatory reporting and with the Operating Centre Directors and AOAs responsible for assimilation, analysis and for directing action.

21.86 For the avoidance of doubt, for Recommendation 21.D.3: (1) Given that the current reporting systems have evolved from differing organisations, driven by differing requirements, the Regulator will need: (a) to conduct a review to look at the coherence and relevance of the different systems and to ensure they achieve their intended aim; (b) to conduct a process of alignment to iron out inconsistencies across the three Services and to establish a more effective and coherent reporting system; and (c) to look across the areas of Airspace Management, Flight Operations and Airworthiness; and (2) Making the Regulator the higher authority for mandatory reporting will ensure that reports are sent to specific addressees for action (Operation Centre Directors and AOAs), providing the Regulator with essential oversight of Airworthiness trends and issues which may affect policy and regulation as a consequence, with the added benefit of independent assessment. As this will be a new function for the Regulator, appropriate resources will need to be found to enable the Regulator to carry it out.

Recommendation D.4: In order to ensure that HF (M)EMS has the opportunity to realise its full potential for Defence:

Recommendation 21.D.4.1: There shall be an adequately resourced single dedicated IPT created to implement a project of this scale across four different TLBs.

21.87 For the avoidance of doubt, for Recommendation 21.D.4.1: (1) The IPT will need specialist training in HF (M) EMS; (2) Continuity of these key posts is critical during the implementation programme; and (3) Without a dedicated team, the programme implementation is no longer manageable at SO1 level, particularly with the increased interest across the four TLBs.

Recommendation 21.D.4.2: There shall be a coherent Single Implementation Programme across all four TLBs.

21.88 For the avoidance of doubt, for Recommendation 21.D.4.2: (1) There are clear advantages of developing a single implementation programme which could accommodate the specific needs of each Service but yet which maintains an overall coherent and consistent approach. At present, Air Command and DE&S are contracted separately with Baines Simmons; and (2) If Fleet and Land (Joint Helicopter Command) were also to contract independently, each programme would effectively be competing for Baines Simmons resources and in an uncoordinated way. Indeed, under MOD commercial competitive arrangements, this might be a difficult contract to let to Baines Simmons alone.

Recommendation 21.D.4.3: The Implementation Programme shall be properly resourced.

21.89 For the avoidance of doubt, for Recommendation 21.D.4.3: (1) The results of the EMDs show that baseline level of HF training within the RAF engineering community is inconsistent. Therefore, to implement HF (M) EMS properly, it is necessary to train a combined module of HF followed by (M)EMS; and (2) The Business Case for (M)EMS assumed a basic HF knowledge and was mainly costed against (M)EMS training. Accordingly, in order to realise the full potential of HF (M)EMS, the Business Case shall be expanded to include baseline HF training.

Recommendation 21.D.4.4: There shall be adequate funding to implement recommended interventions.

21.90 For the avoidance of doubt, for Recommendation 21.D.4.4: (1) One of the benefits of HF (M)EMS is the resultant smarter interventions/mitigations resulting from MEDA investigations. However, whilst many of the recommended intervention strategies are cost effective, simple and easily achievable, a number of others require solutions that lie outwith the Forward environment, for example in DE&S, and would require financial commitment as 'spend to save measures'; and (2) It is important that these interventions are assessed and prioritised alongside technical airworthiness solutions to ensure limited resources are allocated appropriately to reduce overall risk.

Recommendation 21.D.4.5: HF (M)EMS shall be extended beyond Engineering into a pan-Defence Error Management System (EMS).

21.91 For the avoidance of doubt, for Recommendation 21.D.4.5: The principles of Error Management are applicable across Defence and should not simply be confined to the Maintenance community; the obvious expansion would be into the Operations area. However, the task of converting the current Air Command HF (M)EMS project into a wider EMS programme should not be underestimated and would need to be carefully scoped and project managed. The reason why the Boeing designed MEDA has evolved within the Maintenance environment is because similar operator specific systems were not suitable for engineers.

Recommendation 21.D.4.6: There must be a commitment to cultural change at the highest level.

21.92 For the avoidance of doubt, for Recommendation 21.D.4.6: the introduction of a successful Error Management programme in the RAF is essentially about changing current behaviours, particularly recognising that human error is inevitable and not always unprofessional. The new 'Just Culture' policy lays down the 'Code of Conduct' and behavioural changes that I would expect to prevail to create a just and open culture within the RAF, and seeks to address the concerns expressed by the Chief of Defence Staff's in his *Aviate* article.[41] Cultural change is key in the Air domain.

E. Single Safety Case and Single Risk Management System

Current position and shortcomings

21.93 Safety Cases (SC) have been adopted by the Military in order to seek assurance that every airborne military platform was 'safe' at a given point in time against an agreed 'baseline' of knowledge. SCs are also used to provide evidence to the RTSA that equipment is 'safe' and can be fielded to the AOAs. SCs apply to equipment modifications. SCs are mandated by BP1201. All air platforms now have SCs. SCs are intended to be kept current throughout the life of the platform. Many IPTs outsource the development of SCs to Industry.

21.94 A superfluity of ostensibly different types of SC has emerged in the MOD, namely 'Equipment Safety Case', 'Platform Safety Case', 'Operating Safety Case', 'Operator Safety Case', 'Operational Safety Case', 'As-Flown Safety Case' *etc.* This is confusing and undermines the purpose of having a SC. Further, the volume and complexity of the documentation that goes to make up many SCs has grown exponentially, such that 'roomfuls' of documents are involved which have become impossible to manage and access properly, let alone assimilate.

21.95 The Release to Service issued by the RTSA equates to the Type Certificate that EASA issues to civil manufactures when their designs are approved for use. Whilst the Type Certificate provides assurance that the aircraft has been designed in accordance with approved design standards and manufacturing methods, the Release to Service provides the Duty Holders in the AOAs with a much more in-depth assurance that the equipment is safe

[41] Aviate 2007 Journal Edition – Giving Weight to a 'Just' Culture in Aviation by Air Chief Marshal Sir Jock Stirrup, CDS.

to operate. In the Civil Sector, operators also apply to EASA for a Certificate of Airworthiness for each specific platform, renewed annually by an Annual Review Certificate (ARC) which confirms that the aircraft has been maintained in accordance with the maintenance schedule by approved maintenance organisations and approved tradesmen. Defence uses the F700 to provide an auditable record of maintenance that has been undertaken on each of its aircraft and check whether the maintenance conforms with the maintenance schedule.

21.96 SCs in the MOD currently vary considerably in their format, content, length and value. In the absence of clear guidance on what should constitute a SC, and what are acceptable means of compliance, over the past eight years, IPTs have produced their own differing SC solutions. This has made it difficult for those with Airworthiness responsibilities to make a relative assessment of one SC against another. Many SCs are, in any event, too lengthy, complex and dense to provide a meaningful safety tool in the first place, let alone one which is capable of ready use and assimilation by those most in need of it.

21.97 SCs in the MOD are currently deficient in that they have too narrow a focus. They normally do not include an assessment of the risks of the use of equipment and other pertinent issues that have a direct bearing on the Airworthiness of the platform such as spares, engineering standards and practices, or MOB manning levels and experience. In contrast, the Australian Air Force undertakes a review of all of the Defence Lines of Development (DLODs) relevant to the Airworthiness of a platform annually to ensure their equipment can continue to be operated safely.

21.98 Hazard logs are formatted on the basis of probability. Therefore, those risks that fall into the catastrophic impact category that are assessed to have a likelihood of occurrence of improbable are not deemed to be a concern. The problem with this approach is that this assessment is based on the expected rate of arisings, which is routinely determined on a small sample, particularly for a new aircraft. If a catastrophic event were to happen, it would immediately elevate the assessment to probable and invite mitigation action; the Nimrod accident is a potential example where the assessment of the likelihood of a fire and explosion was elevated post the event happening, only then did it receive attention and mitigation action. The opportunity is therefore being missed to mitigate the potentially catastrophic risks before the events happen; a fundamental flaw in the philosophy for risk management that needs to be addressed.

21.99 There is a need to review and align the re-certification processes used by each of the three Services, and to consider the benefits of adopting a military version of the civil Type Certificate, Certificate of Airworthiness and Aircraft Release Certificate. Currently, each of the three Services has a different approach. This cannot be sensible and the new MAA needs to address this.

Objective

21.100 The objectives of the Recommendations E below are: (1) First, to provide for each platform a concise and useful SC that sets out the safety evidence for a platform, which can be readily assimilated and used as evidence to support the Release to Service issued by the Regulating Authority. The SC needs to follow a standard format to allow for independent assessment and comparison with other SCs. It also needs to be in an easily accessible form so that it can be referred to by both the Regulator and the Duty Holder in the operating authority throughout the platform's life. (2) Second, to ensure that SCs are seen as a means to an end, not an end in themselves, and the 'box-ticking' culture is replaced with pro-active management, ownership and analysis of risk. (3) Third, to establish common criteria for managing Airworthiness risks across DE&S and the AOAs for individual platforms, and for comparative assessment of all-platforms' Airworthiness risks. (4) Fourth, to align the certification process for military aircraft across the three Services, similar to the civil certification process, in particular an AOA quality assurance system which looks far more closely at the individual aircraft themselves, and audits which focus on actual compliance and maintenance standards.[42]

[42] Work is underway to realise this requirement under the 'Can Do Safely' campaign which is sponsored by Air Command, but which is currently limited to the RAF's AOA.

Recommendations E

21.101 In order to achieve these objectives, I make the following Recommendations:

<u>Recommendation 21.E.1</u>: The Regulator shall set the requirements for a single, concise, through-life *"Risk Case"*[43] for each platform in a format which stimulates effective analysis, encourages focus on key risks and can easily be assimilated and understood by the intended user.

21.102 For the avoidance of doubt, for Recommendation 21.E.1: (1) The Regulator needs to define clearly what constitutes an Airworthiness 'Risk Case' and set out the regulatory requirements for managing the case through life with a view to ensuring that what is produced it is not just a 'snapshot' report or an 'archaeological' collection of documents; (2) A paradigm shift is required away from the current verbose, voluminous and unwieldy collections of text, documents and GSN diagrams to Risk Cases which comprise succinct, focused and meaningful hazard analysis which stimulate thought and action; and (3) The requirements laid down by the Regulator shall be in line with the further detailed Recommendations regarding best practice for Risk Cases which I set out in **Chapter 22**.

<u>Recommendation 21.E.2</u>: The MAA shall own the Risk Case. IPTs shall be responsible for keeping Risk Cases current. The MAA shall ensure that IPTs keep Risk Cases current.

21.103 For the avoidance of doubt, for Recommendation 21.E.2: (1) Whilst the MAA has ownership of the Risk Case, the IPT is charged with ensuring the Risk Cases remains current and identifying new risks that emerge to the Duty Holder; (2) The process for transfer/acceptance of the Risk Case throughout the procurement, testing and in-service phases must be clearly defined; (3) The Regulator shall retain an independent overview of the Risk Case; and (4) The Regulator shall be advised by either the IPT or the Duty Holder of any issue which invalidates the Risk Case, or part of it, or which would justify the rescinding or amendment of the Release to Service or where an Operational Emergency Clearance is required.

<u>Recommendation 21.E.3</u>: A single Military Aircraft Airworthiness Risk Register shall be established, comprising those equipment and operating risks that involve a Risk to Life, and using common criteria.

21.104 For the avoidance of doubt, for Recommendation 21.E.3: (1) As well as a copy of the Risk Case and the Release to Service, AOA Duty Holders will have ownership of a single Airworthiness platform Risk Register covering all equipment and operating Airworthiness risks; (2) It shall be the Duty Holder's responsibility pro-actively to manage all platform risks, tasking the relevant IPT as necessary. Duty Holders in the AOAs shall own and manage a single Risk Register for each platform comprising prioritised risks across all DLOD (including equipment and operating risks); (3) The Regulator shall direct that Airworthiness risks are managed separately from other safety, environmental and business risks; (4) The Regulator shall define the common criteria for Airworthiness Hazard and Risk Assessment (though IPTs may be permitted to use existing logs provided that they comply with the common data format required); (5) A single Airworthiness equipment and operating Risk Register for each platform will allow the Duty Holders to make informed decisions on employing the aircraft, and taking appropriate mitigation action; and (6) Dedicated Airworthiness Risk Registers based on common criteria will enable relative assessments to be made across Defence in order to prioritise resources, to stimulate mitigation strategies and to ensure that risks are owned at the right level.

<u>Recommendation 21.E.4</u>: The Regulator shall establish a common process for the management and regular review of all platform risks.

21.105 For the avoidance of doubt, for Recommendation 21.E.4: (1) The Regulator will need to establish a clearly defined policy as to the rank at which particular levels of risk may be accepted/managed/mitigated, *i.e.* a defined system for the elevation of risk to named individuals in the Airworthiness governance chain; (2) The Regulator will need to establish a clearly defined process for the transfer/ownership of Risk across

[43] Safety Cases are to be re-named *"Risk Cases"*. See further **Chapter 22**.

organisational boundaries (*e.g.* IPT to AOA); (3) All platform risks and the associated mitigations shall be managed and reviewed in order to uphold and document decisions that the specific risks are ALARP; and (4) If a platform has a significant risk that cannot be mitigated, it should be possible to trace that risk from platform-level to the appropriate rank/individual where it has been accepted, *i.e.* traceability from platform-level through to the DESB.

Recommendation 21.E.5: The Regulator shall provide independent assessment of Defence Airworthiness risk management.

21.106 For the avoidance of doubt, for Recommendation 21.E.5: the Regulator shall ensure coherence across the air domain as well as regulatory compliance in a similar manner to the Australian Defence Force, which undertakes an annual independent review of Airworthiness risks across all Defence Lines of Development.

Recommendation 21.E.6: The Regulator shall undertake a review of the certification process for military aircraft in order to align the Airworthiness assurance processes used by the three Services and to establish clear lines of accountability for the design, manufacture of aircraft types, and continued Airworthiness of specific platforms.

21.107 For the avoidance of doubt, for Recommendation 21.E.6: the review shall consider the benefits of the civil certification system, and the requirement to review the Airworthiness of individual aircraft or fleets annually, considering all of the Defence Lines of Development that contribute to the Airworthiness of a platform.

Recommendation 21.E.7: The Regulator shall devise and stipulate a simple, common Hazard Risk Matrix which is to be used across Defence.

21.108 For the avoidance of doubt, for Recommendation 21.E.7: given the myriad of Hazard Risk Matrices that are used to determine risk categorisations, the Regulator shall devise and lay down requirements for a simple, common Hazard Risk Matrix which: (a) comprises no more than a 4 x 4 matrix grid (to encourage intelligent assessment over subjective and prescriptive numerical assessments); (b) provides a system for pro-actively managing all risks that fall under the 'catastrophic' heading where assessments on likelihood are often based on small samples; and (c) provides for meaningful comparative assessments to be made between platforms (this requires a common data format to be defined at the lower level, *i.e.* individual platforms, so that the higher-level register can extract relevant risk data from IPT/AOA hazard logs).

F. New Joint Independent Accident Investigation Process

Current position and shortcomings

21.109 The Service Inquiry (SI) process for investigating military aircraft is based on Boards of Inquiry (BOI) convened by the relevant AOA.[44] The AAIB is normally invited by the AOA to undertake the technical aspects of the investigations unless the aircraft is embarked, or deployed, in an operational theatre, in which case the RN's own accident technical investigation team undertake that role. Presidents of BOIs and their fellow board members are nominated within a few hours of an accident occurring, and usually comprise a senior aircrew of Wing Commander rank, supported by another aircrew member and an engineering officer, both of Squadron Leader rank. The officers involved would normally have recent experience of the aircraft involved, but would not be associated with the Squadron concerned. The SI team would be advised throughout by a full time trained Inquiry specialist from the Flight Operations Regulator's team (DARS) who would advise on protocol, process and provide links to the relevant specialists' organisations. The publication of the Inquiry report may take over a year, due in part to the extensive high level staffing that is undertaken prior to publication. Once the report is issued, BOI members are increasingly likely to be involved in the civil scrutiny which further extends their involvement. BOI reports attempt to identify the cause of the accident but no longer apportion blame. The SI process is now aligned across the three Services.

[44] See JSP832.

21.110 The BOI process for investigating military aircraft accidents has not always proven effective in identifying the technical and human factor issues associated with military aircraft. The SI presidents are neither trained nor experienced in undertaking an investigation. The results of SIs are very much dependent on the calibre of who is appointed, which in turn may depend on who is available at the time. Whilst the commitment of members of BOI/SIs to carry out the task thoroughly is not in doubt, and many BOI Reports are of remarkably impressive quality,[45] the current system has more than an element of happenstance and amateurism about it. However, the AAIB is unlikely to be familiar with the weapons and systems on military aircraft and does not undertake investigations into accidents that occur on deployed operations. The RN, however, who make up this shortfall, lack experience of large aircraft or fast jets.

Tench Report (1986)

21.111 In 1986, the then Defence Minister, Lord Trefgarne, commissioned the UK's Chief Air Accident Inspector, Mr William Tench, to *"review the procedures pertaining to Service Boards of Inquiry"*. The Tench Report was highly critical of the MOD BOI system of accident investigation on two main basis: (1) low standards; and (2) lack of independence. As regards (1), the Tench Report pointed to *"mediocre standards"* where investigations were conducted by *"complete novices"*. As regards (2), the Tench Report said: *"pervasive nature of the involvement of some Station Commanders, Air Officer Commanding's Staff Officers and even the Commander-in-Chief, is an unwelcome intrusion upon what should be the complete independence of the Board of Inquiry"*. The Tench Report concluded that BOIs had *"outlived their usefulness"*. The thrust of Mr. William Tench's Report was the need for high quality, independent investigations of military accidents which were immune from interference. Lord Trefgarne recently expressed dismay that the 1986 Tench Report had not been implemented. I share his disquiet on the failure to implement the major tenets of the Tench Report (though I do not agree with all of it). It is fair to observe, however, that there have been significant improvements in the military inquiry regime in the past 20 years, in particular: (a) BOIs have been able to involve the Air Accident Investigation Branch (AAIB); (b) BOIs can no longer investigate fault; and (c) differences in procedure between the three Services have been ironed out under the new SI process. But, in my view, further fundamental reform of this area is long overdue to put military inquiries on a sound footing as outlined below.

Three important points for the future

21.112 In my view, there are three points of importance for the future. First, it is vital that military accident investigations are carried out in a thorough and professional manner by personnel who have the requisite training, experience and support. The ability of BOIs to use the good offices of the AAIB to assist in more recent investigations has been a welcome advance. But it is no longer sufficient for 'gifted amateurs' to be expected to be taken off the Front Line and thrust into conducting an investigation without any previous training or experience. (The RAF were fortunate in the current case that the President and members of the Nimrod XV230 Board of Inquiry happened to be of particularly outstanding ability, integrity and experience and showed remarkable forensic perseverance throughout their painstaking inquiry: the President, Group Captain Nick Sharpe had over 20 years experience on Nimrods; Squadron Leader John Nelson had almost 30 years, and is recognised as one of the most experienced and capable air engineers in the fleet, whilst Squadron Leader Andrew Gransden's experience as an engineer stretched back over 34 years.)

21.113 Second, it is vital that military accident investigations are independent, and seen to be independent and impartial. The military at all ranks, and the public, need to have confidence both in the process and the outcome. Increasingly in recent times, BOIs have understandably been the subject of public, media and legal scrutiny as to their effectiveness and independence. There has always been a constitutional problem in terms of demonstrable independence arising from the simple fact that AOAs are their own convening authority. SIs are convened by the respective AOAs from each Service. Further, those appointed to BOI Inquiry teams may have flown the aircraft in question and may even have known the individuals involved in the accident. Whilst there are real advantages in investigators having this sort of close knowledge, equally, it may give rise to questions as to real or perceived objectivity and partisanship, namely criticism that AOAs are investigating

[45] *e.g* the BOI Report into the loss of XV230.

their own accidents. The answer is to remove the convening power to the independent authority of the Regulator.

21.114 Third, it is vital that the results of military accident investigations are collated, analysed and the wider trends and lessons learned disseminated across the relevant domains and Defence generally. Currently, the manner in which BOI Reports are handled is somewhat haphazard. This is another reason why the SI process should be in the hands of a central Regulator.

21.115 The current SI process is, in any event, not ideal for dealing with accident investigations when Industry is involved. Industry may be involved in military accidents either through Industry supporting or operating the aircraft as part of their Depth role on the MOB, or where military aircraft are being flown by civilian crews, or where Service crews are operating a civil-registered platform. Whilst the technical, operating and support issues are the same, the process associated with a SI versus a civil accident investigation are quite different and have different legal requirements.

Type experience

21.116 It is important, in my view, that the engineering and operational members of SIs have relevant experience on type. The pool of suitable candidates for appointment will probably have spent much of their career operating/maintaining the aircraft concerned. Aircrew will have undertaken a conversion course (usually six months) to fly the aircraft. Aircrew and engineers associated with type will normally have extensive experience of the aircraft, its operations and diagnosing problems with the aircraft in normal day-to-day operation. The three members of an SI should have a comprehensive knowledge of the aircraft, its systems and the normal operating procedures. It would take much longer for an uninitiated investigator to acquire the necessary background information, let alone to garner a full understanding of the aircraft. Civil and military aircraft are different. Civil aircraft have broad similarities. Military aircraft differ markedly. Larger military aircraft tend to be extensively modified and are often older designs than those in civil use. Fast jets are completely different to larger aircraft and have nothing in common with civilian aircraft. Military aircraft operations are (on the whole) completely different to civilian operations. The SI team understand the particular regulations within which the aircraft and its crews work; they also understand the stresses of military operations and the context within which the aircraft will have been operating. The majority of crashes are the result of human factors, engineering issues or operating factors (*e.g.* bird strike). Determining what happened is a result of analysing available data about the crash/incident and the people best placed to do so are those who are 'educated' both in the aircraft's systems and the way in which it is operated. Currently, what is missing is a knowledge of how to go about proving theories, what tests might be useful and practical *etc.* The AAIB is (and has been) a valuable source of guidance to previous BOIs carrying out military air investigations as well as often conducting a parallel/joint inquiry with AAIB inspectors appointed to assist BOIs. In the case of XV230, it produced a report which coincided in all essential detail with that of the BOI.

Summary

21.117 In summary, therefore: (1) Currently, the SI system is not independent and seen to be independent. It should be. (2) Currently, there is no joint military accident technical investigation team that has the skill set and training to investigate the whole spectrum of military aircraft accidents. There should be. (3) Currently, there is no satisfactory system for drawing together the results of BOIs and learning the lessons of BOIs across Defence. There should be. (4) It is important that engineering and operational members of SIs have experience on type. and (5) Even closer liaison between the military and the AAIB would be valuable.

Objective

21.118 It is important that SIs are, and are seen to be, non-partisan, independent, skilled and professional investigations in which the Services, Industry and the Public can have complete confidence. Presidents and members of BOIs need to be given appropriate education, training and support to be able to carry out their investigatory role in a professional manner. In order to protect SIs from a future legal challenge, and to enhance the credibility and effectiveness of BOIs, changes to the SI process are required.

21.119 The objective of Recommendations F below is to establish a single accident investigation process for all aircraft accidents involving military aircraft and/or military personnel which has similar authority, status and effectiveness on a par with that afforded by the AAIB in civil accident investigations.

Recommendations F

21.120 In order to achieve this objective, I recommend as follows[46]:

Recommendation 21.F.1: The MAA shall be the single convening authority for Service Inquiries for all aircraft accidents involving military aircraft and/or military personnel.

21.121 For the avoidance of doubt, for Recommendation 21.F.1: (1) The MAA shall have the legal authority to convene investigations on behalf of the three Services for all accidents involving military registered aircraft and/or Service personnel, including those where Industry is involved; (2) The Head of the MAA shall appoint the President and members of the SIs; (3) The Head of the MAA shall have regard to the significance, complexity and potential legal implications of the case when making such appointments; (4) The pool of candidates from which such appointments shall be made may include retired judges and other suitable legally qualified personnel skilled in this sort of investigation; (5) Potential candidates for SI Presidents shall be identified and suitably trained so that they may be available to be appointed during their SO1 career; (6) SI Presidents and members should be encouraged to build up expertise in conducting such inquiries by being re-appointed to several SIs; (7) The President, Aircrew and Engineering Members of the SI should normally have type experience; and (8) The practice of Station Commanders and other Senior Officers commenting on final SI Reports is valuable and should be retained.

Recommendation 21.F.2: The MAA shall establish a Joint Service Military Air Accident Investigation Branch (MAAIB) which shall comprise a permanent team of specialists to carry out investigations into the immediate causes of air accidents.

21.122 For the avoidance of doubt, for Recommendation 21.F.2: (1) The MAAIB should be created bringing together skills and experience from other platform types; (2) The RN accident investigation team should be folded into the MAAIB, which should, therefore, also be able to cover RN embarked operations; (3) There should be a closer association of military technical investigators with the AAIB, with individuals seconded to the AAIB and, if necessary, teams co-located; and (4) The relevant members of the MAAIB involved should counter-sign the SI Report.

Recommendation 21.F.3: The investigation shall focus on two key areas: first, a technical/operational investigation by the Service Inquiry/MAAIB into the immediate causes of the accident; second, a detailed investigation into the wider aspects and implications of the accident.

21.123 For the avoidance of doubt, for Recommendation 21.F.3: (1) The technical/operational investigation shall be undertaken by the SI/MAAIB, under the direction and control of the President of the SI, to ensure the technical or operational reasons for the accident are identified and understood as quickly as possible and timely remedial action taken as needed.[47] If necessary, an interim report shall be issued, detailing the determined cause and any necessary recommendations; (2) The MAAIB and SI should work together as a team led by the President

[46] Service Inquiries are governed by Section 343 of the Armed Services Act 2006. This is a broad enabling section and will not require amendment as a result of recommendations in this Report. The detailed regulations are contained in Statutory Instrument No 1651 of 2008 and JSP 832. Both of these will require alteration to reflect these recommendations.

[47] This is not to suggest a rushed investigation and the fact that it may take many months to determine the cause(s) of some accidents (if, indeed, they are determined) is acknowledged.

of the SI; (3) The SI inquiry should include the findings of the technical/investigation but also focus on the wider issues that caused or contributed to the accident, including Human Factors and organisational factors;[48] (4) Presidents of SIs should retain ownership of the case and Report throughout any legal proceedings; and (5) The non-attribution of blame recommended by Tench should continue.

Recommendation 21.F.4: Presidents and members of Service Inquiries should have proper administrative, secretarial and legal support.

21.124 For the avoidance of doubt, for Recommendation 21.F.4: The MAA should ensure that Presidents and members of SI have proper administrative, secretarial and legal support throughout the course of their inquiries, in particular: (a) administrative advice on SI procedure and process by someone knowledgeable and experienced in the field; (b) secretarial support in taking statements and drawing up reports; and (c) legal advice as and when required.

Recommendation 21.F.5 The President and members of Service Inquiries should not be *functus* following the delivery of their Report but retain the residual responsibility to confirm to the Head of the MAA in due course whether their Recommendations have been enacted correctly, adequately and in a timely fashion.

21.125 For the avoidance of doubt, for Recommendation 21.F.5: in order to ensure that SI Recommendations are properly actioned, the President and members of the SI should retain the power and responsibility to report to the Convening Authority, the Head of the MAA, their views on whether they are satisfied that the SI Recommendations have or have not been enacted correctly, adequately or in a timely fashion.

Recommendation 21.F.6: In any case where a Service Inquiry has to investigate the decisions or activities of the Regulator itself, the President of the SI shall report direct to the 2nd Permanent Under-Secretary.

21.126 For the avoidance of doubt, for Recommendation 21.F.6: (1) I consider that the advantages of overall responsibility for accident investigation being discharged by the Regulator (coherence, simplicity and oversight) outweigh the disadvantages (potential conflict of interest);[49] and (2) To obviate the latter risk, however, where it is necessary for the investigation to examine the decision or activities of the Regulator itself, the SI shall have a direct line to 2nd PUS.

Recommendation 21.F.7: The MAAIB should maintain a close liaison with other international organisations, both military and civil, entrusted with the investigation of air accidents.

21.127 For the avoidance of doubt, for Recommendation 21.F.7: (1) I believe that there is much to be gained by greater, and more regular, international liaison between military and civil aviation authorities; (2) The US Air Force Flight Safety Center (AFSC) at Kirtland Air Force Base, New Mexico, USA, is a remarkably impressive organisation from which the new MAAIB could learn a great deal; and (3) In particular, the AFSC runs an impressive Accident Investigators' Course which suitable UK personnel should attend.

G. Readable and Concise Airworthiness Regulations

Current position and shortcomings

21.128 Current Military Airworthiness regulation documentation is primarily derived from 'high-level' policy documents for Safety, Health, Environment and Fire Management (*i.e.* SHEF). It is generally referred to as the Military Airworthiness Regulation Documentation Set (MARDS), or the JSP550 series. It can broadly be sub-divided into two sets: (a) a set governing Acquisition and the Release to Service Regulatory Set from

[48] See the Human Factors checklist published by ICAO (ICAO Circular 240-!N/144).

[49] This potential conflict of interest was discussed by Lord Cullen in the *Ladbroke Grove Rail Inquiry Part 2 Report,* Chapter 1, paragraph 1.30.

which the platform specific regulations are derived; and (b) a set governing Operational Airworthiness. The Acquisition set includes an extensive range of Defence Standards which set out requirements for design and configuration, and specific standards for civil owned aircraft and Unmanned Air Vehicles (UAVs). Alongside the Acquisition set is a parallel, and in many areas duplicating set of DE&S Safety and Engineering documents, which regulate Safety Management, Safety Cases and Risk Management.

21.129 The current Airworthiness regulatory documentation is not fit for purpose. It is too complex, prolix, obscure, repetitive, overlapping, voluminous and impenetrable. It comprises a mixture of policy, guidance and regulation that is open to considerable interpretation, with regulations often written retrospectively to accommodate specific arrangements made by IPTs with their industry partners. The regulations are difficult to assimilate and to navigate, with most users referring to them *post hoc* only to justify action they have taken already rather than using them to guide their activity.

21.130 The vagaries in regulatory documentation have encouraged considerable disparity in the way support is provided across various platforms, causing strains in the interfaces between Forward and Depth. Whilst DARS are protective of their authorship responsibilities for the JAP550 series of Airworthiness regulations, the reality is that the document set is a disparate collection of policy, guidance and ambiguous regulations which cannot realistically be assimilated by those who are accountable for complying with them. They also conflict with, and are dominated by, the Safety Management System document set that governs the Acquisition domain across all types of platform. Safety regulation takes a broader view of safety and risks, diluting the management of Airworthiness, reinforcing the mistaken view that Airworthiness is a 'bounded' DE&S responsibility. This is to be contrasted with, for instance, the Nuclear Safety set which is defined in a limited number of publications which are clear and concise in their nature and understood by all involved.

Objective

21.131 The objective of Recommendations G below is to found an authoritative Airworthiness regulatory document set that can be easily read, taught and assimilated by all those that have to comply with Airworthiness regulations at whatever level. Regulations need to be clear and explicit to reduce the risk of 'local' interpretation and divergent support solutions. The new regulatory set should enshrine the principle of Airworthiness being managed as a discrete and bounded discipline in its own right, and not merely as a facet of Safety management.

Recommendations G

21.132 In order to achieve this objective, I recommend as follows:

Recommendation 21.G.1: There shall be a complete overhaul and re-write of the current Military Airworthiness document set to reflect the Recommendations in this Report and the proposed new MAA, drawing on the Australian Defence Force Airworthiness Document set as a model.

21.133 For the avoidance of doubt, for Recommendation 21.G.1: (1) The re-drafted Airworthiness Regulatory set shall: (a) focus Airworthiness acutely on Risk to Life as aforesaid; (b) cover (i) the acquisition of equipment, (ii) the provision of equipment, (iii) the support of equipment and (iv) the ability to operate the equipment; and (c) ensure that AOA Duty Holders own all Airworthiness risks when the equipment is in service; (2) The Australian Defence Force Airworthiness Document set has recently been comprehensively reviewed to slim down the text so that the documents can be readily assimilated, and to make the structure and contents concise, comprehensive and logical. The Australian Defence Force Airworthiness Document set covers operational Airworthiness and Technical Airworthiness, and places Airworthiness accountability firmly and unequivocally upon the aircraft operating authorities, who have ample authority to direct their supporting authorities as required.

Recommendation 21.G.2: Airworthiness shall be defined as, and confined to, risks associated with Risk to Life and managed accordingly. Airworthiness shall be regulated and managed as a discreet and bounded discipline in its own right. Airworthiness regulations shall form a separate and discrete set.

21.134 For the avoidance of doubt, for Recommendation 21.G.2: (1) Airworthiness shall not be concerned with general Safety management risks such as 'business', 'environmental' and 'capability' risks, but be focused solely on reducing net Risk to Life; (2) There needs to be a clearer distinction between DE&S Safety regulation and Airworthiness regulation. Aircraft are different; (3) Whilst IPTs have general safety risk managers, they do not have specific 'Airworthiness risk' managers; further, whilst the Airworthiness (and Safety) risk managers are actually the EAs they do not manage safety risk as they are currently not empowered to do so. (4) The AOAs do not recognise or use the safety management system used by DE&S, known as ASEMS[50] (specifically POSMS[51] and POEMS[52] which are elements of ASEMS). There should be a single Airworthiness Management System across the whole of DE&S and the AOAs focused on Risk to Life.

Recommendation 21.G.3: The Regulations shall be re-drafted in clear, simple language and be as succinct as possible.

H. Coherent Flight Safety management across the three Services.

Current position and shortcomings

21.135 Ironically, whilst the Army and Navy still have their own Flight Safety (FS) organisations, the RAF does not.

21.136 Historically, all three Services had their own FS organisations. These separate Service FS organisations were combined together upon the formation of DASC (later DARS, the Regulator for Flight Operations). During this process of convergence, however, important features of FS were lost: the traditional 'Inspectorate' FS practices, *i.e.* visits by FS inspectors to user communities, crew room discussions and flying with crews *etc.,* were replaced with 'one down' assessments to address Service-specific concerns. This represented a critical weakening of FS oversight. Following the formation of DARS (the tri-Service Flight Safety organisation), both the Army and Navy re-constituted their own FS organisations, leaving the RAF as the only Service without a dedicated focus on this vital aspect. Whilst recent changes now allow DARS to undertake assessment across the three Services, the scope to spend informal time with crews and around operating units, such as would have been done in the days of the FS Inspectorate, is still limited. The valuable Inspectorate role remains all but lost.

21.137 With DARS as the appointed Airworthiness regulator, the focus on Airworthiness and FS has become blurred. With the Army and the Navy now undertaking their own FS management, but the RAF AOAs relying on DARS, there is an evident anomaly. At a time when several aircrew have been lost in a very short period of time for non-technical reasons, it is clearly imperative that FS management is made more effective. The FS Inspectorate role needs to be restored and a clearer definition made between the regulation of Airworthiness and FS. Although CAA undertakes FS management in the civil sector, the military construct requires that each of the AOAs have their own FS Inspectorate to serve their Duty Holders who undertake both the self-regulation of flight operations and the management of FS.

Objective

21.138 The objective of Recommendations H is to establish single-service FS management organisations within each of the AOAs, each headed by a Senior Operator who has responsibility across all disciplines for deploying/managing FS policy and undertaking an FS Inspectorate role. The Regulator's responsibility would be to

[50] Acquisition Safety and Environmental Management System
[51] Project Oriented Safety Management System
[52] Project Oriented Environmental Management System

provide oversight of FS Safety to help inform strategic Airworthiness management decisions (*e.g.* addressing a rise in FS-related fatalities across whole defence aviation domain).

Recommendations H

21.139 In order to achieve this objective, I recommend as follows:

Recommendation 21.H.1: Each AOA shall establish its own Flight Safety organisation, headed by a Senior Operator, responsible for the delivery/deployment of Flight Safety throughout the AOA. The Regulator's role in Flight Safety management shall be that of central oversight, to inform strategic Airworthiness decisions/direction and to act as the 'high level' governing authority for Flight Safety.

21.140 For the avoidance of doubt, for Recommendation 21.G.1: (1) Each AOA will need to re-establish a FS Inspectorate role to complement the Standards and Evaluations Teams who monitor flying procedures and competence; In the case of the RAF a single Flight Safety organisation shall be formed under the command of Cinc Air. (2) The FS organisations will be required to look across all disciplines that influence Flight Safety; and (3) The Senior Operator will also have responsibility for managing the self-regulation of flight operations and to provide assurance to the Duty Holder that the equipment is being used safely and, where necessary highlighting Airworthiness concerns.

Recommendation 21.H.2: The Regulator will establish a clearer distinction between the disciplines of Airworthiness and Flight Safety.

21.141 For the avoidance of doubt, for Recommendation 21.G.2: (1) *Airworthiness* is ensuring aircraft platforms are *safe to use* (this involves a dual responsibility of DE&S and AOAs, namely: the responsibility of DE&S to provide safe equipment and the responsibility of AOA Duty Holders: (a) to maintain Airworthiness; (b) to operate the equipment in accordance with approved procedures; and (c) to use appropriately trained and competent personnel; (2) *Flight Safety* involves ensuring aircraft platforms are *used safely* (a responsibility of the AOA Duty Holders alone).

I. Clarification of Integrated Project Team Responsibilities

Current position and shortcomings

21.142 The AOAs are supported by DE&S IPTS who, following the amalgamation of the DLO and DPA to form DE&S, now have responsibility for the equipment through life, *i.e.* including procurement and in-service support. Although the AOAs fund their respective IPTs, Joint Business Agreements (JBAs) provide the mechanism for agreeing output requirements and for monitoring performance. The IPTs in turn set up their own contracts with Industry to provide Depth support, an arrangement that means neither Depth nor the IPTs primarily face the Unit level users who operate the equipment.

21.143 DE&S has grown into a dominant organisation within the MOD. The emergence of DE&S has tilted the centre of gravity away from AOAs, such that the latter are considered part of the process of the former rather than vice-versa. Many IPTs have extended their remit regarding fleet-wide issues and policy and have become increasingly involved at a local and tactical level in issues specific to individual platforms. The remit of IPTs has 'evolved' to such an extent that many seek to exert control over the Forward (*i.e.* Duty Holder) environment notwithstanding that they are neither empowered, nor best placed, to manage this arena. The tail is beginning to wag the dog.

21.144 CDM has assumed the *de facto* position of senior 'Duty Holder', even though his remit is limited to the provision of safe equipment. This has strengthened the mistaken perception that Airworthiness is primarily a DE&S responsibility.

21.145 Conversely, the Units which operate the equipment have increasingly little influence over the IPTs who support them, having to accept the output provided by their Depth support and comply with the input requirements set by the contractor so that he can meet his contractual obligations. Missing is the customer status of the Unit Duty Holder and his Forward domain which would allow him (OC Forward/OC Engineering Wing) to assess the Airworthiness of the Depth output and to dictate, within contractual bounds, what support they need from Depth and the IPTs to maintain the Airworthiness of their aircraft. The role of the IPT should be to provide the policies and enable the Depth support contracts, leaving the users to work with these boundaries. The AOAs for their part need to relinquish any 'role office' functions that are not associated with their cross-platform overview role, to the Units so that the IPTs again face the Unit level duty holder they are funded to support.

Objective

21.146 The objective of Recommendation I is to clarify the roles and responsibilities of DE&S, the IPTs and Depth in providing the appropriate support to the Duty Holders.

21.147 IPTs should be responsible for setting the policy boundaries within which the AOA CAMO operates. Depth support should to face the Unit Level Duty Holder and his Forward support. CAMO/HQ should be the single tasking organisation responsible for continuous airworthiness management within bounds set by the IPTs.

Recommendations I

21.148 In order to achieve these objectives, I recommend as follows:

Recommendation 21.I.1: IPTs shall be responsible for issuing policy and laying down the boundaries for the continued Airworthiness of the Platform. The AOA shall be responsible for ensuring the platform is operated within the boundaries prescribed in the RTS.

21.149 For the avoidance of doubt, for Recommendation 21.I.1: This would be achieved through the CAMO, a Unit Duty Holder organisation (see below).

Recommendation 21.I.2: Where deviation from the Release To Service or maintenance policy is necessary due to operational or engineering reasons, the AOA shall have the authority to make its own decision as to whether or not the aircraft can fly.

21.150 For the avoidance of doubt, for Recommendation 21.I.2: Mechanisms already exist for approving Operational Emergency Clearances, capability limitations and for deferring corrective maintenance.

Recommendation 21.I.3: Unit level CAMO/HQ shall to undertake all tasking functions necessary for maintaining the continued airworthiness of their aircraft.

Recommendation 21.I.4: Each IPT shall have a designated and dedicated Project Engineer. Dual-hatting the IPTL as Project Engineer is undesirable and should be avoided where possible. The decision as to the designation of the Project Engineer should be made by those appointing the IPTL.

J. Restoration of the Chief Engineer

21.151 As explained in **Chapter 13**, and for the reasons set out therein, in my view the abolition of the title and post of Chief Engineer RAF in 2000 was a retrograde step. It removed an important lodestar of best practice and oversight in engineering and weakened the Airworthiness system.

21.152 I welcome the recent decision by 2nd PUS and CDM to establish of the new role of *"Defence Chief Airworthiness Engineer"* to be held by Chief of Materiel (Air) within DE&S. This is an important first step in the right direction; but the new role is dual-hatted and with a limited remit. It should be folded into the new full-time post of "Chief Engineer" that I recommend below (Recommendation J) by way of restoration of the post of Chief Engineer RAF. A full-time Chief Engineer is required to assist each of the Services to ensure compliance with Airworthiness standards and regulations. The new Chief Engineer will enable the AOAs to be intelligent customers, to ensure the quality of service received and to be a focal point for technical airworthiness in the operating environment.

Recommendation J

Recommendation 21.J.1: Each Service will appoint a Chief Engineer to ensure support for the AOA Duty Holders and to ensure the Airworthiness of platforms and Airworthiness regulatory compliance.

21.153 For the avoidance of doubt, for Recommendation 21.J.1: (1) The Chief Engineer of the RAF shall be a 2-Star officer; (2) Chief Engineers will provide engineering Airworthiness advice and support to AOAs and end-to-end governance of the Technical Arms in order to ensure Airworthiness regulatory compliance and safe operation. In this regard, their role vis-a-vis the AOA Duty Holders would mirror on the Technical side the role of the Flight Safety/Flight Operations officers on the Operational Side; and (3) The Chief Engineer will have a direct line to each of the PEs in the IPTs and *vice-versa*.

CHAPTER 22 – BEST PRACTICE FOR SAFETY CASES

"Safety Cases were intended to be an aid to thinking about risk, not an end in themselves"
(Lord Cullen, 2009).

"Safety Cases are often written for the benefit of the writer, not the reader."
(Ian Wheavell, Health & Safety Executive, 2008)

"Our risk mitigation hierarchy is: Eliminate, Control, Warn, Train."
(David W. Harper, US Air Force Safety Center, 2008)[1]

Contents

Chapter 22 makes Recommendations for Best Practice in Safety Cases.

Summary

1. The Safety Case regime has lost its way. It has led to a culture of 'paper safety' at the expense of *real* safety. It currently does not represent value for money.

2. The current shortcomings of Safety Cases in the military environment include: bureaucratic length; their obscure language; a failure to see the wood for the trees; archaeological documentary exercises; routine outsourcing to Industry; lack of vital operator input; disproportionality; ignoring of age issues; compliance-only exercises; audits of process only; and prior assumptions of safety and 'shelf-ware'.

3. Many of these criticisms of Safety Cases are not new: see the Ladbroke Grove Rail Inquiry and the writings of Professor McDermid's Department at the University of York.

4. Safety Cases were intended to be an aid to thinking about risk but have become an end in themselves.

5. Safety Cases themselves are not used by the Civil Sector nor other military fleets such as the US, Canadian and Australian air forces, who employ different methods to manage airworthiness, which are similar in effect to the MOD's Safety Case and Ageing Aircraft Audit regimes.

6. Safety Cases still have a useful role to play as an Airworthiness management tool for MOD military platforms, so long as (a) they are brought in-house, slimmed down and re-focused in accordance with the Recommendations outlined in this Chapter and (b) they are put under the overall ownership of the Regulator in accordance with the Recommendations in **Chapter 21**.

7. Safety Cases should be renamed *"Risk Cases"* and conform in the future to the following six Principles:

   - ✔ Succinct;
   - ✔ Home-grown;
   - ✔ Accessible;
   - ✔ Proportionate;
   - ✔ Easy to understand; and
   - ✔ Document-lite.

[1] (David W. Harper, Chief Engineer & Deputy Chief, Aviation Safety, USAF HQ AFSC/SEF, 2008).

Introduction

22.1 The background to Safety Cases and the MOD Safety Case regime is set out in **Chapter 9** of this Report.

22.2 A Safety Case itself is defined in the military context as *"a structured argument, supported by a body of evidence, that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment".*[2]

22.3 I am concerned that the Safety Case regime has lost its way. Many Safety Cases are not currently achieving the purpose for which I believe they were originally intended. As Lord Cullen pointed out in the Ladbroke Grove Rail Inquiry, the purpose of the Safety Case regime was to *"encourage people to think as actively as they can to reduce risks".*[3] Instead, in some instances, Safety Cases seem to be achieving the opposite effect: giving people a false sense of security that a Safety Case is some sort of paper 'vault' into which risks may be safely deposited and forgotten about. There is a pervading sense that the mere fact of a Safety Case means the platform is safe.

22.4 I am concerned that the exponential growth of 'the Safety Case industry' has led to a culture of 'paper safety' at the expense of *real* safety.

22.5 I am concerned that the growth of Safety Cases has led to a significant diversion of resources and reasoning away from the platform or equipment itself; time, money, and manpower which would be better spent on more hands-on attention, maintenance, checks and/or upgrades for the platform itself.

22.6 It is easy to produce vast quantities of paper; it is more difficult to focus on the key hazards and think about them.

Current Shortcomings

22.7 The current shortcomings of a significant proportion of Safety Cases include:

(1) *Bureaucratic length*: Safety Cases and Reports are too long, bureaucratic, repetitive and comprise impenetrable detail and documentation. This is often for 'invoice justification' and to give Safety Case Reports a 'thud factor'.

(2) *Obscure language*: Safety Case language is obscure, inaccessible and difficult to understand.

(3) *Wood-for-the-trees*: Safety Cases do not see the wood for the trees, giving equal attention and treatment to minor irrelevant hazards as to major catastrophic hazards, and failing to highlight, and concentrate on the principal hazards.

(4) *Archaeology*: Safety Cases for 'legacy' platform often comprise no more than elaborate archaeological exercises of design and compliance documentation from decades past.

(5) *Routine outsourcing*: Safety Cases are routinely outsourced by Integrated Project Teams (IPTs) to outside consultants who have little practical knowledge of operating or maintaining the platform, who may never even have visited or examined the platform type in question, and who churn out voluminous quantities of Safety Case paperwork (*'bumpf'*[4] *and outsized GSN charts*) in back offices for which IPTs are charged large sums of money.

(6) *Lack of vital operator input:* Safety Cases lack any, or any sufficient, input from operators and maintainers who have the most knowledge and experience about the platform. In his comments on the Nimrod XV230 BOI Report the Commander-in-Chief Air Command, Sir Clive Loader, said, correctly in my view, that any review of the Nimrod Safety Case (NSC) *"must involve appropriate air and ground crews in order to ensure that current practices are fully understood; those personnel, after all, both know most about how our aircraft are operated and flown, and also have the greatest personal interest in having levels of safety with which all involved are comfortable."*[5] Operators at RAF Kinloss were not even aware of the existence of the original Nimrod Safety Case.

[2] Defence Standard 00-56, paragraph 9.1.

[3] *Ladbroke Grove Rail Inquiry Part 2 Report*, paragraph 7.19.

[4] The term used by one of BAE Systems' employees drawing up the Nimrod Safety Case in 2004.

[5] BOI, Part 5, Commander-in-Chief Air Command's Comments dated 2 November 2007.

(7) *Disproportionate:* Safety Cases are drawn up at a cost which is simply out of proportion to the issues, risks or modifications with which they are dealing.

(8) *Ignoring age issues:* Safety Cases for 'legacy' aircraft are drawn up on an 'as designed' basis, ignoring the real safety, deterioration, maintenance and other issues inherent in their age.

(9) *Compliance only:* Safety Cases are drawn up for compliance reasons only, and tend to follow the same, repetitive, mechanical format which amounts to no more than a secretarial exercise (and, in some cases, have actually been prepared by secretaries in outside consultant firms). Such Safety Cases tend also to give the answer which the customer or designer wants, *i.e.* that the platform is safe.

(10) *Audits:* Safety Case audits tend to look at the process rather than the substance of Safety Cases.

(11) *Self-fulfilling prophesies*: Safety Cases argue that a platform is 'safe'[6] rather than examining why hazards might render a platform unsafe, and tend to be no more than self-fulfilling prophesies.

(12) *Not living documents:* Safety Cases languish on shelves once drawn up and are in no real sense 'living' documents or a tool for keeping abreast of hazards. This is particularly true of Safety Cases that are stored in places or databases which are not readily accessible to those on Front Line who might usefully benefit from access to them. (The NSC was only fully accessible from one computer terminal at BAE Systems at Chadderton).

Criticisms not new

22.8 The above criticisms are not new, nor confined to Safety Cases for military platforms.

Lord Cullen in the Ladbroke Grove Rail Inquiry

22.9 A number of similar criticisms of Safety Cases were highlighted in the evidence before Lord Cullen in the Ladbroke Grove Rail Inquiry. Lord Cullen's report highlighted that operators were not thinking constructively about safety.[7]

22.10 First, Safety Cases had a tendency to become bureaucratic with unnecessary detail.[8] Lord Cullen said: *"... I do not consider that it is necessary for the detail of the examination, assessment and control of individual risk to be set out in the safety case. There is an existing tendency for safety cases to become bureaucratic and I have no wish to encourage that tendency. It should be sufficient if the safety case points to the methods which have been used and to where the details can be found."*[9]

22.11 Second, operators too often relied on outside experts for the writing of their Safety Cases.[10] Lord Cullen quoted the words of one expert witness, Mr. Brown, Assistant Chief Inspector of Railways, who told the Inquiry that the use of outside consultants to produce safety cases was *"…completely ineffective. I think if people do not actually do this process in-house and do not involve all parties in it, it will not work. And I have got personal experience of that".*[11] Lord Cullen also referred to a report which he had commissioned from Entec,[12] which stated: *"If employees are involved in producing the safety case (rather than just being told about it) they would have 'ownership'. This can bring stronger commitment to the arguments".* Lord Cullen quoted Mr Brown, who remarked that failure on the part of management to ensure that *"the message gets through"* to all levels was*" …very much related to the failure to involve everybody in the process and very much the failure of constructing documents that people could find accessible and understandable and, crucially, helpful".* Lord Cullen referred to the evidence of other senior executives who remarked they had been surprised at just how valuable the input of employees had been.

[6] The 'top goal' in Goal Structured Notation, *"The platform is deemed acceptably safe",* can drive a conclusion that is already assumed.

[7] *Ladbroke Grove Rail Inquiry Part 2 Report,* paragraph 7.6.

[8] *Ladbroke Grove Rail Inquiry Part 2 Report,* paragraph 7.20.

[9] *Ladbroke Grove Rail Inquiry Part 2 Report,* paragraph 7.20.

[10] *Ladbroke Grove Rail Inquiry Part 2 Report,* paragraph 7.6.

[11] *Ladbroke Grove Rail Inquiry Part 2 Report,* paragraph 7.23.

[12] In the course of the *Ladbroke Grove Rail Inquiry,* Lord Cullen commissioned two reports from Entec UK, on *Safety Management and Safety Culture* and *Accident Causes and Responses.*

22.12 Third, Safety Cases tended to be compliance-driven, *i.e.* written in a manner driven primarily by the need to comply with the requirements of the regulations, rather than being working documents to improve safety controls.[13]

22.13 Fourth, audits of Safety Cases were inadequate and confined to process rather than product.[14] Lord Cullen said: *"Auditing is a vital component in both the management and the regulation of safety."* He explained that audit was, on the one hand, a quality assurance exercise and, on the other, a compliance process. Lord Cullen quoted the evidence of a number of witnesses, including Major Holden, Transport Safety Consultant, formerly Inspector of Railways, who drew attention to weakness in auditing: *"My concern has been that there has been a lack of penetration in the audits, which have tended to chase paper trails rather than check that what should be going on the ground is, in fact, going on. This lack of penetration may, in part, be due to the lack of skill of the auditors but it may also lie in the belief that all that is required is a pure compliance audit of the accepted safety case. The vital question as to whether or not the safety case itself is adequate and appropriate to the circumstances is seldom asked"*.[15]

Nimrod Safety Cases 1 and 2

22.14 As I explain in **Chapters 10A** and **10B** and **Chapter 11**, Safety Case 1 is a regrettable exemplar of most of the above shortcomings. Safety Case 2 (see **Chapter 15**) is, unfortunately, not much better. The growth in the size of Safety Case 2 has not been matched with an improvement in clarity: Safety Case 2 remains an impenetrable and repetitious document which is of little use to Operators.

22.15 On 30 April 2009, BAE Systems produced to the Review a list of 42 lessons which it said it had learned from Safety Case 1:

"Contracting Framework

Action 1: Determine scope of task and only then agree budget.

Action 2: Equipment Level SC is to be subjected to appropriate management and technical governance review.

Action 3: Seek guidance from the "Legal & Risk Dept" on the proposal prior to its submission.

Action 4: Ensure that the proposal is subjected to senior management review prior to its submission.

Action 5: Ensure continuity of funding and resource.

Task Management

Action 6: A dedicated core team is to be established.

Action 7: A dedicated project manager and dedicated task managers are to be nominated throughout the task.

Action 8: Clear ownership of tasks amongst team members to be defined.

Capability

Action 9: Ensure that the required skill set is defined, and that the team has the requisite balance of safety engineering expertise and Nimrod domain expertise.

Roles and Responsibilities

Action 10: "Safety Engineer" position to be established.

Action 11: Ensure roles and responsibilities of all stakeholders are fully defined.

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13 *Ladbroke Grove Rail Inquiry Part 2 Report,* paragraph 7.19.

14 *Ladbroke Grove Rail Inquiry Part 2 Report,* paragraph 7.34.

15 *Ladbroke Grove Rail Inquiry Part 2 Report,* paragraph 7.35.

Processes

Action 12: Ensure that the independence of Airworthiness from the Project Team is established.

Action 13: Ownership of the methodology for undertaking the SC Review is to be clearly defined.

Action 14: Ensure greater awareness of Cassandra hazard log content at analyser level.

Action 15: Photographs of zones assessed to be available for reviewers.

Action 16: All processes to be clearly defined and documented.

Action 17: Ensure that the assessment processes are under configuration control.

Action 18: Ensure that all team members are working to the latest processes.

Action 19: Processes to be reviewed and approved by key stakeholders.

Action 20: Process to be developed for identifying quality and husbandry issues during the ZHA surveys.

Action 21: Advise the NimIPT immediately of any safety related issues discovered.

Action 22: Method of escalating issues to be defined, in particular in relation to "out of scope issues".

Action 23: Cross-zonal interactions to be addressed by "Integration Assessments".

Action 24: Clearer definition of A,D&Es and any limitations to be established.

Action 25: A Stakeholder Group Technical Review, with representatives from all Stakeholders, to be established to review all SC products.

Action 26: The breakdown of zonal interactions into individual mechanisms to be documented.

Action 27: Review the approach, within the Cassandra hazard log, for the method of identifying differences between MR2 and R1.

Action 28: Ensure zonal differences between MR2 & R1 zones are fully understood.

Action 29: Seek additional sources of information for determining failure rate.

Action 30: Ensure that there is one owner for each hazard who is responsible for collating information from supporting Functions when compiling the assessment.

Action 31: Ensure that a full description of hazard to be analysed is included within the assessment (to avoid misinterpretation).

Action 32: Separate assessment to be undertaken for each hazard cause.

Action 33: Investigate alternative video technologies that could be used to support the assessments.

Action 34: Ensure that photographs of zones are clearly annotated with the aircraft orientation.

Action 35: All zonal hazard assessors to visit the aircraft when reviewing the aircraft zone.

Action 36: Assessments of zonal hazards to include maintainer input.

Deliverables and Acceptance

Action 37: Define the approach to be taken by the NimIPT and by BAES in relation to any "Open" hazards.

Action 38: Establish a clear point of ownership transfer to the NimIPT for the deliverables from SC2.

Action 39: Refine the handover process for the deliverables from SC2.

Action 40: Evidence of concurrence from the ITE (QinetiQ) should be obtained for each hazard.

Action 41: A record of the acceptance of the hazard assessment by the Stakeholder Group Technical Review should be maintained.

Action 42: Review the technical accuracy of any NimIPT mitigation actions, against the hazards, prior to entry into Cassandra hazard log."

The University of York

22.16 Leading experts and service personnel charged with reading Safety Case material have expressed concerns to me as to whether Safety Cases are, in fact, improving safety and whether they are a cost-effective means of so doing. I share these concerns. Professor John McDermid's Department at the University of York is a centre of excellence and the world's largest academic research group looking at safety critical systems. Professor McDermid made a number of pertinent points to me about Safety Cases:

22.16.1 First, 'legacy' Safety Cases should focus on identifying hazards, their potential causes, controls and mitigation, and assessing the priority areas where remedial action is needed to reduce risk to an acceptable level, *i.e.* where controls or mitigations are deemed inadequate.

22.16.2 Second, it is counter-productive to try to 'reverse engineer' the Safety Case which should have been produced at the time the system was developed.

22.16.3 Third, it is important to look at the problem from the operational end (this is, after all, where the risks actually manifest themselves) and to ask what information is needed to support risk management, *e.g.* equipment safety cases, evidence of training, *etc.*

22.16.4 Fourth, no system is absolutely safe. Indeed, systems are normally released with limitations. Accordingly, the Safety Case should argue that *"the risks are controlled",* not *"the system is safe"*, and should indicate those areas where remedial action is needed to achieve an acceptable level of safety.

22.16.5 Fifth, the focus needs to be on decision-making, both decisions as to the acceptance of risk and decisions as to the deployment of resources to reduce risk. Priority attention must be given to the most significant risks. This is the real point underlying ALARP.[16] Better methods and procedures for communicating risk information to senior management must be employed.[17]

Are Safety Cases Working?

22.17 In a recent article entitled *'Are Safety Cases Working?'*[18] Dr Tim Kelly of the University of York listed seven examples or 'traps' to avoid (this article should be compulsory reading for many of the current purveyors of Safety Cases):

22.17.1 *The "Apologetic Safety Case"*: Safety Cases which avoid uncomfortable truths about the safety and certifiability of systems in production so that developers do not have to face the (often economically and politically unacceptable) option of re-design (*"X doesn't quite work as intended, but it's OK because…").*

22.17.2 *The Document-Centric View:* Safety Cases which have as their aim to produce a document. Dr Kelly describes this as 'the biggest bear-trap'. The goal of Safety Cases should not simply be the production of a document; it should be to produce a compelling safety argument. We should not be reassured by *"paper, word-processor files, or HTML documents"*. There was a danger of *"spending a lot of money to produce a document"* of no safety benefit.

22.17.3 *The Approximation to the Truth:* Safety Cases which ignore some of the rough edges that exist. For example, Safety Cases which claim in a Goal Structured Notation diagram that 'All identified hazards have been acceptably mitigated'[19] and direct the reader to the Hazard Log when, *in reality*, the mitigation argument is not so straightforward.

22.17.4 *Prescriptive Safety Cases:* Safety Cases which have become run-of-the-mill or routine or simply comprise a parade of detail that may seem superficially compelling but fails to amount to a compelling safety argument.

22.17.5 *Safety Case Shelf-Ware:* Safety Cases which are consigned to a shelf, never again to be touched. The Safety Case has failed in its purpose if it is *"so inaccessible or unapproachable that we are happy never to refer to it again."*

22.17.6 *Imbalance of skills:* The skills are required of both someone to develop the Safety Case and someone to challenge and critique the assumptions made. Too often, the latter skills are missing.

22.17.7 *The illusion of pictures:* People are 'dazzled' by complex, coloured, hyper-linked graphic illustrations such as Goal Structured Notation or 'Claims-Arguments-Evidence' which gives both the makers and viewers a warm sense of over-confidence.[20] The quality of the argument cannot be judged by the node-count on such documents or number of colours used.

[16] The reduction of risks to 'As Low As Reasonably Practicable'.

[17] J A McDermid, PhD, FREng, University of York, *Through Life Safety Management: Some Concepts and Issues* (2007).

[18] Safety Critical Systems Club Newsletter, Volume 17, No. 2, January 2008, pages 31-33.

[19] *i.e.* the argument has become bald assertion or 'meta-discussion.

[20] Some Goal Structured Notation diagrams are yards long and cover an entire wall. Rather than being merely one aid to structured thinking, Goal Structure Notation appears to have become an end in itself.

Lack of Expertise in Integrated Project Teams

22.18 In a paper entitled *"Goal Based Standards Opportunities and Challenges"* by Kelly, McDermid and Weaver,[21] the authors highlighted two problems regarding customer expertise, *i.e.* in the IPTs:

> *1.1 "…IPT leaders often do not have expertise in safety engineering, but they are formally responsible for risk related decisions."*
>
> *1.2 "A challenge is finding the necessary skills and expertise to enable the potential benefits of goal based standards to be realized. Arguably in the defence context, most of the suppliers have the requisite technical skill. However it requires similar levels of skill and expertise in the customer community. This is not always to be found and preserving the skills and ensuring consistent decision making in long running projects will be a challenge. [It] requires education training and active support for IPTs and guidelines on a sector /technology specific process for evidence deemed acceptable by MOD and practical by industry. This challenge is exacerbated for military projects where there is a regular turnover of personnel."*

Appearance and Reality

22.19 It is important to be aware of the existential gap between the appearance and reality of safety.

22.20 There is a danger that Safety Cases give the strong impression of safety, but do not deliver it. This is particularly true of Safety Cases which employ compelling graphic illustrations. In a recent monograph on Safety Case depictions, Ibrahim Habli and Dr. Tim Kelly emphasised two points: [22]

> *20.1 "It is extremely important to note that a notation is only a tool for depicting safety arguments. Such a tool may be misused. For any argument it is important to persuade rather than state. Persuasion is primarily a logical and not syntactic or semantic exercise. There can sometimes be an illusion of truth with GSN (and other graphical) depictions of an argument – i.e. the goal structure <u>depicts</u> child goals G2, G3 and G4 adequately supporting parent goal G1 <u>therefore</u> this is assumed by the reader to be true. Any presentation of a safety case argument (whether graphically) or through the text of a safety case depiction does not mean that the actual safety case is compelling if the two are mismatched."*
>
> *20.2 "We have highlighted the potentially dangerous illusion of being swayed too heavily in our belief of the case through the use of compelling (but potentially inaccurate) depictions of the case. The problem of correspondence between the actual and depicted world is a universal dilemma, best exemplified in Rene Magritte's famous painting "The treachery of images – this is not a pipe but a picture of a pipe". In the safety case domain, it is essential to comprehend and manage the differences that exist between actual, depicted and reported cases".*

Over-complication

22.21 In my view, the 'science' of Safety Cases can become over process-driven and over-complicated, as illustrated by *e.g.* the flow chart from the Nimrod MRA4 System Safety Working Practices (see Figure 22.1 below).[23]

[21] In Proceedings of the 23rd International System Safety Conference, August 2005, proceedings published by the System Safety Society.

[22] *Safety Case Depictions vs Safety Cases – Would the real safety case please stand up?* by Habli and Kelly (August 2007)

[23] Figure B-11 "Overview of How The Hazard Version Changes":AWN/NIM/897, Issue 7 (Revision 7 Version 2), March 2003.

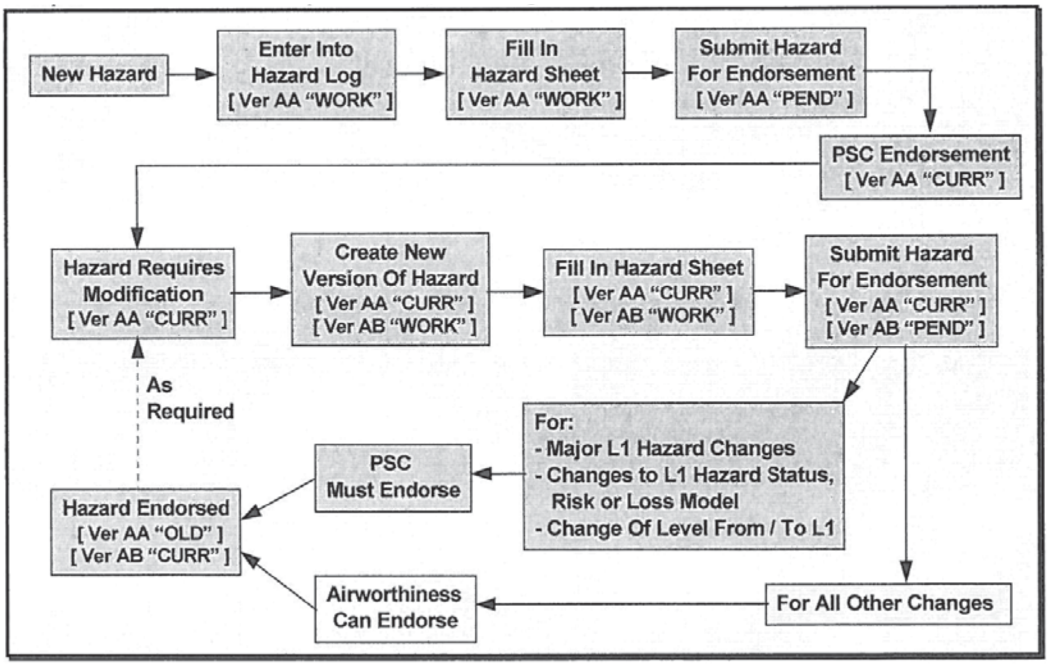

Figure 22.1: Flow chart from the Nimrod MRA4 System Safety Working Practices

Genesis of Safety Cases

22.22 It is important to understand the genesis of Safety Cases. I deal with this in some detail in **Chapter 9** of this Report. The concept has its origins primarily in the context of major industrial and oil refinery accidents involving threats to public safety and the need to evacuate workers (see also the CIMAH and COMAH Regulations).[24] It was in this context that Lord Cullen decided in *Piper Alpha* that the Safety Case regime, which already applied to on-shore oil installations, should also (obviously) apply to off-shore oil installations. Lord Cullen described a Safety Case as the means by which an operator demonstrated to itself and the regulator the safety of *"its activities"*.[25] In his later report into the *Ladbroke Grove* accident, Lord Cullen cited the evidence of one of the expert witnesses, Mr Waite, on the purposes of a Safety Case:

> *"The principal purpose, I believe, is as a tool, a route map, a record of commitments for management to set out how they organise their operation to work safely. It also follows from that and it is sometimes combined with it that it is also a document that the regulators can use to check the company's, the operation's compliance and wider than compliance coverage of all matters that might affect safety. Thirdly, it gives confidence to the regulators, and perhaps through the regulators to the members of the public, and also to the management of the company that they have adequate controls to manage their operations safely".* [26]

22.23 In the *Piper Alpha* report, Lord Cullen pointed to a number of tools by which a *"Formal Safety Assessment"* (FSA) could be carried out, including: hazard and operability (HAZOP) studies; quantitative risk assessment (QRA); fault tree analysis (FTA); human factor analyses; and safety audits. Lord Cullen was not prescriptive as to how precisely an FSA should be carried out in any particular case. Lord Cullen emphasised that QRA is only one tool and said that QRA should not be used in isolation or as an automatic mechanism for risk assessment.[27]

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[24] The Control of Industrial Major Accidents Hazards Regulations 1984 (CIMAH Regulations) implemented European Council Directive 82/501/EEC[24] *"on the major-accident hazards of certain industrial activities"*, issued in 1982 (known as the 'Seveso Directive'). The CIMAH Regulations were later superseded by the Control of Major Accident Hazards Regulations (COMAH Regulations), which came into force on 1 April 1999 by way of implementation of European Council Directive 87/216/EEC[24], which amended the Seveso Directive (known as the 'Seveso II Directive').

[25] *Cullen*, paragraph 17.11.

[26] *Ladbroke Grove Rail Inquiry Part 2 Report,* paragraph 7.16.

[27] *Cullen,* paragraph 17.38. This is a view endorsed by the Health & Safety Executive.

Aid to thinking

22.24 The overriding theme which emerges from the *Piper Alpha* Report is that Lord Cullen wanted organisations to think more clearly and logically about the risks inherent in their installations and activities. He saw Safety Cases as a sensible means of achieving this end. Lord Cullen reiterated these views to me when I had the privilege of visiting him in Edinburgh to discuss his *Piper Alpha* and *Ladbroke Grove* Reports. He emphasised to me: *"Safety Cases were intended to be an aid to thinking about risk, not an end in themselves"*.

Civil Sector and other Military Fleets do not use Safety Cases

22.25 The Civil Sector does not use Safety Cases as an airworthiness management tool. Nor do the US Air Force (USAF), Canadian Air Force or Australian Air Force use Safety Cases. They were unaware of the concept. They each manage airworthiness in slightly different ways but aimed at the same general effect in terms of risk identification and mitigation.

US Air Force Airworthiness Model (OSS&E)

22.26 The USAF concept of assuring Operational Safety, Suitability and Effectiveness[28] (OSS&E) provides an all-encompassing structure within which the USAF governs the airworthiness of its mission systems,[29] whether passenger carrying commercial derivative aircraft, hybrid commercial derivative aircraft,[30] or pure military aircraft developments. OSS&E is intended to apply throughout the life of a product, from initial design to eventual retirement. It is applied retrospectively to those systems whose conception predates OSS&E. Operational Safety,[31] Operational Suitability,[32] and Operational Effectiveness[33] are established by 'base-lining' system characteristics and airworthiness documentation at programme initiation, preserving them throughout project life and updating them when required and authorised. The concept strives to achieve clear responsibility and accountability by designating a Single Project Manager (SPM), who is *"responsible for ensuring and preserving the OSS&E throughout the operational life of the system and end items they manage, in support of the operational commands and other users"*.[34] He is responsible for approving all configuration and maintenance changes, and modifications to the systems he manages. The SPM is required to work closely with the operational commands that operate the system to promote a coherent and effective approach to ensuring that the system provides the capability required. OSS&E is governed by a systems engineering (SE) process,[35] which in turn focuses on configuration management, operational risk management and system safety. At the technical level the SPM is assisted by a Project Chief Engineer. The Project Chief Engineer is the SPM's designated technical authority in the disciplined execution of the SE process, including development of the Systems Engineering Plan. He is responsible to the SPM for the establishment, implementation, management, and control of the SE activities necessary to develop and field robust products and systems that exhibit attributes of system security, OSS&E and Mission Assurance[36]. It should be noted that USAF acquisition projects (and SPM responsibility) transfer from the acquisition agency to a logistics centre (responsible for the long-term support of the mission system) as the project enters service. However, the acquisition agency will retain responsibility for the acquisition and introduction of new equipment to the fielded mission system. This differs from the UK position in which a single IPT will be responsible for a weapons system throughout its acquisition and life.

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[28] Detailed in Air Force Planning Document (AFPD) 63-12, Air Force Instruction (AFI) 1201 and Military Handbook (Mil Hdbk) 514.

[29] The term mission systems encompasses aircraft, weapons and support equipment.

[30] For example the E3 AWACs aircraft derived from a Boeing 707 airliner.

[31] **Operational Safety**—The condition of having acceptable risk to life, health, property, and environment caused by a system or end-item when employing that system or end-item in an operational environment. This requires the identification of hazards, assessment of risk, determination of mitigating measures, and acceptance of residual risk.

[32] **Operational Suitability**—The degree to which a system or end-item can be placed satisfactorily in field use, with consideration given to availability, compatibility, transportability, interoperability, reliability, wartime use rates, maintainability, full-dimension protection, operational safety, human factors, architectural and infrastructure compliance, manpower supportability, logistics supportability, natural environmental effects and impacts, and documentation and training requirements.

[33] **Operational Effectiveness**—The overall degree of mission accomplishment of a system or end-item used by representative personnel in the environment planned or expected (e.g., natural, electronic, threat) for operational employment of the system or end-item considering organization, doctrine, tactics, information assurance, force protection, survivability, vulnerability, and threat (including countermeasures; initial nuclear weapons effects; and nuclear, biological, and chemical contamination threats).

[34] AFPD 63-12, paragraph 3.9.1.

[35] SE may be referred to as a discipline, a methodology, an approach, a practice, a process, a set of processes and sub-processes, or various other terms; however, its fundamental elements – systematic technical processes and measurements – remain the same regardless of the collective nomenclature. AFI63-1201 23 July 2007, paragraph 1.1.

[36] AFI63-1201 23 July 2007, paragraph 1.1.2.2.

22.27 The physical implementation of OSS&E, and concomitant airworthiness, is achieved through the Weapon System Integrity Programme. This programme is composed of a number of sub-programmes, considering specific areas: the Aircraft Structural Integrity Programme (ASIP), the Mechanical Equipment and Subsystems Integrity Programme (MECSIP)/Functional Systems Integrity Programme (FSIP),[37] the Avionics/Electronic Integrity Process (AVIP) and the Engine Structural Integrity Programme (ENSIP).[38] Through a pro-active and reactive series of examinations (including aircraft tear-downs) and the examination of maintenance data, airworthiness is monitored and, for example, component fatigue lives can be calculated. A key component of the Weapon System Integrity process is frequent interaction between maintainers, operators and planners. Within the ASIP, individual aircraft are monitored through an Individual Aircraft Tracking Programme, which is used to determine maintenance requirements. These programmes are providing the data to enable the USAF to predict that the B52 and KC135 could continue to operate until 2040, despite having an average fleet age of 47 in 2008.

22.28 Although there is no direct comparison between the programmes by which the US and UK seek to assure airworthiness, the MOD's Safety Case and Ageing Aircraft Audit regime appears to have much in common with the USAF OSS&E. The UK Safety Case currently focuses on the mechanical/technical aspects of the mission system; however, the operator will operate the system within the limitations imposed by its Release-to-Service (RTS) and, as long as this is done, the system will be operated within a safe range of parameters. Specific consideration to theatre-specific risk is given by the operational commander. Suitability and Effectiveness are dealt with in the UK as part of the acquisition process lines of development; thereafter the Operating Authority considers these topics as part of its in-service management. Should changes to an aircraft's role change the assumptions made on entry to service, they are dealt with by the operational commander as part of the normal staffing process. Nonetheless, accepting the disparity in scales and resource between the UK and US, the procedures followed exhibit parallels, without displaying significant differences of intent or process.

UK Military equipment Safety Cases

22.29 In my view, however, MOD military equipment Safety Cases have become too elaborate. They should not seek to mimic Safety Cases in relation to major industrial installations or activities. Military equipment Safety Cases are generally concerned with a much more limited problem, both in scope and scale. The issue is simply: "Is this piece of equipment safe to operate?".

'Operational' Safety Cases and 'Hierarchy' of Safety Cases

22.30 The Review has heard much discussion about the 'hierarchy' of different types of Safety Case. The hierarchy of Safety Cases is said to include five layers:[39] (1) OEM[40] Safety Case; (2) IPT Equipment Safety Case; (3) RTSA Operational Safety Case; (4) AOA Operating Safety Case; and (5) Whole Aircraft Safety Case (WASC).

22.31 The Review has heard much discussion, in particular, about 'Operational' Safety Cases, especially from the Directorate (Air Systems) and those in Industry who advocate their benefits, such as QinetiQ. It is envisaged that Operational Safety Cases would apply elaborate Safety Case techniques, not just to the Platform 'As Designed', but also to analysing: (1) Weapons systems 'As Flown'; (2) Peacetime Training 'Steady State'; and (3) Contingent Operations/Transition to War/War-Fighting.[41] As an academic exercise, there might be some sense in taking the Safety Case concept to its logical conclusion. But I remain firmly sceptical as to the real benefit of Industry generating yet more warehouses of inaccessible and impenetrable paper anticipating and analysing the myriad of potential operational events and environments which platforms might encounter in the future. Currently, when (for example) commanders switch platforms such as the Nimrod from a wet/cold maritime to an entirely new a hot/dry desert role, they naturally ensure that an analysis is carried out of the new risks that operating the platform in a different environment might engender before deployment. The pragmatic and

[37] The FSIP is an attempt to apply the MECSIP, originally intended for new mission systems, to the sustainment of existing systems. It has a wide ambit, including hydraulic systems, engine conditioning systems and electrical/lighting systems.

[38] USAF Military Handbooks describe each of these programmes, but are for guidance and cannot be mandated on a contractor.

[39] BAE Systems September 2004, Baseline Safety Case Report.

[40] Original Equipment Manufacturer.

[41] QinetiQ Brief to the Nimrod Review dated 13 February 2009.

sensible time to do this exercise, however, is as and when such new operational challenges present themselves. With limited resources available, spending money on theoretical paper exercises should be firmly discouraged. Full Operational Safety Cases of the type proposed to the Review would require a pile of paper the size of the Tower of Babel.[42]

22.32 Equally, I do not think it is useful to have a 'Russian doll' series of separate Safety Cases along the lines of the 'hierarchy' suggested above. It seems to me that the most effective arrangement is the simplest: to have a single Safety Case for each platform covering the risks of operating the platform which can be used: (a) to inform and influence the daily management of a platform's Airworthiness; and (b) to underpin the aircraft's Release to Service.

What is the best value for money?

22.33 As Counsel to the Inquiry put it to one witness, the essential question is 'what is the best value for money?:

> *"**MR PARSONS QC:** … How do you improve safety and get the best value? …You have a pot of money which will always be limited, and in the present climate it is going to be even more limited. What is the best activity you can do to actually improve safety for the people who fly these aeroplanes or use them? Is this kind of quite formal document-heavy process, that requires a lot of time and effort to produce, the very best way of doing that, or is there a better way to go forward?"*

22.34 I do not believe that the current Safety Case regime represents value for money in terms of the net benefit to Airworthiness for the MOD's financial outlay. Much of this money would be better spent on improving Airworthiness in other ways. The costs being charged by Industry for Safety Cases are very substantial. BAE Systems' charges for Nimrod Safety Case 2, for instance, are in excess of £3 million (which at the standard rate advertised by BAE System for safety engineers of £40 per hour amounts to 75,000 man hours). As one former QinetiQ safety engineer commented: *"It's a phenomenal sum of money. You could get some of the best safety engineers in the country. You could employ York University to do that work and still make a massive profit and end up with a safety case at the end of it that is absolutely thorough, that you could hang your hat on."*

Safety Case concept has a useful role

22.35 In my view, although it is not used by other fleets, the Safety Case concept has a useful role to play as an Airworthiness management tool for MOD military platforms. It provides a useful vehicle and reference point for risk management and, properly applied, should *"encourage people to think as actively as they can to reduce risks",* as Lord Cullen envisaged.[43] But the current Safety Case regime needs to be brought in-house, slimmed down and re-focused in accordance with the Recommendations below.

Current definition of Safety Case is unhelpful

22.36 The situation has not been helped by the definition of "Safety Case" in Defence Standard (Def-Stan) 00-56[44], which tends to encourage a laborious, discursive, document-heavy 'argument' ("*a structured argument", "a body of evidence"*) aimed at justifying a self-fulfilling prophesy ("*system is safe"*). Further, the tenets in BP1201 that Safety Cases must be *"Credible, Consistent, Complete, Comprehensible and Changeable"* are, in my view, too amorphous to inject real rigour and focus into the process.

[42] According to Genesis Chapter XI, the Tower of Babel was built in Nimrod's kingdom by the survivors of the flood and their descendants. However, as the Tower was built out of vanity for the glory of man, God dispersed the people throughout the world and made them speak different languages to spread confusion. Hence the dictionary definition of Babel includes "a foolishly conceived lofty structure" and "a scene of confusion".

[43] *Ladbroke Grove Rail Inquiry Part 2 Report*, paragraph 7.19.

[44] See further **Chapter 9**.

Six Principles for "Risk Cases" in the future

22.37 In my view the following six Principles should shape *"Risk Cases"* in the future:

- ✔ **S**uccinct
- ✔ **H**ome-grown
- ✔ **A**ccessible
- ✔ **P**roportionate
- ✔ **E**asy to understand
- ✔ **D**ocument-lite

Recommendations

22.38 I set out below my further Recommendations regarding best practice for Risk Cases.

Recommendation 22.1: The Safety Case concept should be retained by the MOD, provided it is brought in-house, slimmed down, and made consistent both with the Recommendations below and the Recommendations in **Chapter 21** that there should be a single, concise, through-life *"Risk Case"* for each platform owned by the Regulator, and backed up by a single Risk Register.[45]

Recommendation 22.2: Safety Cases should be re-named *"Risk Cases"* in order to focus attention on the fact that they are about managing risk, not assuming safety.

Recommendation 22.3: *"Risk Cases"* should henceforth be drawn up and maintained in-house by the Regulator/Services and not outsourced to Industry. All Safety Cases which are currently being managed or drawn up by Industry should be re-named and brought in-house.

Recommendation 22.4: Front Line maintainers and operators should have a major role in drawing up and maintaining *"Risk Cases".*

Recommendation 22.5: Business Procedure (BP) 1201 and other relevant regulations should be redrafted to reflect the principles relevant to *"Risk Cases"* outlined above, namely that "Risk Cases" should be Succinct, Home-grown, Accessible, Proportionate, Easy to understand and Document-lite (SHAPED).

Recommendation 22.6: The definition of a Safety Case in Defence Standard 00-56[46] should be replaced with the following simple definition of Risk Case: *"A Risk Case is reasonable confirmation that risks are managed to ALARP."*

[45] See **Chapter 21**, Recommendations E.21.1 to E.21.7..

[46] Defence Standard 00-56, paragraph 9.1: A Safety Case itself is defined in the military context as *"a structured argument, supported by a body of evidence, that provides a compelling, comprehensive and valid case that a system is safe for a given application in a given environment"*

Application of the Principles

22.39 The aim of the SHAPED Principles is to ensure the flexibility, economy, and effectiveness of Risk Cases for the future. They are intended to help ensure that Risk Cases are appropriate to the task, effective in identifying the key risks, useful to those managing risk on a daily basis, and represent best value for money. I envisage that that Risk Cases should vary considerably in length, scope and content.

Risk Cases for Modifications

22.40 For many simple modifications, Risk Cases should be no more than a couple of lines (*e.g.* 'consideration has been given to the risks inherent in fitting the modification and no additional material risks are anticipated'), or a couple of pages listing the key additional risks and existing and recommended mitigations. For more complex modifications, Risk Cases would naturally be longer.

Risk Cases for Legacy aircraft

22.41 For legacy platforms, full Risk Cases should be required, although there needs to be a pragmatic approach. I would envisage teams of half-a-dozen personnel spending no more than two to six months using their engineering knowledge and experience to produce a Risk Case. The team would typically include personnel who were very knowledgeable and had maintained and operated the platform in question, personnel with experience of other types, a design specialist and a specialist in safety management who understood how to put the process together, manage the evidence and turn the information and data into the required format. Much of the work, analysis and thinking would be carried out whilst around and examining the aircraft itself.

22.42 In my view, consistent with the SHAPED principles, a Risk Case for a 'legacy' aircraft should typically comprise:

- Identification of the major hazards causing Loss of Aircraft and/or Loss of Life (*e.g.* Uncontrolled Fire/ Explosion, Controlled Flight into Terrain/Mid-Air Collision, Loss of Thrust, Loss of Control, Structural Failure, *etc.*) and high risk systems (*e.g.* fuel, hydraulics, flying controls, electrics, hot air, *etc.*).
- HAZOP Analysis of key risks, Zonal Hazard Analysis (ZHA) of high risk zones and FMECA[47]/teardown and/or sampling and/or non-destructive testing of key systems or materials where appropriate.
- Appropriate checks on fault data trends and relevant databases.
- Appropriate engineering judgments on risks probabilities.
- Appropriate risk mitigation recommendations.
- Entry of all hazards on the Hazard Log (and Risk Register).
- A short Report highlighting the key hazards and mitigations.

Approach

22.43 I set out below a number of matters which those drawing up *"Risk Cases"* in the future might wish to bear in mind:

(1) Care should be taken in project planning. It is necessary to decide at an early stage the aim of the exercise, the desired product and how it is to be achieved. In cases breaking new ground it might be wise to perform a scoping exercise; in effect a dry run on a small area to refine the process. This would determine a useful structure for the project (training, equipment, personnel, information, doctrine, organisation, infrastructure, and logistics).

[47] Failure Mode Effects Critical Analysis.

(2) Common sense should be applied from the outset. Many aspects of an aircraft will obviously represent little or no hazard based on existing operational and maintenance knowledge. So time should not be wasted time on them at the start of the process. It would be much better to identify and target the high risk systems (*e.g.* fuel, hydraulics, flying controls, electrics, hot air *etc*) at the outset of the project.

(3) There must be the right personnel involved from the outset, namely the appropriate mix of designer, maintainer, air operator and engineering staff in order correctly to capture and interpret all relevant information and eventually to consider mitigations. The quality and consistency of personnel should be maintained throughout the project. Strong operator involvement is crucial throughout. As emphasised in, *e.g.,* the Railways 'Yellow Book': *"When considering methods of risk reduction you should involve the system users. A good safety process involves the system users throughout the project, investigating with them how the system may be improved, either to help them avoid error, or to mitigate other system errors."*[48] As the former CEO of General Electric, Jack Welch, once said, *"The people closest to the work know the work best."* In a prescient memorandum, dated 18 July 2001, it was suggested that the operators, not the IPTL, should make the judgment as to what risks were and were not acceptable: "*with regard to the acceptance of risk, the IPTL is the custodian of hazard information and the focus for assessment of technical risks, but he does not own the risk. Whether or not a risk is acceptable is a judgment not for the IPTL but for Customers one and two."*[49]

(4) There should be clarity and definition at the outset as to what constitutes a *"Hazard", "Control", a "Mitigation"*, and a *"Cause"*.

(5) Care should be taken to ensure that preparation of the Risk Case is platform-centric rather than office-based, *i.e.* that the majority of thinking and analysing takes place in and around the aircraft whilst examining it and not in a remote office. Ready access to the aircraft and its zones throughout the drawing up of the Risk Case is vital.

(6) The Risk Case should take the platform/aircraft as it finds it. I do not believe that previous artificial distinctions defining types of the Risk Case, *i.e.* 'As Designed', 'As Flown', 'As Used', *etc.* are helpful. Realism should be applied from the outset. With 'legacy' aircraft, it makes no sense to look at the 'as designed' case when it is obvious that, after 30 to 40 years, an aircraft 'on the Front Line' will not be the same as the one which rolled out of the factory. It is unrealistic and pointless to assess the operating risks of such an aircraft without taking into account its actual condition after 30 to 40 years of age and deterioration. In my view, Risk Cases should look at all platforms/aircraft 'As Is'.

(7) Care should be taken when utilising techniques such as Goal Structured Notation or 'Claims-Arguments-Evidence' to avoid falling into the trap of assuming the conclusion ('the platform is safe'), or looking for supporting evidence for the conclusion instead of carrying out a proper analysis of risk.

(8) Care should be taken when using quantitative probabilities, i.e. numerical probabilities such as 1×10^{-6} equating to *"Remote"*. Such figures and their associated nomenclature give the illusion and comfort of accuracy and a well-honed scientific approach. Outside the world of structures, numbers are far from exact. QRA is an art not a science. There is no substitute for engineering judgment. As the HSE emphasised to the Review: *"Quantative Risk Assessment has its place, but should never be used as an absolute measure of safety."*

(9) Care should be taken when using historical or past statistical data. The fact that something has not happened in the past is no guarantee that it will not happen in the future. *Piper Alpha* was ostensibly 'safe' on the day before the explosion on this basis. The better approach is to analyse the particular details of a hazard and make a decision on whether it represents a risk which needs to be addressed. Word-searching on the Incident Report database may be a useful guide in some cases towards particular systems which may warrant closer inspection because of recurring faults; but it is no more than a single tool.

(10) Care should be taken with 'legacy' platforms not to indulge in a soft 'archaeological' exercise, *i.e.* simply finding documents to prove the aircraft complied with its original safety and certification requirements. The Review was told that a high percentage of Safety Cases tend to comprise simply a process of *post hoc* documentation of what engineers originally did to design the system in question. This is waste of time and money (see **Chapter 9**).

[48] http://www.yellowbook-rail.org.uk/site/the_yellow_book/yellow_book_vol1and2_issue4.pdf, paragraph 15.3.3.5, page 181.

[49] Customer 1 is Procurement and Customer 2 is the Operator.

(11) Care needs to be taken to define the process whereby new hazards can be added to the Risk Case, incorporated in the Hazard Log, and dealt with in due course, and how original assumptions about hazards or zones are to be re-examined in light of new events. In the case of the XV227 incident in 2004, for example, although the fact of the incident was entered in the CASSANDRA Hazard Log in relation to Hazard H73 ('no further action'), there is no evidence to suggest that the original assumptions of probability and risk were ever looked at.

(12) Do not assume that, simply because an aircraft has flown safety for five or 25 years, it is safe (*i.e.* 'implicit' safety). The right attitude is a questioning attitude, as the former QinetiQ Safety Engineer, Witness L [QinetiQ], emphasised to the Review:

> **MR PARSONS QC:** *The trouble is, if you start with the assumption that it is safe, you don't ask the questions.*
>
> **WITNESS L [QinetiQ]:** *Yes. You should start with the assumption this aircraft isn't safe. You start with the assumption it is a fatigued aircraft. Prove to me that the wings are going to stay on. Prove to me that the engines will keep flying. Prove to me that the engineers that are servicing these engines have not become complacent because they have been working on them so long. Regularly, when I joined QinetiQ, people would say: this is a steam driven aircraft, nothing can go wrong with it, it is all hard wired, there is virtually no software, there is very low risk, it is a very safe aircraft. That is the wrong position to be in, especially if you are a safety engineer.*

(13) The key question to be asked at all stages is: 'What if?'

CHAPTER 23 – AGE MATTERS

"Age will not be defied."
(Francis Bacon, 1561-1626)[1]

"The Nimrod fleet is old and its systems appear to be reaching the wear-out phase of the reliability 'bath tub' curve."
(HQ Logistics Command, Nimrod 'Health Check', 21 February 1996)

"The philosophy is, if you are going to make do with old aircraft, you have to capture the maximum amount of data available and study the data sets carefully."
(Garry Copeland, Director of Engineering, British Airways, 2008)

Contents

Chapter 23 deals with matters relating to Aircraft Age and makes Recommendations.

Summary

1. Aircraft age matters, but is not a bar to airworthiness.
2. Older aircraft generally need greater rigour, resources, and vigilance to ensure they remain airworthy. With the right care, 'legacy' aircraft can continue to fly safely for many years. It is a question of resources, priorities, and unrelenting attention to detail.
3. Further work and research needs to be carried out in relation to the ageing of aircraft systems.
4. In the late 1990s, the Nimrod fleet was already beginning to be described as *"old"* and reaching the end of the 'bathtub' curve. I do not believe that there was sufficient attention paid to airworthiness management generally in the MOD during the period 1998-2006 or, in particular, in relation to the Nimrod fleet.
5. The harsh reality is that poor maintenance practices can become ingrained over time, if left unchecked by management.
6. Degradation is progressive, and often imperceptible, and needs specific periodic audit and rectification to overcome.
7. The inconvenient truth is that elastomeric fuel seals do deteriorate, over time, for a variety of reasons. More international research is required in this area. Meanwhile, it is vital that active thought is always given to the appropriate management of all elastomeric seals.
8. The generic problems in relation to some aged and 'legacy' aircraft include:
   (1) Design to standards which would not be acceptable today;
   (2) Difficulties of access and maintenance;
   (3) Diminishing pool of skilled engineers;
   (4) Decline of 'corporate knowledge';
   (5) Dwindling spares;
   (6) Difficulties of incorporating modifications and new systems;
   (7) Different aging rates of systems and components;
   (8) Degradation of components; and

[1] Francis Bacon: Essays (1625) *'Of Regime of Health'*.

(9) Determination of 'baseline' safety.

9. The lesson learned from the Nimrod XV230 case is that age matters. The following matters are all the more important as an aircraft gets older:

(1) Good trend monitoring;

(2) Good husbandry;

(3) Good attention to spares;

(4) Good attention to skills;

(5) Good corporate knowledge; and

(6) Good forensic teardowns.

Introduction

23.1 'Age' in relation to aircraft is, understandably, an emotive subject. There is a perception that 'old' is bad and 'new' is good. The equation is, however, not as straightforward as that. Age is not *ipso facto* bad, so long as its effects are understood, appreciated, and defied. Age may even bring some advantages in the form of reliability and predictability. The average age of the US Air Force B52 Bomber fleet is 47 years, and I understand that it is the current intention of the US Air Force to continue to operate this fleet until it is at least 75 years old, and perhaps beyond.

23.2 Nonetheless, older aircraft generally need more care, not less. Ever greater rigour, resources, and vigilance are required to ensure they remain airworthy. Given the right levels of care, repair, and maintenance, however, there is no reason why many 'legacy' aircraft should not continue to fly safely for many years. It is a question of resources, priorities, and unrelenting attention to detail.

'Bathtub' curve

23.3 The 'bathtub' curve is a useful graphical representation to illustrate a common reliability trend during the life of a product or piece of equipment (See Figure 23.1 below). The 'bathtub' curve comprises three periods: (a) the 'infant mortality' period with an initially high but (immediately decreasing) failure rate as 'teething' problems are sorted out; (b) a 'normal' or 'useful' life period with a low, relatively constant failure rate (as the product or equipment and its use settles down); and (c) a 'wear-out' period which exhibits an increasing failure rate as age and reliability begins to take its toll.

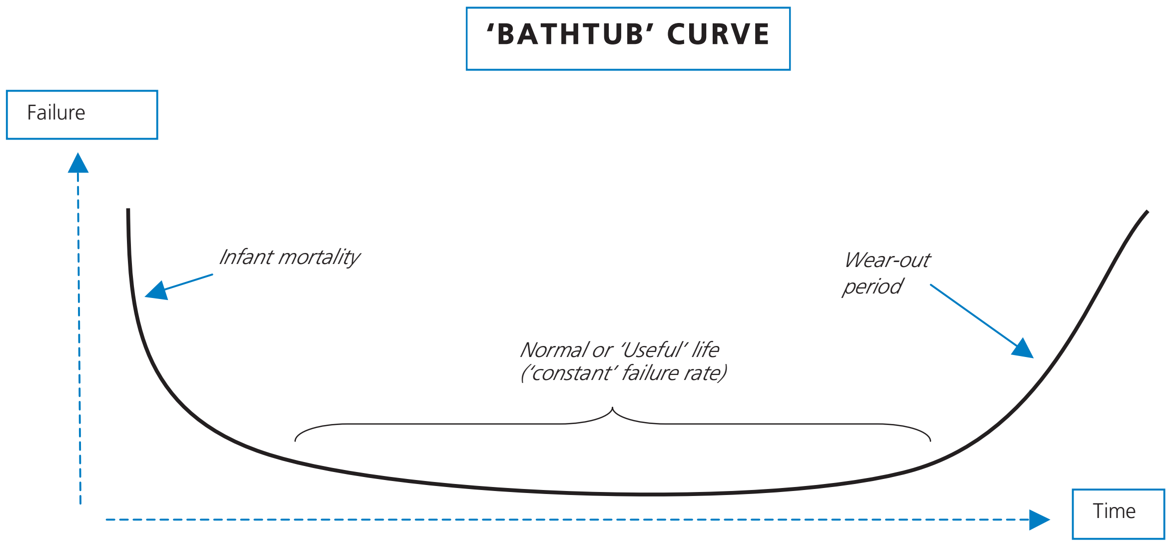

Figure 23.1 The 'bathtub' Curve

23.4 Manufacturers seek to reduce 'infant mortality' problems by good design and 'stress testing' to identify design weaknesses and specific assembly and materials problems.[2] The term 'Military Specification' is sometimes used to describe systems, usually life-critical or system-critical, in which the 'infant mortality' section of the bathtub curve has been 'burned out', or removed by means similar to accelerated stress testing.

23.5 It is not possible to eliminate all risk of 'infant mortality': there will always be initial design or manufacturing problems that manifest themselves early on in the life of a new piece of equipment, *e.g.* initial software problems in on-board computers in modern 'fly-by-wire' aircraft or the vulnerable 'square' window design on early Comets. Equally, those charged with assuring and ensuring the airworthiness of aircraft need to grapple firmly with issues which will inevitably arise in the 'wear-out' period, *i.e.* incipient failures as structures, materials and systems begin to enter their 'wear-out' phases. The airframe failure cases, such as the Aloha Flight 243 accident in 1988, first highlighted the need to consider, *e.g.*, the effects of long-term corrosion and interaction with shortcomings in design, maintenance or manufacture of aircraft structures. Since this case, there has been a great deal of work done on aged aircraft structures and structural failures in aircraft due to stress and corrosion; and, as a result, fatigue and failure rates and modes in relation to aircraft fuselages and structures are, for the most part, now well understood, documented, and predictable.

23.6 Much less is known, however, about aircraft systems and the effects of age and long term use on many of the systems contained within airframes, comprising as they do a wide variety of different designs, functions, and materials.[3] There has been considerable work in certain areas which have manifested problems, *e.g.* 'Kapton' wiring. The approach to aged systems generally, however, has been piecemeal and reactive. Work, research, and knowledge need to increase in this field, since the numbers of 'legacy' aircraft in operation are growing. In a 2002 paper COM(Air) highlighted that the average age of the MOD fleet was 21 years, and the majority of MOD aircraft had exceeded the 15-year threshold which initiated the Ageing Aircraft Audit management to preserve and sustain airworthiness (see further below).[4]

Nimrod and 'Bath tub' curve

23.7 In the late 1990s, the Nimrod fleet was already beginning to be described as *"old"* and reaching the end of the 'bathtub' curve. In February 1996, a Nimrod 'Health Check' carried out by HQ Logistics Command itself reported: *"The Nimrod fleet is old and its systems appear to be reaching the wear-out phase of the reliability 'bath tub' curve."* In July 1998, the Nimrod Airworthiness Review Team (NART) referred to the demands "*symptomatic of keeping an old aircraft flying"*.[5]

23.8 A decade later, a number of witnesses to the BOI raised concerns in 2007 regarding the age of the Nimrod fleet and its position on the 'bathtub' curve:

23.8.1 Witness 33 said: *"The Nimrod is certainly towards the end of the "bath tub" curve". We are starting to see things we may not have seen before and these take time to investigate. There are some advantages in having an ageing aircraft. Compared to something like Typhoon it is a relatively simple aeroplane. The things that go wrong are the mission system but the bits that keep it in the air are very tried and tested."*

23.8.2 Witness 34 said: *"Do you understand the bathtub? To my mind you have an aircraft which is beyond its sell by date and is an ageing aircraft.… Your maintenance should change to more inspection or forced replacement of critical components…I think it is wrong to have these components on condition."*

23.9 As I explained in **Chapter 13**, I do not believe that, in the period 1998-2006, there was the sort of "*highly attentive management, closely attuned to the incipient threat to safe standards if* [Nimrod] *airworthiness is to be safeguarded"* that the NART called for.[6] For instance, as the BOI pointed out, there was insufficient fuel leak trend analysis. I do not believe that there was sufficiently attentive airworthiness management generally in the MOD during this period.

23.10 There were, nevertheless, Life Extension Programmes and Ageing Aircraft Audits applied to the Nimrod fleet.

[2] *E.g.* HALT (Highly Accelerated Life Test) or HAST (Highly Accelerated Stress Test).

[3] There has been considerable work in certain areas, such as 'Kapton' wiring. The approach to aged systems has been piecemeal and reactive rather than pro-active.

[4] COM(Air)/105/02 paper.

[5] Paragraph 30 of Nimrod Airworthiness Review Team Report, dated 24 July 1998.

[6] Paragraph 30 of Nimrod Airworthiness Review Team Report, dated 24 July 1998.

Life Extension Programme

23.11 XV230 was the first Nimrod to enter service in 1969 (in MR1 form). XV230 underwent the MR2 conversion programme in 1981. At the time of the accident in September 2006, XV230 was, therefore, 37 years old.

23.12 The Nimrod MR2 has a 'Safe Life' based upon its structural integrity, managed through the consumption of platform's Fatigue Index (FI) but has no specific flying hour life.[7]

23.13 A Nimrod platform Life Extension Study was undertaken by BAE Systems in 1990. A life extension exercise seeks to increase the limiting elements of the platform's life (fatigue, landings, cycles etc). The BAE Systems Life Extension Study in 1990 concluded that there was little doubt that the Nimrod MR2 airframe and systems were essentially capable of extended life, well into the 21st Century, but that a programme of work would have to be undertaken to ensure that the fleet life was not curtailed by fatigue, corrosion, or excessive support costs.[8] This may, or may not, have had an effect on the platform's Out-of-Service Date (OSD).

23.14 Nim(ES)AWS(AV)Con2 confirmed to the Review that, since BAE Systems' 1990 report, there has been no other life extension study undertaken on the Nimrod. There was, however, an OSD extension study. An OSD extension study investigates whether or not the platform's current usage rates (fatigue, landings, cycles etc) will allow the OSD of the platform to be extended. Regrettably, of the two files relating to the Nimrod OSD extension study, one was destroyed on 24 May 2005[9] and the other was located and reviewed, but did not contain any OSD extension data.[10]

Ageing Aircraft Audits

Regulations

23.15 Joint Service Publication (JSP) 553 mandates that IPTLs conduct Ageing Aircraft Structural Audits (AAAs). Periodicity is defined as initially after 15 years from the in-service date, and every 10 years thereafter until the aircraft is out of service, with the requirement that the audit activity is to be completed within a 3-year period. However, whilst JSP553 sets out the requirement to undertake an AAA, it refers only to aircraft structures. Although the AAA requirement was extended to include aircraft systems around September 2006, with the specific requirements set out in the JAP 100A-01, JSP553 has yet to be updated to include the additional requirements, even though it is the higher level policy document.

23.16 AAAs, as defined in JAP 100A-01, comprise Structural Audits, Aircraft Systems Audits (*e.g*. mechanical, avionics and weapons), and Propulsion System Audits. For some aircraft, this undertaking will be closely related to the management of obsolescence and life extension programmes. The JAP 100A-01 defines an AAA as:

23.16.1 A periodic, independent assessment of the airworthiness of the aircraft and its systems as they age.

23.16.2 A vital through-life management (TLM) activity that is to be reflected in the aircraft's TLM Plan.

23.16.3 An activity intended to bring together the routine management activities, often carried out in isolation, in order to build a coherent picture of the state of the aircraft fleet.

23.16.4 An activity that should also seek to identify patterns or trends that point to future integrity problems.

23.16.5 An activity to identify significant risks to the aircraft and its systems: it is not simply to record the status of the aircraft and its systems, management processes, technical information and documentation. These risks are to include both current and potential risks to the planned OSD being reached.

23.17 JAP 100A-01, Chapter 16.4, paragraph 1.1, provides: *"The risk to airworthiness, cost and operational availability due to ageing of aircraft in service is partly mitigated by maintenance activities, however, the insidious nature of degradation and the interaction of apparently unrelated ageing processes is often only found by rigorous periodic audit of trend data, procedures and, if necessary the aircraft's physical condition"*.

[7] BOI Report, Exhibit 25; and the IPT's response of 15 March 2007.

[8] BAES report 807/RGJ/1609/11 *"Extension of Nimrod MR Mk 2 Operational Life until circa 2025"*, dated 19 September 1990.

[9] DLO(Strike)(Wyt)/512740/13 Part A.

[10] DLO(Strike)(Wyt)/512725/17 Part A.

Ageing Air Audits: Background

23.18 AAAs have historically been purely structural inspections of fleet leaders to determine the structural integrity of the aircraft and, thus, its airworthiness. These audits were intended to complement the full scale fatigue specimen tests undertaken by the Design Authorities. As aircraft systems became more complex and software-based, there began to be recognition that the systems on an aircraft were similarly affected by ageing and that their condition had a bearing on an aircraft's airworthiness. The AAA programme was therefore extended to include an assessment of the ageing effects on propulsion and aircraft systems to determine the current and future airworthiness of the aircraft/fleet. The analysis is also intended to provide a validation and update of the aircraft's maintenance policy.

Nimrod Aged Aircraft Audits

23.19 AAAs were conducted on the Nimrod fleet in 1993. These were reviewed in 2003. In common with both civilian and military practice at the time, however, the AAA focused solely on the structural integrity of the airframe and not systems.[11] The AAA review of 2003 addressed the delay in the MR2 OSD to 2010 and made a number of airframe recommendations in response to the delay. In 2005, as part of a life extension programme, a Nimrod Fatigue Specimen Teardown was carried out by BAE Systems (for the Nimrod IPT) in relation to certain parts of the airframe.

Nimrod XV236 teardown 2008

23.20 The first aircraft to undergo an Ageing Aircraft Systems Audit (AASyA), rather than a purely structural audit, was Nimrod XV236, comprising a destructive 'teardown' undertaken by QinetiQ. Further QinetiQ (destructive) AASyA activity has commenced on a VC10, and will soon start on a C130. Other platforms are at various stages of maturity with respect to this requirement.

Comment

23.21 The Nimrod AASyA was called for in the XV230 BOI recommendations. As a result of which, XV236 has been subject to a forensic teardown by QinetiQ comprising destructive dismantling in order to assess the airworthiness of the aircraft's systems, and the impact of age on the aircraft's airworthiness. No fatigue analysis of the aircraft structure has so far been undertaken.

23.22 The AASyA does not stipulate a requirement for forensic teardown, rather it is intended to provide a periodic independent assessment of the aircraft's airworthiness by examining maintenance data, components, and aircraft systems. However, for the Nimrod AASyA, QinetiQ were contracted by the IPT to undertake a forensic, destructive teardown of the aircraft, even though there was no requirement for such an undertaking in the JAP 100A-01or JSP553 regulations governing AASyA.

23.23 No maintenance data analysis was undertaken prior to the destructive teardown to determine 'trends or patterns' that may indicate future integrity issues or to provide a focus for the audit. Given that a destructive assessment undertaken by QinetiQ would not have identified the gradual increasing in fuel coupling leaks identified by Squadron Leader Andrew Gransden during the BOI, this raises the question whether, the AASyA should have begun with a comprehensive analysis of the maintenance data to determine other underlying trends and patterns that might indicate a developing airworthiness risk.

23.24 The audit was benchmarked against the standard of a new aircraft and identified all deviations from the benchmark standard. The assessment was then compared against the aircraft log book to determine what faults had been accepted and corrective action deferred. What the team found was an extensive number of faults that were not recorded in the aircraft ADF[12] log or in the aircraft husbandry log. The RAF's response was to review QinetiQ's findings to determine which of the faults identified by QinetiQ represented an airworthiness risk. A visual audit (limited to those areas considered by QinetiQ) identified that most of the faults were minor in nature and did not represent an airworthiness risk, although a small number were assessed as a potential airworthiness risk requiring further investigation. The detailed investigation into these faults subsequently confirmed they did

[11] AAAs were expanded to include aircraft systems in September 2006 (too late for Nimrod XV230). Formal guidance on implementation has yet to be issued: see BOI Report, paragraph 31b [2-18] and Exhibit 25.

[12] Acceptable Deferred Faults.

not represent an immediate airworthiness risk, although corrective action was undertaken. For the subsequent QinetiQ reports, faults were sentenced to determine their potential airworthiness risk, and then forwarded to the IPT who initiated fleet inspections where they considered it necessary. Recommendations were made by the Unit requesting a change to the maintenance policy to provide for a defined level of reconditioning appropriate to the Nimrod; to provide guidance on what additional areas should be checked prior to the next Equalised Maintenance; and to define the husbandry standard for all aircraft undergoing Depth maintenance given that the maintenance policy is somewhat vague in its definition.

Root cause of poor husbandry: inadequate contracting arrangements with Industry

23.25 In terms of context, it is important to note the following points. Whilst the initial attention focused on standards and practices of Front Line personnel, the reality is somewhat more nuanced. In moving Nimrod from Scheduled to Equalised Maintenance, much of the husbandry activity was shifted to Depth, the corrosion control team was disbanded, and the number of personnel at Forward was reduced accordingly. The contract arranged with Industry to undertake Equalised Maintenance gave rise to financial and time constraints that have resulted in aircraft being repaired 'to fault', rather than being reconditioned. Accordingly, over time, the husbandry standard of the fleet has declined. It is likely, however, that there were husbandry shortfalls prior to the move from Scheduled to Equalised Maintenance given the findings on other aircraft fleets. Moreover, it appears that the gradual decline had become accepted by those involved with the Nimrod who did not expect the aircraft to be reconditioned, and who had become accustomed to the output standard of aircraft from Depth. It is also important to note than many of the areas identified by QinetiQ during their assessment and the teardown are not inspected by Forward personnel, nor are they inspected on every, Equalised Maintenance. Whilst Forward may reproach themselves for (a) not recording husbandry issues, (b) accepting the declining husbandry standard, and (c) some standards and practices issues, in my view the root cause was the contracting arrangement with Industry which did not provide a means for the aircraft to be reconditioned periodically. For example, expectations that a line tradesman undertaking a post-flight walk around would be able to spot a degrading 'p' clip (amongst several hundred) by cross-referencing the aircraft documentation, particularly given that an aircraft is not de-panelled during such an inspection, is unrealistic and naive; yet it is a criticism that has been levied at all Forward personnel and which has been read across to other platforms.

23.26 As degradation is progressive and often imperceptible, it needs *specific* periodic audit and rectification to overcome. Line personnel who inspect aircraft on a daily basis quickly become accustomed to levels of degradation and are unable to see a slow, insidious accumulation of minor faults. What is needed is a comprehensive maintenance policy which inspects and rectifies the effects of ageing at periodic intervals, and assesses trends and data over a longer term so that potential airworthiness risks can be identified.

23.27 It is clear from the AASyA findings that the assessments in the Safety Case and in the support policy are based on assumptions about aircraft maintenance which are not reflected in the as-maintained condition of the aircraft. Moreover, there is no system in place to close this gap in order to make sure the assumptions bear witness to reality. Many of the faults found during the AASyA could have been in place for many years. The question is: 'Why they were not identified during Equalised Maintenance?'. This is most likely a reflection of the maintenance policy and the maintenance support contract. It is perhaps inevitable that maintenance practices in Depth reflect the fact that most of the maintainers are former Nimrod technicians who have become used to traditional maintenance practices over many years, unchecked by a very thin management chain.

QinetiQ Final AASyA Report

23.28 At the time of writing, conclusions to the AASyA are still in draft but reflect the following:

(1) The predominant observation observations were in the categories of corrosion, wear/chaffing/fretting and incorrect fitment/routing/clearance/alignment. The majority of these observations had passed previous maintenance activities undetected and/or unrecorded.

(2) The inability to achieve the required clearances is a major contributing factor.

(3) There are shortfalls in maintenance practice that are not reflected in the existing Nimrod Safety Case.

(4) Shortfalls in maintenance practices should be reflected in the Safety Management System.

23.29 A wide range of recommendations are made relating to: the review of skills, training and awareness; Forward and Depth policies, procedures and practice; the importance of fault recording; the frequency and depth of zonal inspections; and the need for the safety management system to reflect the 'as-maintained' rather than the 'assumed as-maintained' condition of the aircraft.

Out-of-Service Date continually extended

23.30 23.30 Attention to a number of these matters was bedevilled by the fact that the OSD of the MR2 fleet was continually put back because the In-Service Date of the MRA4 slipped on no less than six occasions in the period 1999-2008 (see **Chapter 14**).

Elastomeric seals – lessons to be learned

Inconvenient truth

23.31 As explained in **Chapter 5**, the inconvenient truth is that elastomeric fuel seals do deteriorate. This can be due to: (1) age; (2) misalignment; (3) pressure; (4) vibration or airborne stresses; (5) temperature; (6) drying out; and (7) manufacture. Fuel coupling leaks are difficult to predict and hence any catastrophic consequences of their failure should be mitigated by design. Elastomeric seals are widely used in military and civilian aircraft around the world. Many legacy aircraft may contain seals which have been in place for decades. Not enough is known about fuel seal behaviour. More international research is required in this area.

'To life or not to life?'

23.32 A major issue remains: 'To life or not to life?'. The question is whether or not to place a hard life on elastomeric seals used in aircraft fuel and hydraulic systems, such that they must be replaced after a defined period.

23.33 There are two schools of thought, one in favour and the other against. Respectable arguments can be made either way. Experienced opinions within the RAF itself diverge. The BOI recommendation that a life be determined for FRS coupling seals seemed to many, heretical. The RAF Kinloss Station Commander supported the BOI recommendation that a life for FRS Series 1 fuel seals be determined, but rightly said *"such a life should be based on an understanding of the failure mode and factors that promote degradation as these will determine when a seal is not fit for purpose rather than simply installed or shelf life"*.[13] The Air Member for Materiel took the view that applying a finite life to seals might not yield improvements in safety because of *e.g.* associated disturbance to other systems and the fuel system itself, and said primacy should be afforded to taking action to mitigate any consequential hazard from a leak.[14] In November 2007, DE&S Safety & Engineering Air-CASD-AVI Hd carried out a detailed review of the MOD's lifing policy for aircraft system seals, which concluded that there was no requirement for an MOD-wide single policy for lifing seals, but this depended on *"design requirements being met throughout the life of the aircraft and best practice maintenance policies with regard to seals being applied"*.[15]

23.34 Eaton Aerospace's post-XV230 decision to revise its Declaration of Design and Performance (DDP) for the FRS seal to recommend replacement after 25 years was rejected by the MOD. This was primarily because Eaton was unable to offer any evidence of analysis to support its recommendation, as was the case when they presented to the Review. There appears to be little evidence of other manufacturers or operators following a similar path. Fuel seals are still regarded to some extent as a product to be fitted and forgotten. This is not a view unique to the MOD or the UK, but appears to be common among other nations' military and, indeed, civilian aircraft fleets. However, it is clear that, on a few occasions, certain fuel seals have been lifed.

[13] See Comments on BOI Report by Station Commander, paragraph 9.

[14] See Comments on BOI Report by Air Member for Materiel, paragraph 3.

[15] See DE&S Safety & Engineering Air-CASD-AVI Hd: *Review of the Lifing Policy for Aircraft System Seals*, dated 22 November 2007.

23.35 I consulted the United States Air Force (USAF) on this specific question of lifing seals. I had the benefit of advice from a leading USAF expert in the field, from AFRL/RXSA (System Support), Wright-Patterson Air Force Base.[16] The expert explained that seals contain a lot of entropy[17] and there are a large number of variables that can affect them, including stress, heat, and drying out. He told me that *"there are no current methods that can reliably predict seal life"*. For this reason, the USAF does not life seals. He said that there was currently a lack of sufficient knowledge about the materials from which seals were made and the constituent properties had not been translated into a Finite Element (FE) model. He said that this topic was still in the "*too difficult*" box and further research was required. I fully accept all his advice and views.

Prevailing attitude that fuel leaks 'inevitable'

23.36 There was, and remains, a prevailing attitude that leaks in aviation fuel systems are an inevitable fact of life.

23.37 This is reflected in, *e.g.* the DE&S "*Review of Lifing and Maintenance Policy for Aircraft System Seals,*"[18] dated 22 November 2007, which stated that *"ultimately, leaks from seals are inevitable and the system design principles used for aircraft in both the civil and military environments to mitigate against leak hazards (sic)"*. The term 'leak tolerant' (which seems to have sprung up since the loss of XV230) appears intended to convey the sense that fuel leaks in themselves should not pose a significant hazard because aircraft should be designed and constructed in such a way that leaks would never reach a point of ignition. This is undoubtedly true in theory: any competent designer should naturally do everything to eliminate the risk posed by sources of ignition. Nonetheless, as the *TWA 800* case[19] and XV230 have starkly illustrated, however careful you think you have been, you cannot be sure you have anticipated all potential ignition sources.

Ignition/Leak Philosophy

23.38 As I state in **Chapter 5** and repeat, any philosophy which relies primarily on a belief that all potential ignition sources have been eliminated is, in my view, unsound. Further, it is not generally a good approach to tolerate recurrent defects, even minor ones, they might have unexpected, unforeseen or cumulative consequences. It is also a well known adage that 'fuel will tend to find a source of ignition'. Liquid paths are eccentric. Accordingly, good practice, and the principle of ALARP, require that the risk of both parts of the ignition source/fuel sources equation be equally carefully addressed.

'To disturb or not to disturb'?

23.39 As stated in **Chapter 5** there has been a widespread policy in the MOD, and other air forces and the civil sector, that fuel seals should generally be left undisturbed. There has been a prevailing and widely-held belief that pro-actively replacing seals might actually increase the number of fuel leaks by disturbing the system and fuel couplings up and down the line and/or because of early 'failures'[20] of newly assembled couplings.

23.40 Whether this belief is justified in all circumstances is, however, not clear. It is noteworthy that the recent Nimrod Fuel Seal Replacement Programme (FSRP), whereby 42 fuel seals located in specific areas deemed to present a particular risk have been replaced, has not led to an early 'rash' of infant mortality leaks; indeed, the high quality of work has been encouraging and has given cause for optimism as to the benefits of such targeted seal replacement programmes.[21]

23.41 Equally, the Nimrod teardown exercise has yielded valuable data and the opportunity for careful sampling and testing of systems and their component parts.

[16] NADCAP Quality Products Group for Sealants and Elastomeric Seals; voting member of SAE International Aerospace Technical Committees G9 (Sealants) and CE (Elastomeric Seals); chair G9 sub-committee for Sealant Removal Technology.

[17] Thermodynamic/mechanical disorder and randomness.

[18] DE&S(WYT)/365/8/2/CASD, page 18.

[19] *TWA 800* exploded on a flight from Paris to New York on 17 July 1996 over Long Island. Investigators determined that fuel vapour in the almost empty central fuel tank had been ignited by an unknown source, most probably an electrical short.

[20] Probably due to incorrect assembly.

[21] It is still too early to tell the medium and long-term effects of the FSRP.

The Future

23.42 For the future, it is right to emphasise that any decision to sample or replace seals on a periodic basis (*i.e.* such as the Nimrod FSRP) must balance the likely benefits with the potential disadvantages. (It should be noted that because of the fact that: (i) the Cross-Feed air duct is now only used on the ground and the use of the SCP has been prohibited entirely; and (ii) Air-to-Air Refuelling has been stopped, the fuel leak/ignition risk profile in Nimrod aircraft has of course been very substantially reduced.)

23.43 It is also right to emphasise that the mere fact that sampling or periodic seal replacement may not be an easy, straightforward or inexpensive exercise, (particularly in relation to 'legacy' aircraft' which were not always built for ease of maintenance), should not be seen as a reason to fail actively to consider the necessity for such pro-active fuel seal management measures in the light of *e.g.*: (a) current assessments of perceived risks; and/or (b) evidence of an increasing leaks trend; and/or (c) life extensions to the assumed design life of aircraft. The Nimrod FSRP represents the type of outcome that could result from a formal review of maintenance policy prompted by, *e.g.*, adverse trend data or an aircraft life extension in the future.

23.44 In my view, targeted seal replacement and/or seal sampling are sensible, measured, and proportionate approaches to the problem of management of fuel and hydraulic seals, and should be key tools in the management of fuel system reliability in the future, unless and until a better understanding of elastomeric lifing can be found.

23.45 In any event, it is vital in the future that *active* thought is always given to the appropriate management of all elastomeric seals.

Generic Problems with some 'aged' and 'legacy' aircraft'

23.46 Generic problems arising in relation to the maintaining and repair of some aged and 'legacy' aircraft include the following:

(1) They may have been designed and built to standards which would not be acceptable today;

(2) They may not have been designed with ease of aircraft access and maintenance in mind;

(3) There may be a diminishing pool of engineers with the requisite specialist 'old-fashioned' engineering skills;

(4) Maintaining relevant 'corporate knowledge' and records becomes more difficult as experienced design and maintenance personnel at the Design Authority and in Depth and Front Line maintenance retire;

(5) The availability of spare parts becomes more difficult as the number and interest of manufacturers dwindles as the OSD looms and 'robbing' spares from other aircraft become less easy;

(6) Adding modifications and integrating new systems with old can become more difficult as an aircraft ages;

(7) Different systems and components age at different rates;

(8) Not enough is yet known about the ageing of certain ubiquitous components (I explain above and in **Chapter 5** that elastomeric fuel seals do age for a variety of reasons and refer to research by *e.g.* RAPRA Technology Ltd[22] that *"many rubbers aged in the compressed condition, particularly in the hot climates, have set to such an extent after less than 40 years that their ability to act as an efficient seal is very doubtful"*[23] and research by QinetiQ[24] that Thiokol can suffer long-term temperature-related degradation); and

(9) Determining a 'baseline' of safety for such aircraft becomes more difficult the older an aircraft becomes.

[22] Natural Ageing of Rubber, RAPRA Technology Ltd, 2000.

[23] Ibid, page 10.

[24] Nimrod Fuel Seals, Literature Survey, Issue 1, September 2007.

Lesson Learned – Age Matters

23.47 The reality is that aged aircraft and their systems need more, not less, care and attention. The careful gathering and analysis of information about the aircraft, its systems, maintenance history, and extensive 'trend monitoring' is critical to the safety of aged aircraft. Equally important is good husbandry, so that those charged with maintaining the aircraft do not become inured to, or unsighted on, defects.

23.48 The lesson learned from the Nimrod XV230 case is that age matters. The following matters are all the more important as an aircraft gets older:

(1) *Good trend monitoring*: The BOI demonstrated that the Nimrod fleet showed an increasing leak rate which was not detected because of a lack of sufficient trend monitoring. The Nimrod fleet was not put on the Logistics Information Technology Strategy (LITS) because of its impending OSD. As Garry Copeland from British Airways pointed out, however, with aged aircraft, it is all the more important *"to capture the maximum amount of data available and study the data sets carefully."*[25]

(2) *Good husbandry*: The recent revelations of the forensic teardown of XV236 by QinetiQ show that the standards of husbandry in the Nimrod fleet have shown a marked deterioration in recent years.[26] This is unsatisfactory and potentially dangerous because it makes it more difficult to detect deterioration in aged systems, *e.g.* wiring, pulleys, hydraulics, piping, couplings, insulation, detection systems *etc.,* if an aircraft is not cleaned and looked after properly. For this reason, good husbandry in aged aircraft is all the more important.

(3) *Good attention to spares*: The Avimo seal episode and other evidence shows the increasing difficulty of ensuring the continued availability and quality of spares for aged aircraft. For this reason, it is all the more important to pay good attention to the spares situation with aged aircraft.

(4) *Good attention to skills*: The evidence shows there was a general Nimrod engineering skills fade in the decade before XV230 (in both the Service and Industry) as knowledgeable individuals died, retired, or moved on to attractive jobs in the private sector. Specialist engineering skills and knowledge are all the more important with 'legacy' aircraft. For these reasons, it is essential to ensure good attention is paid to retaining and replenishing skills relevant to aged aircraft.

(5) *Good corporate knowledge*: The evidence shows the level of corporate knowledge and retention of information, *e.g.* in relation to the AEW3 Project, was unsatisfactory. The older an aircraft becomes, the more important it is to ensure good record retention.

(6) *Good forensic teardown*: Teardowns of systems in legacy aircraft can be very illuminating, as demonstrated by the recent QinetiQ teardown of Nimrod XV236 (which may be the first full aircraft systems ever conducted worldwide). It should be noted that the USAF started tearing down systems in 1991.[27] The MOD introduced AAA for systems in 2006.

23.49 Numerous air forces around the world, including the US, Canadian and Australian Air Forces, have 'legacy' aircraft and are grappling with the same age matters. Greater international liaison and sharing of best practice would be fruitful.

Recommendation 23.1:

I recommend that the MOD ensures that greater consideration is given to the age matters set out in this Chapter. In particular, the specific lessons learned from the extensive work undertaken following the loss of XV230 must be carried across to other aircraft types if the MOD is to operate safely an increasingly aged fleet of aircraft.

[25] Garry Copeland, Director of Engineering, British Airways, 2008.

[26] See **Chapter 15** and the summary of QinetiQ's findings by OC Eng RAF Kinloss, in his report to AOISTAR on 18 September 2009.

[27] See US EC3D teardown and Functional Systems Integrity System (FSIP).

CHAPTER 24 – NEW PERSONNEL STRATEGY

"Safety is delivered by people, not paper" (Andrew Macfarlane, Nuclear Regulator, 2008)

"It takes a whole community to ensure that we get [Operational Safety, Suitability and Effectiveness]." (A Fleet Chief Engineer, US Air Force, 2008)

Contents

Chapter 24 makes Recommendations for a New Personnel Strategy.

Summary

1. People deliver Airworthiness.
2. There are currently weaknesses in the area of personnel in the MOD, namely:
   (1) Undervaluing and dilution of engineers and engineering skills.
   (2) Engineers are not required to have professional status.
   (3) Decline in the ability of the MOD to act as an "intelligent customer".
   (4) Turf wars and inter-service rivalries for jobs and roles.
   (5) Short term two-year postings.
   (6) Constant re-naming of posts.
   (7) 'Double-hatting' and 'gapping'.
   (8) Lack of trained Safety Engineers.
   (9) Selfishness, rewards and promotion for 'change'.
   (10) Shortage of manpower and skills fade.
3. There should be a New Personnel Strategy to address each of these weaknesses.

Introduction

24.1 There are a number of current weaknesses in the area of personnel in the MOD which have an impact on the effectiveness of the MOD Airworthiness regime, I discuss these weaknesses below:

(1) Undervaluing and dilution of engineers and engineering skills.

24.2 In recent years, engineers and engineering have tended to be undervalued and diluted notwithstanding their critical role in the overall regime for assuring and ensuring Airworthiness, particularly in the context of 'legacy' aircraft. MBAs and general management skills are no substitute for knowledge and qualifications of a highly technical subject. Equally, it makes no sense to put a sub-mariner in charge of air platforms, just as it would make no sense to put a fast jet pilot in charge of nuclear submarines. Manifestations of this general trend have included:

24.2.1 The *denouement* of the Chief Engineer RAF;

24.2.2 The removal of OC Engineering at RAF Kinloss following the imposition of the Trenchard model;

24.2.3 A 'glass ceiling' regarding job opportunities;

24.2.4 The loss of increasing numbers of skilled and experienced Non-Commissioned engineering Officers to Industry;

24.2.5 The dilution of engineering training by 'multi-skilling';

24.2.6 The notion of 'self-supervision' and removal of layers of Forward and Depth maintenance engineering supervision; and

24.2.7 Increasing outsourcing of engineering roles and tasks to Industry.

(2) Engineers are not required to have professional status.

24.3 Engineering officers within the Services who make Airworthiness decisions are not required to hold professional status. They are authorised to make Airworthiness decisions by virtue of being holders of Letters of Delegation (LOD). Theirs is a heavy responsibility. They are expected to make vital Airworthiness decisions, often on a daily basis and at short notice. They are not, however, required to hold any professional qualification, e.g. membership of the Association of Chartered Engineers.

(3) Decline in the ability of the MOD to act as an "intelligent customer".

24.4 The decline in skilled and knowledgeable manpower, and the reduction of the 'light blue, dark blue, and khaki' has reduced the MOD's ability to act as an 'intelligent customer' in its dealings with Industry. Further, the increasing scale of outsourcing to Industry in relation to an ever-widening range of tasks, has to some extent had a corrosive effect and undermined internal confidence within the Services that they can either do things for themselves, or judge properly tasks which they have outsourced.

(4) Turf wars and inter-Service rivalries for jobs and roles.

24.5 There is much inter-Service rivalry; some healthy, some unhealthy. Tribalism manifests itself keenly in competition for the top and middle-ranking jobs and the creation of new roles. Each of the Services, including the Civil Service, has a natural desire: (a) to enhance its own power, prestige and influence, often in the endearing belief that it knows better than its rivals; (b) to protect its own turf; and (c) to look after, and promote, its own people. Instead of appointing the best person for the job there is sometimes a strong element of either 'Buggins' turn, or Machiavelli, or a political compromise. Jobs or roles are sometimes allocated to the Service that out-manoeuvres the others, or to the Service next in line for that post, or on the basis of a horse-trading. In the arena of Safety and Airworthiness this is not a satisfactory state of affairs. All decisions which have a bearing on Safety and Airworthiness must be made objectively, without fear or favour. The question should always be 'Who is the best person for the job?'.

(5) Short term two-year postings.

24.6 Many officer posts are limited to two years. This is in part in order to give officers a broad range of experience by moving them around to different jobs. This is said to prepare many for top posts, such as Chief of the Air Staff. This continual 'churn' of officers in post, however, can have a deleterious effect on: (a) task and programme continuity; (b) morale of the ranks; and (c) the officers' ability to make a lasting and positive difference whilst in post. Further, it allows and encourages officers to set in train 'change initiatives' or pet initiatives which their successors are then left to sort out (these are sometimes called 'pet-pigs').

(6) Constant re-naming of posts.

24.7 It is remarkable how often the names of posts in the military are changed for no apparent reason or even without the incumbent being aware. It is also remarkable how often identical posts on different bases or units have different nomenclature. This is confusing and unsatisfactory. There should be consistency and continuity of nomenclature pan-MOD.

(7) Double-hatting and gapping.

24.8 There is an increasing amount of systemic 'double-hatting' and 'gapping'. This is not satisfactory, particularly in the arena of Safety and Airworthiness.

(8) Lack of trained Safety Engineers.

24.9 There is a lack of trained Safety Engineers in the MOD. As Professor McDermid[1] has pointed out to me, unless you ensure that 'Safety Officers' have the relevant qualifications, training and experience in Safety Engineering, they will be reluctant to speak up or voice their views at meetings, and when they do, their views are less likely to carry weight.[2]

(9) Selfishness, rewards and promotion for 'change'.

24.10 Officers who effect 'change' are more likely to be noticed and promoted. This was particularly true in the heady post-Strategic Defence Review days of 1998-2006. There was a realisation by ambitious officers that being seen to initiate and effect 'change' in post was good, or at least would be good for them. They would be perceived as 'positive', 'energetic', a 'moderniser', a 'person with ideas', and 'willing to try new things'. The agents and *apparatchiks* of change gained quicker promotion. This culture still persists today. As one senior RAF officer put it to me: *"There is a great deal of change selfishness, particularly in Main Building."* It is reassuring to see the recent statement by the Air Force Board on what it requires from squadron and station commanders:"[The Air Force Board] *want people in command who are confident enough not to succumb to changing things for the sake of change*". There should be more rewards and promotion for those who effect stability. The same should apply to Main Building which is the main agent of much of the change.

(10) Shortage of manpower and skills fade

24.11 The RAF is under-resourced in terms of suitably qualified and experienced personnel and has suffered a significant engineering skills fade in the past decade. These fundamental problems have been apparent to the Review throughout its inquiries. The risks attendant on trimming manpower were highlighted specifically in the Airworthiness arena as long ago as 1998 in the Nimrod Airworthiness Review Team (NART) Report which observed:

> *"Overall, the MOD MAR staff have a very heavy workload and are very concerned about the consequences of any possible further trimming of staff. In the particular area where formal airworthiness responsibility is held, it is essential that staff posts are neither overloaded*

[1] University of York.

[2] Frank Walsh's previous experience in military transport hardly qualified him to be a Safety Officer.

nor perceived continuously to be in danger of being lost or reduced. With the multiple responsibilities within their TOR, staff resources need to be retained in order for them to be able to deal adequately, and without undue pressure, with all airworthiness issues."[3]

24.12 Ten years later, the 'parlous' shortage of manpower and skills fade in the RAF formed a major feature of the findings of the *"Capability Health Check"*, dated 18 August 2008, conducted by the RAF itself.[4] It need hardly be said that a lack of skilled manpower is not healthy for Safety and Airworthiness. Airworthiness must be delivered by people who are suitably qualified and experienced and have the right skills and training. The problems identified in respect of manpower and skills in the RAF are fundamental to Airworthiness and must be addressed as a matter of urgency.

Recommendation 24.1:

I recommend that careful consideration is given to the above weaknesses and a New Personnel Strategy formulated which addresses each of them.

[3] NART Report dated 24 July 1998, paragraph 27.

[4] See **Chapter 19** (20080818-CHX EXECSUM-RSM).

CHAPTER 25 – NEW INDUSTRY STRATEGY

"Industry are ultimately accountable to their shareholders, and it is naïve to assume otherwise." (Garry Copeland, Director of Engineering, British Airways, 2008)

Contents

Chapter 25 makes Recommendations for a New Industry Strategy.

Summary

1. The relationship between the Defence Establishment and Industry is a necessary and vital one.
2. The findings of the Review and lessons of the Nimrod Safety Case reveal disturbing problems with the so-called 'partnership' between the MOD and Industry.
3. The story of the Nimrod Safety Case, in particular, reveals flaws in both the bilateral and triangular relationships between the MOD, BAE Systems, and QinetiQ.
4. There are concerns about the scale of 'outsourcing' and its long-term corrosive effect on the in-house abilities of the Services.
5. I make Recommendations to assist the formulation of a New Industry Strategy for the future.

Introduction

25.1 The relationship between the Defence Establishment and Industry is inevitably complex, sophisticated, incestuous, and elliptical. It is also a very necessary and valuable relationship, not least because of the need to design, develop, build, test and maintain increasingly high-technology and high-cost weaponry.

25.2 In the past decades, huge advantages have flowed from the ever-increasing role that Industry has played, and continues to play, in supporting Defence; including financial, logistical, capability, and technological benefits.

25.3 Fashioning and managing the right relationship with Industry is necessarily a difficult and complex exercise for those in the Defence Establishment, and *vice-versa*. It is made more difficult by different cultures, different *mores,* different motivations, and different rewards. Furthermore, the current 'Decider/Provider' model is often easier to enunciate than to put into effective practice (and suffers from the weakness that Deciders who have no experience of being Providers are at a disadvantage).

25.4 Military forces around the world are grappling with the same Industry issues.

'Partnership' with Industry

25.5 It is against this backdrop that I point to some of the lessons of the Nimrod Safety Case (NSC) and findings of the Review generally, which reveal worrying problems with the so-called 'partnership' between the MOD and Industry, and the way in which the various organisations work together (see especially **Chapters 10A** and **10B**, **11** and **19**). I briefly highlight some of these concerns below.

All three organisations failed in Nimrod Safety Case 1

25.6 There was a collective failure of the three organisations concerned to deal with the NSC properly, and an elemental failure by each of them to fulfil their individual roles *vis-à-vis* each other in satisfactory manner:

25.6.1 BAE Systems failed to act properly as an 'approved organisation'. It failed to carry out the NSC task in a careful, competent or thorough manner. It failed to deal with the customer, the Nimrod IPT, in an open, candid, and straightforward way. Its conduct when handing over the NSC can fairly be described as cynical.

25.6.2 QinetiQ failed to act as a careful, competent or thorough 'independent check' of any sort. It was for much of the time essentially a passenger during the process. It was ultimately prepared to take the line of least resistance. Its conduct can fairly be described as supine.

25.6.3 The Nimrod IPT failed at any stage to act as an 'intelligent customer'. It outsourced its thinking. It was at material times unquestioning, weak, and sloppy.

Flaws in bilateral and triangular relationships

25.7 The story of the NSC reveals flaws and fissures in the relationships of the parties *inter se:*

25.7.1 *The bilateral relationship between BAE Systems and the Nimrod IPT:* this was far from an equal 'partnership', with the former realising that it was unlikely to face much questioning of its work from the latter; the particular relationship between the key personnel at BAE Systems and the Nimrod IPT Safety Officer in charge of project managing the NSC task was altogether too cosy and informal.

25.7.2 *The bilateral relationship between the Nimrod IPT and QinetiQ:* the Nimrod IPT was suspicious that QinetiQ was just 'touting for business' and QinetiQ was keen not to do anything that might upset its customer.

25.7.3 *The triangular relationship between BAE Systems, the Nimrod IPT and QinetiQ:* the former two clearly found the presence of the latter an unnecessary irritation and/or competition. As one contemporary observer said: *"it was obvious to me that QinetiQ was not seen as a partner in ensuring the aircraft* *or crew safety".* The two commercial entities are wary of each other as they compete for the favours of the customer and future business, and jealously guard their own birthright.

25.8 There was a very real sense in which all three parties were simply going through the motions together of producing 'paper safety'; two were getting paid and one was ticking a regulatory box which needed to be ticked.[1]

25.9 Safety slipped between three stools.

Nimrod Safety Case 2

25.10 The unedifying story of the Nimrod Safety Case 2 (SC2) is a cause for concern. It has already taken over 21 months so far, has cost over £3 million, and has *still* not reached a satisfactory conclusion.[2] Much of this is to do with the unsatisfactory way in which BAE Systems have approached the task (see **Chapter 15**). But it also re-enforces concern as to the ability of the three parties (the Nimrod IPT, BAE Systems, and QinetiQ) to work together to a common end, in a cost and time-effective manner, to produce a product worth having. The entire SC2 exercise has, in my view, been a waste of time, energy, and money.

25.11 In the circumstances, I recommend below that the MOD should seek repayment from BAE Systems of the entire cost of Nimrod Safety Cases 1 and 2 from BAE Systems; and[3] it is my firm view that BAE Systems should do so without demur, not least to begin to rebuild trust and confidence which are initial elements of a healthy and effective partnership between industry and the MOD.

Retreat behind contractual terms

25.12 There is much airy talk of 'partnering', 'partnership' and 'support'; but, at the first sign of trouble, a quick retreat by Industry behind the supposed contractual terms of what it was, or was not, in fact expected to do frequently occurs.

Outsourcing

25.13 The breadth, depth, and scale of 'outsourcing' by the MOD to Industry and its long-term effects is a matter of concern for a number of reasons. First, the long-term corrosive effect which the 'habit' of outsourcing is having on the ability and confidence of the Services to think and act for themselves. Second, its undermining effect on the ability of the Services to continue to act as 'intelligent customers'. Third, the long-term damaging effect of the inexorable drain of skilled and experienced manpower at all levels away from the Services to Industry. Fourth, the cost of so much outsourcing which might more effectively, and economically, be done in-house.

QinetiQ

25.14 The sale of the greater part of the Defence Evaluation and Research Agency (DERA) to private interests in 2001 (to form QinetiQ) put the substantial knowledge, advice, and support of DERA behind a commercial wall. This fundamentally changed the dynamics of the relationship on both sides. QinetiQ (formerly DERA) management was henceforth responsible to its private shareholders to garner business and profit. MOD entities could henceforth only gain access to the invaluable 'brains' and expertise of former DERA employees on negotiated commercial terms.

Procurement

25.15 The Procurement story of the Avimo seals is worrying in two respects. First, because of the suitability of the (prosaically-named) Medical & General Stores IPT to negotiate and source aviation parts and spares from

[1] Business Procedure BP1201.

[2] Eventually the IPT contracted QineitQ to produce a 'safety case', which used the BAE Systems data in its argument and is known as Safety Case 3.

[3] See the more detailed analysis in **Chapter 15**.

Industry. Second, because of the apparent absence of any real quality control in the extended Procurement chain, notwithstanding the considerable mark-up applied up the chain.[4]

Conclusions

25.16 In my view, none of the above problems can be dismissed as one-off. They are symptomatic of a wider malaise, and some deeper structural problems, in both the bi-lateral and triangular relationships involving the MOD and Industry.

25.17 The fact of the matter is that commercial imperatives, *i.e.* maximising profit for shareholders, garnering the next piece of business *etc.*, do drive behaviours and not always for the better, as the NSC demonstrates.

25.18 The truth is that a lot of outsourcing does not represent value for money, nor does it produce real Safety and Airworthiness (as opposed to the 'appearance' thereof).

25.19 These fundamental issues must be addressed both for the short-term and long-term health of Defence and the Armed Forces. It is vital that the relationship with Industry works.

25.20 The story of the loss of Nimrod XV230 and the NSC should be a catalyst to a careful re-examination of the various relationships at all levels, in order quickly to rebuild trust in the short term and, in the longer term, to develop joint values and new ways of working together to achieve common outcomes.

25.21 Three matters are key in my view for the future:

(1) First, quickly rebuilding skills and confidence and restoring the ability of the MOD customers to act as 'intelligent customers'.

(2) Second, having arms-length contractual clarity.

(3) Third, to be far more discriminating in the future as to what is, and is not, outsourced in Industry.

Recommendations

25.22 I make the following Recommendations for the future:

Recommendation 25.1: Careful consideration should be given to the above problems and the formulation of a New Industry Strategy which addresses them.

Recommendation 25.2: The MOD should identify the key skills and experience which are required to ensure that it is an 'intelligent customer' when dealing with Industry and ensure that these are maintained and enhanced in-house.

Recommendation 25.3: The MOD should seek repayment of the cost of the Nimrod Safety Cases 1 and 2 from BAE Systems.

Recommendation 25.4: Paramountcy should be given in the future to arms-length contractual clarity.

[4] See further **Chapter 5**.

CHAPTER 26 – NEW PROCUREMENT STRATEGY

> *"[Procurement] is something that we must get right. There can be no room for complacency, and given the current tempo of operations, we have no choice but to act with urgency."*
> (Former Secretary of State for Defence, the Rt Hon. John Hutton MP, 4 June 2009)[1]

Contents

Chapter 26 makes Recommendations for a New Procurement Strategy.

Summary

1. Poor Procurement damages In-Service Support:
   (a) First, delays in new equipment Procurement can cause the Out-of-Service dates of old equipment to be extended way beyond what was originally envisaged or is sensible and cause problems with planning, spares, sourcing and long-term investment.
   (b) Second, cost over-runs in Procurement can put severe financial strain on other parts of the MOD, in particular In-Service Support, as pan-Department year-on-year cuts and savings are required to make up for increasing Procurement shortfalls.
2. This has happened in the past and must not happen again.
3. But for the serious delays in the MRA4 programme, XV230 would probably not have been flying in September 2006.
4. Procurement cost over-runs helped create the 'bow wave' of deferred financial problems which led to the cuts, change, confusion, dilution and distraction and weakening of the Airworthiness system in the wake of the 1998 Strategic Defence Review (1998 to 2006).
5. As Rt Hon. John Hutton said recently, sorting out Defence Procurement is an important and urgent priority.
6. I recommend that Bernard Gray's Report on Procurement is published without delay and appropriate action taken as a matter of urgency.[3]

[1] Hansard Debates, Thursday 4 Jun 2009: Column 438.

Introduction

26.1 I refer to **Chapters 13** and **14**.

26.2 The history of Procurement of the Nimrod MRA4 replacement programme is a sorry story of serial delays and cost over-runs. But for the delays in the MRA4, XV230 would probably no longer have been flying in September 2006. Further, the fact that the MR2 Out-of-Service Date was continually being put back led to planning, spares, sourcing and long-term investment problems.

26.3 As explained in **Chapters 13** and **14**, the history of Procurement generally in the MOD has been one of years of major delays and cost overruns. This has had a baleful effect on In-Service Support and Safety and Airworthiness. Poor Procurement helped create the 'bow wave' of deferred financial problems, the knock-on effects of which have been visited on In-Service Support, with concomitant change, confusion, dilution and distraction and weakening of the Airworthiness system in the post-Strategic Defence Review period, 1998 to 2006.

26.4 On 4 June 2009, the Rt Hon. John Hutton MP[2] promised to publish Mr Bernard Gray's Report on Procurement before the Parliamentary summer recess[3] but resigned the next day. Regrettably, Mr Gray's Report was not published.[4]

26.5 Further major 'bow waves' of deferred financial and other Procurement problems threaten the future integrity of In-Service Support.

26.6 As the Rt Hon. John Hutton said, sorting out Defence Procurement is an important and urgent priority.

Recommendation 26.1: New Procurement Strategy

I recommend that Mr. Bernard Gray's Report is published without delay and appropriate action taken as a matter of urgency with a view to formulating and implementing a New Procurement Strategy.[3]

[2] The immediate past Secretary of State for Defence.

[3] *Hansard*, Thursday 4 June 2009: Column 438.

[4] Bernard Gray's Report was suddenly published on 15 October 2009, after completion of this Report for printing.

CHAPTER 27 – NEW SAFETY CULTURE

"It is not enough to have knowledge, you have to do something with it."
(Lieutenant Colonel Tracy Dillinger, NASA, 2009)

"A company which has got a compliance culture, does not have a safe culture."
(Ian Wherwell, HSE, 2008).

"The greater the number of prescriptions, the more people's sense of personal responsibility dwindles" (Hans Monderman 1945-2008).

Contents

Chapter 27 makes Recommendations regarding a New Safety Culture for the Future.

Summary

1. Fostering a strong and effective Safety Culture is vital to reducing accidents.

2. *"Safety culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, safety issues receive the attention warranted by their significance"* (International Nuclear Safety Advisory Group).

3. Safety should be treated as part of the business, not separate from it.

4. The MOD should learn from the latest work and approach of NASA and the US Joint Planning and Development Office in relation to organisational Safety Culture. The US has adopted Professor James Reason's approach to creating an "Engaged" Safety Culture.

5. In my view, there are five elements required for building an Engaged Organisation and Safety Culture:

   ✔ **A Reporting Culture:** an organisational climate where people readily report problems, errors and near misses.

   ✔ **A Just Culture:** an atmosphere of trust where people are encouraged and even rewarded for providing safety-related information; and it is clear to everyone what is acceptable and unacceptable behaviour.

   ✔ **A Flexible Culture:** a culture that can adapt to changing circumstances and demands while maintaining its focus on safety.

   ✔ **A Learning Culture:** the willingness and competence to draw the right conclusions from its safety information and the will to implement major safety reforms.

   ✔ **A Questioning Culture:**[1] It is vital to ask ***"What if?"*** and ***"Why?"*** questions. Questions are the antidote to assumptions, which so often incubate mistakes.

6. The role of Leadership is critical in Safety Culture.

7. I make appropriate Recommendations with a view to building an Engaged Organisation and Safety Culture for the Future.

[1] Additional element to the US/Reason model.

Introduction

> *"[I]f your are convinced your organisation has a good safety culture, you are almost certainly mistaken. Like a state of grace, a safety culture is something that is striven for but rarely attained. As in religion, the [journey] is more important than the product. The virtue – and the reward – lies in the struggle rather than the outcome."* (James Reason, 1997)[2]

27.1 Since the Chernobyl Nuclear Plant catastrophe in 1986, there has been a growing realisation that organisational 'culture' is a key factor in safety. Many of the major accident reports in the past 20 years have focused on the organisational causes of accidents and the importance of 'culture' as I explain in **Chapter 17**. A good understanding of organisational causes is fundamental to Accident Theory and High-Risk Technologies as I explain in **Chapter 18**.

27.2 A broad consensus has developed across the safety community, academia, and informed opinion in Industry, that fostering a strong and effective 'Safety Culture' is vital to helping reduce the number of accidents that occur in complex systems and organisations.

Definition of 'Safety Culture'

27.3 There are a large number of definitions of 'Safety Culture' but, in my view, the most succinct and compelling is that promulgated by the International Nuclear Safety Advisory Group:

> *"Safety culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, safety issues receive the attention warranted by their significance."*[3]

Lord Cullen

27.4 Lord Cullen emphasised the importance of a strong Safety Culture, the practical aims of which should include *"systematic identification and assessment of hazards and the devising and exercise of preventative systems which are subject to audit and review"*. Lord Cullen pointed out that *"Safety should not be treated as something which was separate from the conduct of the business"*.[4] There are five themes which can gleaned from Lord Cullen's work which are useful 'building blocks' towards maintaining a proper and effective Safety Culture:

(1) *Motivation from the top*, with someone always answerable to the Main Board.

(2) *Clear lines of accountability*, with an unbroken and logical delegation from the top through line managers and supervisors.

(3) *Practical goal-setting for safety*, with strategic goals set by the Main Board.

(4) *Adequate support for line management*, by training, information and expert back-up.

(5) *Auditing of safety standards*, by proper monitoring, auditing and evaluation.

Railways

27.5 Volume 1 of the Railways' 'Yellow Book'[5] sets out the fundamentals of Engineering Safety Management (ESM). It also stresses that 'Safety Culture' should be promoted throughout the organisation and led *"from the top"*, so that it is felt and observed *"throughout the organisation"*.[6] It recommends that 'Safety Culture' should be promoted using the following elements:

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[2] James Reason, *Managing The Risks of Organizational Accidents* (1997), page 220.

[3] "Safety Culture" – A report by the International Nuclear Safety Advisory Group (Safety Series No.75-INSAG-4).

[4] The Rt Hon. The Lord Cullen, Report of The Public Inquiry into the *Piper Alpha Diaster,* 1990, paragraph 21.9.

[5] http://www.yellowbook-rail.org.uk/site/the_yellow_book/yellow_book_vol1and2_issue4.pdf (Railways equivalent of the White Book).

[6] Yellow Book, paragraph 6.2.2.

(1) *Compliance* with applicable standards and procedures.

(2) *Right first time*, *i.e.* insistence on getting things right first off.

(3) *Not accepting poor standards of work, i.e.* a zero tolerance policy.

(4) *Understanding* that: (a) the overall risks that are being managed; (b) risk is not constant; and (c) new hazards need to be captured and managed as they arise.

(5) *Learning* from incidents and near misses to improve the safety of work and overall safety of the railway;

(6) *Sharing information* so that your maintenance staff become the eyes and ears necessary to detect things that are wrong; and

(7) *Action* where something is found to be wrong.

27.6 The 'Yellow Book' stresses three points in particular:

(1) It should be recognised that that there can be a tendency for a Safety Culture to deteriorate, particularly where repetitive tasks can result in perceived familiarity and a false sense of security.

(2) It is essential to put measures in place that minimise the potential for complacency, such as varying people's tasks and encouraging ownership.

(3) The starting point for a good Safety Culture is a commitment on the part of management. This is best expressed by the setting of a safety policy, endorsed by the board of directors. A safety policy should state the organisation's aims for achieving safety.[7]

Challenger and Columbia

27.7 On 28 January 1986, NASA Space Shuttle *"Challenger"* was lost on take-off as a result of a failure of an 'O-ring' Thiokol seal in the Solid Rocket Motor. 17 years later, NASA[8] Space Shuttle *"Columbia"* was lost on re-entry on 1 February 2003 as a result of a failure in its wing foam thermal protection system.[9] The *Challenger* Presidential Commission[10] made recommendations in 1986 regarding improvement to NASA's Safety Organisation. The *Columbia* Presidential Commission (CAIB)[11] found that, although changes had been made to NASA's Safety Organisation following *Challenger,* many of the organisational failures which led to the *Columbia* accident echoed organisational failures in the *Challenger* accident because NASA had failed to alter its essential organisational Safety Culture in the 17 years between the two major accidents. Professor Diane Vaughan[12] attested to the difficulty that NASA had had in addressing the fundamental organisational and cultural problems in the intervening years.

27.8 I was, therefore, interested to learn what steps have been taken by NASA to improve its Safety Culture in the light of the CAIB report post-*Columbia,* particularly given the striking parallels between the organisational causes of the losses of *Challenger* and *Columbia* and the organisation causes contributing to the loss of XV230 (see **Chapter 17**).

NASA's approach to Safety Culture

27.9 I have received valuable assistance from Lieutenant Colonel Tracy Dillinger of the NASA Office of Safety and Mission Assurance.[13] Tracy Dillinger worked on the CAIB and was seconded by the US Air Force Safety Center to NASA to oversee improvements in Safety Culture within NASA post-*Columbia*. Tracy Dillinger explained to the Review how NASA has addressed the challenge of developing an effective Safety Culture by reference to the NASA Safety Programme and the NextGen Project referred to below.

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[7] Ibid, paragraph 6.2.4.

[8] US National Aeronautics and Space Administration.

[9] See **Chapter 17**.

[10] The Rogers Commission was set up by President Ronald Regan and reported in June 1986.

[11] The Columbia Accident Investigation Board (CAIB) was set up by President George W. Bush and reported in August 2003.

[12] Professor, Columbia University Sociology.

[13] Lieutenant Colonel Tracey Dillinger, PsyD, Office of Safety and Mission Assurance, NASA Headquarters Washington DC.

Professor Reason

27.10 NASA has adopted a safety model of Professor James Reason (whom I had the privilege of meeting and whose work on Accident Theory I outline in **Chapter 18**). In his seminal book, *Managing the Risks of Organizational Accidents*,[14] Professor Reason identified the four critical sub-components which interact to create an *"Informed Culture"*, namely a positive Safety Culture that effectively shares information throughout the organisation and actively seeks maximum safety. The four key elements (or 'sub-cultures') are as follows:

- ✔ **A Reporting Culture:** an organisational climate where people readily report problems, errors and near misses;
- ✔ **A Just Culture:** an atmosphere of trust where people are encouraged, and even rewarded, for providing safety-related information; and it is clear to everyone what is acceptable and unacceptable behaviour;
- ✔ **A Flexible Culture:** a culture that can adapt to changing circumstances and demands while maintaining its focus on safety;
- ✔ **A Learning Culture:** the willingness and competence to draw the right conclusions from its safety information and the will to implement major safety reforms.

27.11 Tracy Dillinger explained to the Review that NASA has adopted Professor Reason's model with one important modification: instead of the phrase *"Informed Culture"*, Tracy Dillinger prefers the use of the phrase *"Engaged Culture"*, because it is not sufficient for an organisation simply to be properly informed, it must act on the information to promote and improve safety. Although Professor Reason makes clear that an effective organisation must necessarily act on the information received, I agree with Tracy Dillinger that the phrase *"Engaged Culture"* correctly emphasises the responsibility of an organisation actively to manage safety, *i.e.* not merely to gather information, but to act on it.

JPDO NextGen Project

27.12 The Review has also been briefed by NASA on the work on the US Joint Planning and Development Office (JPDO)[15]. In 2003, the JPDO was tasked with producing a plan for safely implementing the Next Generation Air Transportation System (NextGen) which must be capable of accommodating a threefold increase in air traffic by 2025. The JPDO Safety Working Group's Safety Culture Study Team is made up of representatives from government, industry and aviation safety academia. On 30 July 2008, the JPTO Team produced its *"Safety Culture Improvement Resource Guide"* (Resource Guide) which had gathered source material from 20 industry and government sources worldwide. The JPTO Team concluded from the published data reviewed that there was a clear relationship between a strong Safety Culture and improved safety performance.

27.13 The JPTO Resource Guide endorsed Professor Reason's approach set out above and recommended that it form the cornerstone to improving Safety Culture as part of the NextGen project. I outline the four elements of Professor Reason's model below.

✔ *A Reporting Culture*

27.14 A positive Reporting Culture helps to mitigate errors by encouraging employees to report information about hazards or safety concerns that they encounter. It also enables trends to be picked up and acted upon.

27.15 It is only human nature, however, to be reluctant to report incidents which might involve a degree of personal blame or blaming colleagues. Other impediments to adequate reporting include apathy ('Will any good come from reports?'), or scepticism that management will act on reports. There are five important factors in ensuring the quality and quantity of incident reports: (1) protection from disciplinary proceedings where appropriate; (2) confidentiality or anonymity where necessary; (3) separation of the agency or department that collects and analyses reports from those with the authority to discipline; (4) rapid, useful, accessible and intelligible

[14] *Managing the Risks of Organizational Accidents*, James Reason, December 1997, ISBN 1840141050.

[15] The US Joint Planning and Development Office (JPDO) is the central organisation that co-ordinates the activities of the US Departments of Transportation, Defense, Homeland Security, Commerce, FAA, NASA and the White House Office of Science and Technology Policy.

feedback to the reporting community; and (5) ease of reporting. Tracy Dillinger emphasised the necessity of training to explain the importance of reporting and highlighted techniques such as recognising reporting with commendations and building adequacy of reporting into the appraisal process.

27.16 I have recommended in **Chapter 21** that one of the key roles of the MAA will be to develop an effective reporting system in place of the dysfunctional reporting system presently in existence.

✔ *A Just Culture*

27.17 A Just Culture strikes a sensible balance between a 'blame culture' and a 'blame-free culture', *i.e.* between holding people properly accountable for their acts or omissions and ensuring the right lessons are learned for the future

27.18 Following an incident or accident, organisations have an automatic tendency to assign blame to the individual responsible for the last action prior to the problem. This often ignores the organisational causes, discourages the reporting of unsafe conditions, hampers co-operation with incident investigation, and limits the organisation's ability to learn lessons. Equally, an organisation that never finds any fault with its people breeds complacency.

27.19 The answer is a 'Just Culture'. This seeks to strike a balance between an unacceptable 'blame culture', where all errors and unsafe acts are punished regardless of the degree of fault, and an unacceptable 'blame-free culture', where there is a blanket immunity irrespective of the culpability of individuals involved. A prerequisite for creating a Just Culture is an agreed set of principles of acceptable and unacceptable behaviour. There must be an element of trust, which is the single most important element in guaranteeing adequate reporting. This is achieved through agreement and/or by building trust within the organisation.

27.20 In a recent article, the Chief of Defence Staff (CDS), Sir Jock Stirrup, correctly described a Just Culture as *"a culture that encourages open and honest reporting, that allowed for structured investigation of errors which lead to an incident, and that takes 'just' action which is fair and measured."*[16] He said establishing a Just Culture was one of the greatest challenges for senior leaders with command responsibility and went on explain:

> *"To me, such a culture is based on trust. ... It should promote a sense that they will be treated fairly and with integrity while we investigate why mistakes have been made to make sure we get things right next time. But it is not a blame-free regime where no-one is ever held to account. Everyone one must be clear where the line is drawn between acceptable and unacceptable behaviour."* [17]

✔ *A Flexible Culture*

27.21 An organisation which is flexible and value-based, *i.e.* is guided by core principles, is more likely to deal with the challenges of changing circumstances and hazards.

27.22 An organisation, however, which is heavily reliant on complex process, with detailed and highly prescriptive procedures and complex or rigid or ill-defined chains of command will inevitably struggle to deal with challenges of change or when faced with novel circumstances. As has been seen in **Chapter 19**, an organisation with a complex safety structure, ill-defined responsibilities, and a highly complex and prescriptive regulatory set is more likely to become diluted, reactive, and unfit for purpose in the face of substantial change.

27.23 An organisation, however, which is guided by core principles is flexible and better equipped to meet challenges. A Flexible Culture allows all employees to question procedures, behaviour and their seniors. People are central to Safety. The inevitability of Human Error is acknowledged. The flexibility to question procedures, behaviour or seniors means that potentially unsafe practices may be stopped and interrupted before they result in actual mishap.

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[16] Chief of the Defence Staff, Air Chief Marshal Sir Jock Stirrup writing in the "Desider" magazine, January 2009

[17] Ibid.

Safety Managers

27.24 Tracy Dillinger explained that NASA has invested in training and academic qualification for Safety Mangers so that they are more likely to speak up at meetings and more likely to be listened to when they do so. I have made recommendations to the same effect in **Chapter 24**.

Grounding and 'Red cards'

27.25 Another initiative, which has been used in certain parts of the US Air Force is to authorise all individuals with the power to ground platforms if they are concerned about safety. Such action will be the subject of commendation and the decision to fly must be passed further up the chain of command. The purpose of this is to ensure that every employee feels a responsibility for safety. A further programme has been to issue employees with *"Red cards"* to be placed on the table at meetings if an employee feels his or her views on safety are not being considered. When a red card is played, the senior management are obliged to take notice. Each of these programmes are not ends in themselves, but aimed at driving safety practices, attitudes and behaviours.

✔ A Learning Culture

27.26 An organisation that demonstrates a strong Learning Culture is willing to adapt and change based on safety indicators and hazards uncovered through assessments, data and incidents. A 'learning' organisation, its employees and policies allow for continuous learning and improvements to safety, through observation and evaluation. It does not consider it is the 'perfect place' and understands that there is no room for complacency. As Professor Reason points out, *"if you think your organisation has a good safety culture, you are almost certainly mistaken"*.[18]

27.27 The organisation invests in training and makes links with other organisations to ensure that it keeps up to date with new ideas and best practice. These various activities help identify vulnerabilities or weaknesses to organisational safety. Implementing a Learning Culture can be difficult because it often requires a great deal of co-ordination, a change in attitudes and management commitment. One of the reasons for a dedicated and independent accident investigation team is to pick up trends and organisational failings by comparing accidents.

✔ Fifth element: A Questioning Culture

27.28 The above four cornerstones underpin the over-arching edifice of a strong Safety Culture. The keystone of a strong Safety Culture is, in my view, however, a vital fifth element, namely a Questioning Culture. At all stages of the safety pilgrimage it is vital to ask questions such as *"What if?"*, *"Why?"*, *"Can you explain?"*, *"Can you show me?"*, *"Can you prove it?"*. Questions are the antidote to assumptions, which so often incubate mistakes.[19]

27.29 A Questioning Culture is the key to a true Safety Culture. In my view, people and organisations need constant reminding of the importance of asking questions rather than making assumptions, of probing and testing rather than assuming safety based on past success, of independent challenge of conventional wisdom or shibboleths, of the exercise of judgment rather than retreat behind the assignment of arbitrary quantitative values.

27.30 Questioning is a catalyst for thinking. As Professor McDermid told me, if he could replace all of the regulations with one word it would be: **"THINK"**. Thinking can often be painful, difficult and not always immediately productive. It is, of course, much easier and quicker to make convenient assumptions, or slavishly follow procedure or tick boxes.

27.31 It is worthwhile having regard to the work of Hans Monderman, the Dutch road engineer and innovator, who pioneered the concept of "naked streets" or "shared space". He realised that by removing a *plethora* of prescriptive road signs in urban streets you would encourage drivers and pedestrians alike to think more about safe conduct and reduce accident rates accordingly. He has been proved right.

18 James Reason, *Managing The Risks of Organizational Accidents* (1997), page 220.

19 *"Assumptions are the mother of all [mistakes]."* (An SAS saying).

27.32 If leaders and membership of organisations were briefed on the loss of *Challenger* and *Columbia* and other major accidents, including XV230, there would be a greater understanding of the importance of questioning and critical thinking.

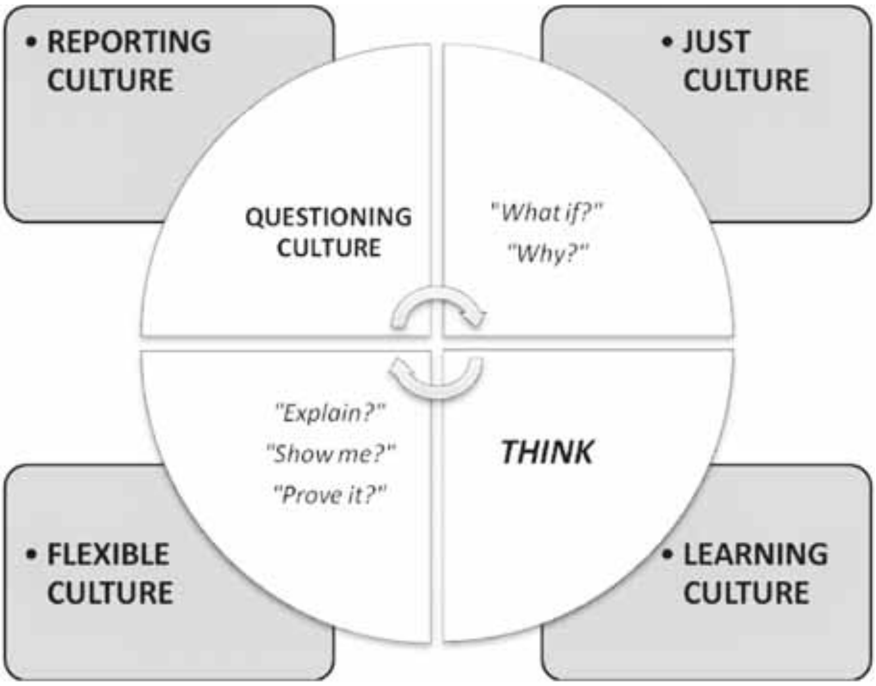

Figure 27.1: Engaged Organisation and Safety Culture

27.33 The five elements explained above, namely *Reporting Culture, Just Culture, Flexible Culture, Learning Culture* and *Questioning Culture*, combine to form a safety-conscious, informed and, above all, Engaged Organisation and Safety Culture with the following characteristics:

- Leadership commitment
- Open communication
- Just environment
- Involvement of everyone at all levels of the organisation
- Learning throughout the organisation
- Effective decision making process
- Follow up, feedback and reporting
- Critical thinking and questioning

27.34 As explained and summarised by the JPDO:

> *"These characteristics typify a vibrant safety culture in which each employee sees his/her role as a critical part of the organization's commitment to safety. In such an environment, every employee will feel both comfortable – and feel responsible for – reporting any incident or issue that he/she perceives as being a potential safety risk without fear of reprisal or retribution. A vibrant safety culture is built on trust at all levels of the organisation working with each other. It depends upon the values and behaviours of each individual."*

The critical role of Leadership.

27.35 There are numerous steps required to create, implement and maintain a proper Safety Culture. The Recommendations made in **Chapters 20** to **26** of this Report are intended to provide a route map to achieving an Engaged Organisation as described above.

27.36 Numerous distinguished figures, including Lord Cullen in *Piper Alpha* and *Ladbroke Grove*, the authors of the *CAIB* Report, the former Secretary of State James Baker in the *BP Texas Refineries Report*, William C. Redmond of the USAF Safety Center, Judith Hackitt of the UK Health & Safety Executive, have repeatedly stressed, however, that the vital ingredient to effecting real cultural change in any organisation is Leadership. It is the thought, word and deed of leaders that most influence the attitudes, behaviours and priorities of employees.[20] I have listed Leadership as the first Principle in **Chapter 20**. I have made Recommendations in **Chapter 21** which address Leadership (including the appointment of a 3-Star Head of the MAA, 2-Star Technical and Operating Regulators, and the restoration of the posts of Chief Engineer and Flight Safety/Flight Operations Lead). It is the responsibility of all those who lead to inculcate the values and cultures outlined above.

Recommendations: New Safety Culture

In addition to the Recommendations contained **Chapters 20** to **26**, I make the following further Recommendations aimed at fostering a New Safety Culture:

(1) A New Engaged Safety Culture be built by the adoption, promulgation and inculcation of the above five-element model, namely a *Reporting Culture, Just Culture, Flexible Culture, Learning Culture and Questioning Culture.*

(2) The lead role in this process shall start and be sustained from the very top of the organisation.

(3) There shall be briefings for all those in Leadership positions of the lessons to be learned from the loss of *Challenger*, *Columbia*, Nimrod XV230 and other major accidents.

(4) The MAA shall employ experienced and qualified personnel to develop and promote an Engaged Safety Culture.

(5) The audit and inspection teams set up as part of the New Airworthiness Regime outlined in **Chapter 21** should be instructed and trained in the value of an Engaged Safety Culture so that they can both promote and audit the Safety Culture of the organisations which they visit.

(6) The MAA should, by liaison, secondment and regular contact with other organisations such as the CAA, HSE, and JPDO, ensure that it remains aware of best practice and new initiatives in promoting an Engaged Safety Culture.

(7) Part of the remit of the MAAIB shall be positively to consider and investigate on organisational causes or failures and report these to the Head of the MAA.

[20] See especially the HSE Conference *Leading from the Top*, London, 29 April 2009.

CHAPTER 28 – FURTHER RECOMMENDATIONS

Contents

Chapter 28 makes a number of Further Recommendations.

Further Recommendations

1. **Recommendation 28.1:** The excessive use of acronyms should be discouraged. It can be confusing, even to the Military.

2. **Recommendation 28.2:** The ubiquitous use of PowerPoint should be discouraged. It can lead the audience to watch rather than think.

3. **Recommendation 28.3:** The writing of prolix and repetitive reports should be discouraged. It can dishearten even the diligent reader.

4. **Recommendation 28.4:** A single professional body should be formed for Safety Experts to set professional and ethical standards, accredit members and disseminate best practice. Currently, there are a number of different professional bodies which provide some learned-society facilities for those with some expertise in the safety field. There is a need, however, for a single professional body to provide focus, rigour and a centre of excellence.

5. **Recommendation 28.5:** There should be regular articles in in-house magazines[1] and websites drawing attention to, and discussing, safety and airworthiness issues and best practice.

6. **Recommendation 28.6:** Consideration should be given as to whether maintenance shift patterns, in particular for 'legacy' aircraft, are optimum for ensuring the quality of work meets the ALARP principle.

7. **Recommendation 28.7:** Officers' terms on appointment should no longer include 'change objectives' but should, in future, include a statement requiring them to consider carefully the impact of any changes or initiatives and whether there might be any indirect or direct implications for Safety or Airworthiness.

8. **Recommendation 28.8:** The Orwellian-named DE&S "*Director General Change*" and "*Director Business Change*" should be re-named, respectively, "*Director General Stability*" and "*Director Business Stability*".

[1] *e.g.* Desider and Defence Focus and Single Service Flight Safety magazines.

CHAPTER 29 – MILITARY COVENANT AND FINAL REMARKS

29.1 A sacred and unbreakable duty of care is owed to the men and women of the Armed Forces by reason of the fact that they are necessarily called upon to make substantial personal sacrifices, including the ultimate sacrifice, in the service of the Nation.

29.2 Early manifestations of this duty are to be found as far back as Elizabeth I's reign in statutes providing for relief for sick or wounded veterans.[1]

The Military Covenant

29.3 This duty has found modern expression in the term 'Military Covenant'. The Military Covenant is most commonly voiced, and understood, in the context of the care and support which should be given to wounded Service personnel returning from theatre and to service families who have suffered loss. The duty is, however, in my view, much wider than that, and embraces the whole panoply of measures which it is appropriate the Nation should put in place and sustain for Service personnel, including adequate training, suitable and properly maintained equipment, sufficient provisions in theatre and proper support and conditions for Service personnel and their families at home. This view of the Military Covenant finds eloquent articulation in the land domain in the Army Doctrine Publication of 2000 which provides not only that soldiers and their families should always be able to expect *"fair treatment"* and *"commensurate terms and conditions of service",* but also that the (unique) nature of land military operations means that that the Army *"must be sustained and provided for accordingly by the Nation".* [2] In my view, exactly the same rationale applies to the Navy and Air Force.

29.4 The acquisition and maintenance of modern military equipment is increasingly complex-technically, financially and logistically. The history of In-Service Support has seen a shrinking of the role of uniformed and Crown personnel and commensurately greater devolvement of responsibilities to, and reliance, on the Defence Industry. It is important, for the future, that all organisations involved in this endeavour recognise their *collective* responsibility to work together to ensure that the Military Covenant is never broken, as it was in the case of Nimrod XV230.

The Nimrod Review

29.5 The Nimrod Review has found manifold shortcomings in the UK Military Airworthiness and In-Service Support regime, and uncovered matters which are as surprising as they are disturbing. The wholesale failure of *all* three organisations involved in the Nimrod Safety Case to do their job, and the apparently inexorable deterioration in the Safety and Airworthiness regime in the period 1998-2006, are particularly troubling aspects of the Nimrod XV230 story. There has been a yawning gap between the appearance and reality of safety. The system has not been fit for purpose.

[1] In the reign of Elizabeth I, an *Act for the Necessary Relief of Soldiers and Necessary Relief of Soldiers and Mariners* was passed in 1593 which laid down a law that each parish should contribute money to help sick and wounded veterans. A revised Act in 1601 provided: *"And forasmuch as it is found more needful that it was in the making of the said Acts, to provide the Relief and Maintenance of Soldiers and Marines that have lost their limbs, and disabled their Bodies in the Defence and Service of her Majesty and the State, in respect the Number of the said Soldiers is so much the greater, by how much her Majesty's just and honourable defence Wars are increased.* ***To the End therefore that the said Soldiers may reap the fruits of their good Deservings*** *and others may be encouraged to perform their like Endeavours.* ***BE IT ENACTED****... That from and after the said Feast of Easter next, every Parish within this Realm of England and Wales shall be charged to pay a weekly Sum of Money towards the Relief of Sick, Hurt and Maimed Soldiers and Mariners"* (42 Elizabeth CAP III, 1601).

[2] Chapter 1, MOD Army Doctrine Publication (2000) (the main author was Major-General Simon Roberts):

> *"Soldiers will be called upon to make personal sacrifices – including the ultimate sacrifice – in the service of the Nation. In putting the needs of the Nation and the Army before their own, they forego some of the rights enjoyed by those outside the Armed Forces.*
>
> *In return, British soldiers must always be able to expect fair treatment, to be valued and respected as individuals, and that they (and their families) will be sustained and rewarded by commensurate terms and conditions of service.*
>
> *In the same way the unique nature of military land operations means that the Army differs from all other institutions, and must be sustained and provided for accordingly by the Nation.*
>
> *This mutual obligation forms the Military Covenant between the Nation, the Army and each individual soldier; an unbreakable common bond of identity, loyalty and responsibility which has sustained the Army throughout its history.*
>
> *It has perhaps its greatest manifestation in the annual commemoration of Armistice Day, when the Nation keeps covenant with those who have made the ultimate sacrifice, giving their lives in action."*

29.6 I recognise that some of the matters revealed in earlier Chapters may come as a shock, both to members of the public and to many of those in the Services and the organisations concerned. But my Report should not herald a collective, or individual, loss of confidence by the public or those within the Services or Defence Industry generally, or a reluctance by organisations or individuals to shoulder responsibility in the future. Indeed, quite the opposite. The important point is that the facts leading to the loss of XV230 have now been investigated and examined carefully and have yielded numerous lessons and truths. Many of these lessons and truths may be unwelcome, uncomfortable and painful; but they are all the more important, and valuable, for being so. It is better that the hard lessons are learned now, and not following some future catastrophic accident.

XV230

29.7 Tragically, for the crew of XV230, the lessons have come too late, and at an infinite price. The most fitting memorial to the loss of the crew of XV230 will be that the lessons from their sacrifice are truly learned, and the Recommendations which I have set out are fully implemented. I believe that my Recommendations will immeasurably strengthen safety for the future.

Charles Haddon-Cave QC
London
October 2009

GLOSSARY

AAA	Ageing Aircraft Audit
AAIB	Air Accident Investigation Branch
AAR	Air-to-Air Refuelling
ACAS	Assistant Chief of the Air Staff
ACS	Airworthiness Competency Set
ADRP	Airworthiness Design Requirements and Procedures
ADS	Aircraft Document Set
AEDIT	Aircraft Engineering Defect Investigation Team
AFB	Air Force Board
ALARP	As Low As Reasonably Practicable
AMM	Aircraft Maintenance Manual
AOA	Aircraft Operating Authority
BP	Business Procedures
CAS	Chief of the Air Staff
CDM	Chief of Defence Materiel
CGS	Chief of the General Staff
CNS	Chief of the Naval Staff
COS	Chief of Staff
COO	Chief Operating Officer
CSDE	Central Servicing Development Establishment
DAATM	Directorate of Airspace & Air Traffic Management
DAOS	Defence Approved Organisation Scheme
DARA	Defence Aviation Repair Agency
DAS	Directorate of Air Systems
DASB	Defence Aviation Safety Board
DASC	Defence Aviation Safety Centre
DASMS	Defence Aviation Safety Management System
DASSR	Defence Aviation Safety Strategic Risk Register
DDP	Declaration of Design and Performance
DEC	Directorate of Equipment and Capability
DE&S	Defence Equipment and Support
DESB	Defence Environment and Safety Board
DLO	Defence Logistics Organisation
DPA	Defence Procurement Agency
EA	Engineering Authority
EAA	Engineering Airworthiness Authority

FI	Fatigue Index
FS	Flight Safety
FTA	Fault Tree Analysis
FSRP	Fuel Seal Replacement Programme
FWAMG	Fixed Wing Airworthiness Management Group
GARP	Generic Aircraft Release Process
GSN	Goal Structured Notation
HADRP	Hot Air Duct Replacement Programme
IPT	Integrated Project Team
IPTL	Integrated Project Team Leader
IR	Incident Report
ISA	Independent Safety Adviser or Auditor (as appropriate to context)
ISD	In-Service Date
JAP	Joint Air Publication
JBA	Joint Business Agreement
JSP	Joint Service Publication
LARO	Logistics Analysis Research Organisation
LITS	Logistics Information Technology Strategy
LOD	Letter of Delegation
MAFTR	MOD Airworthiness & Flight Test Regulator
MAOS	Maintenance Approved Organisation Scheme
MARDS	Military Aviation Regulatory Document Set
MAR	Military Aircraft Release
MARG	MOD Aviation Regulatory Group
MASG	MOD Aviation Steering Group
MARSB	MOD Aviation and Regulatory Safety Board
MARSG	MOD Aviation Regulatory and Safety Group
MASG	MOD Aviation Safety Group
MDG	Multi-Disciplinary Group
MDS	Maintenance Data System
MOD	Ministry of Defence
NAEDIT	Nimrod Aircraft Engineering Defect Investigation Team
NSG	Nimrod Support Group
NSIWP	Nimrod Structural Integrity Working Party
NSP	Nimrod Sustainment Programme
OSD	Out-of-Service Date
PE	Project Engineer
POEMS	Project Oriented Environmental Management System

POSMS	Project Oriented Safety Management System
PSWG	Project Safety Working Group
PUS	Permanent Under Secretary
RPO	Resident Project Officer
RTI	Routine Technical Instruction
RTO	Resident Technical Officer
RTS	Release to Service
RTSA	Release to Service Authority
SCP	Supplementary Cooling Pack
SFR	Serious Fault Report
SMO	Safety Management Organisation
SMP	Safety Management Plan
SMS	Safety Management System
STI	Special Technical Instruction
TAA	Type Airworthiness Authority
TLB	Top Level Budget
TLM	Through Life Management
TRM	Task Review Meeting
UOR	Urgent Operational Requirement

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A large number of organisations and many people have advised, assisted, encouraged and supported the Nimrod Review, and the individual members of the team, throughout the inquiry in a variety of different ways. I would like to express my personal thanks and gratitude to all these organisations and individuals and, in particular:

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