Lessons identified from initial Ageing Aircraft Systems Audits and Condition Survey Programmes

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DISTRIBUTION

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EXECUTIVE SUMMARY

At the inaugural meeting of the MOD/Industry Systems Airworthiness Advisory Group (SAAG), on 23 September 2009, it was agreed that lessons identified during the initial Ageing Aircraft Systems Audits (AASysA) and Condition Survey (CS) programmes should be collated to update MOD policy and to identify best practice. Lessons from the initial AASysA and CS, including VC10, Nimrod, C130, Sentry, Tucano and Historic Aircraft have been collated, with gratefully-acknowledged inputs from the Military Aviation Authority (MAA), QinetiQ, Musketeer Solutions, Aviation Support Consultants, Marshall Aerospace, 1710 Naval Air Squadron and General Dynamics. The background to each lesson identified has been described and recommendations have been made. These recommendations have been divided into:

- Policy issues.
- Programme conduct issues.
- Wider airworthiness issues.

A draft paper was circulated for peer review in September 2010 and comments received from the SAAG and the wider community have been addressed within the paper. Furthermore, it was agreed at the 3rd SAAG meeting on 3 November 2010 to widen the scope of the paper to include an initial review of the latest MOD AAA policy, to be promulgated in the JAP100A-01. As a result, the AAA policy issues section has been expanded to accommodate this review and additional recommendations. In addition, several of the key recommendations contained within this paper have already been accepted by the MAA, from the draft issue, and have been included in the latest iteration of the MOD’s AAA policy. Foremost among the recommendations accepted and implemented by the MAA were:

- Including a requirement to validate the effectiveness of integrity assurance methods by undertaking a physical survey of aircraft within the fleet.
- Reinforcing the airworthiness requirements of the AAA, rather than cost of ownership and availability issues.
- Including a requirement to address emergency systems within the AAA.
- Streamlining the three independent audits into a single AAA.

This paper was accepted by the SAAG on 5 May 2011.
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# Abbreviations

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<tr>
<td>AAA</td>
<td>Ageing Aircraft Audit</td>
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<td>AAP</td>
<td>Ageing Aircraft Programme</td>
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<td>AASA</td>
<td>Ageing Aircraft Structural Audit</td>
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<td>AASysA</td>
<td>Ageing Aircraft Systems Audit</td>
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<tr>
<td>AMC</td>
<td>Acceptable Means of Compliance (with regulation / rule)</td>
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<td>APU</td>
<td>Auxiliary Power Unit</td>
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<td>ASI</td>
<td>Aircraft Structural Integrity</td>
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<td>CASD</td>
<td>Continuing Airworthiness Support Division (now MAA)</td>
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<td>CS</td>
<td>Condition Survey</td>
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<td>CSWG</td>
<td>Condition Survey Working Group</td>
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<td>Def Stan</td>
<td>Defence Standard (UK MOD)</td>
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<td>DSAC</td>
<td>Defence Scientific Advisory Council</td>
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<td>Dstl</td>
<td>Defence Science and Technology Laboratory</td>
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<tr>
<td>ESVRE</td>
<td>Establish, Sustain, Validate, Recover, Exploit</td>
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<td>EWIS</td>
<td>Electrical Wiring Interconnection Systems</td>
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<td>FSI</td>
<td>Functionally Significant Item</td>
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<td>FTA</td>
<td>Fault Tree Analysis</td>
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<td>FME(C)A</td>
<td>Failure Modes, Effects (and Criticality) Analysis</td>
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<td>JAP</td>
<td>Joint Air Publication</td>
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<tr>
<td>MAA</td>
<td>Military Aviation Authority</td>
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<td>MAEI</td>
<td>MOD Aviation Engineering and Integrity</td>
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<td>MASAAG</td>
<td>Military Aircraft Structures Airworthiness Advisory Group</td>
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<td>MOD</td>
<td>Ministry of Defence</td>
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<tr>
<td>MSI</td>
<td>Maintenance Significant Item</td>
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ODR - Operational Data Recording
OLM - Operational Loads Measurement
PE - Project Engineer
PSWG - Platform Safety Working Group
RAF - Royal Air Force
RN - Royal Navy
RoHS - Restriction of Hazardous Substances (EC Directive 2002/95)
R&D - Research and Development
R&M - Reliability and Maintainability
RCM - Reliability Centred Maintenance
SAAG - Systems Airworthiness Advisory Group
SAE - Society of Automotive Engineers
STANEVAL - Standards and Evaluation
STWG - Specialist Technical Working Group
TSB - Transportation Safety Board (of Canada)
TWA - Trans World Airlines
UK - United Kingdom
US - United States (of America)
VICS - VC10 Intrusive Condition Survey
VISSAGE - VC10 Integrated Systems and Structures Age Exploration
ZSA - Zonal Safety Assessment
ZHA - Zonal Hazard Analysis / Assessment
1 INTRODUCTION

The MOD has now been undertaking Ageing Aircraft Structural Audits (AASA) for over 15 years. These audits were initiated following the well-known Aloha Flight 243, Boeing 737 pressure cabin failure in 1988 [1]. However, several civil accidents in the mid 1990s, including TWA Flight 800 [2] and Swiss Air Flight 111 [3], made the aviation community aware of the need to consider ageing effects of electrical and mechanical systems alongside structural implications. For the MOD the need to understand these ageing systems issues was reinforced by the loss of Nimrod XV230 over Afghanistan in 2006. Thereafter, the inclusion of aircraft systems aspects into the MOD’s Ageing Aircraft Audit (AAA) process was introduced.

At the inaugural meeting of the Systems Airworthiness Advisory Group (SAAG), on 23 September 2009, it was agreed that lessons identified during the initial Ageing Aircraft Systems Audits (AASysA) and Condition Survey (CS) programmes ¹ should be collated to update policy and to identify best practice.

Within this paper, lessons from the initial AASysA and CS programmes, including VC10, Nimrod, C130, Sentry, Tucano and Historic Aircraft have been collated. Contributions and comments on drafts of this paper from the Military Aviation Authority (MAA), QinetiQ, Musketeer Solutions, Aviation Support Consultants, Marshall Aerospace, 1710 Naval Air Squadron and General Dynamics are gratefully acknowledged. The background to each lesson has been described and recommendations have been made. For completeness, recommendations that were initially identified within the Ageing Aircraft Research and Development (R&D) paper [4] and Dstl report [5] have been annotated with the original recommendation numbers from these reports in the form [R&D[4] Rec X] and [Dstl [5] Rec X], accordingly.

A draft of this paper was circulated for peer review in September 2010 and comments received from the SAAG and ageing aircraft communities have been addressed within the latest draft. Furthermore, it was agreed at the 3rd SAAG meeting on 3 November 2010 to widen the scope of the paper to include an initial review of the latest MOD AAA policy, understood to be AL 23 [6]. As a result, additional sections were added to the paper. This additional requirement has also forced a renumbering of the sections and recommendations from the September 2010 draft.

¹ Condition Surveys have been undertaken as an element within an AAA programme or as a stand-alone programme, without the wider audit aspects.
In addition, following the circulation of the first draft of this paper, in September 2010, the MAA accepted several of the key recommendations made and these have been included in the latest iteration of the MOD's AAA policy. For completeness, where recommendations have been accepted by the MAA and incorporated into the latest AAA policy, this has been identified at the end of the recommendation.

It should be noted that this paper does not cover all aspects of ageing aircraft. For example, no reference is made to the ageing issues surrounding avionics line replaceable items. It is recognised that these are significant issues that do need to be addressed. However, the aim has been to restrict the issues tackled within this paper to those specifically identified within the AAA and CS programmes undertaken to date.
2 AGEING AIRCRAFT AUDIT POLICY ISSUES

2.1 DEFINITION OF AGEING

The issue of what is meant by ageing has been argued within several of the initial AASysA and related programmes. In some cases there have been quite significant differences of opinion which, if unresolved, could have significantly affected the direction of the programme. In several cases, the fact that an AAA is necessarily timed in calendar terms (i.e. half original life but no less than 15 years) has led to a view that ageing was entirely associated with elapsed time. As a result, ageing (degradation) issues could have been erroneously excluded from the programme. Therefore, it is recommended that a clear definition of ageing should be incorporated into the MOD policy in the JAP100A-01 [6]. A suggested definition, which directly links degradation with the consequences of that degradation, is detailed below. This definition is based very closely on that used by the Defence Scientific Advisory Council (DSAC) in its recent cross-domain review of ageing issues [7] (the difference in definition proposed is the addition of ‘information’ to the clarification of system) is provided below:

Ageing is defined as the degradation of the system (equipment, people\(^2\) or information) leading to an increased safety risk.

**Recommendation 1:** It is recommended that a clear definition of ageing should be incorporated into the MOD policy in the JAP100A-01 [6]. A suggested definition, which directly links degradation with the consequences of that degradation, is detailed below. This definition is based very closely on that used by the Defence Scientific Advisory Council (DSAC) in its recent cross-domain review of ageing issues [7] (the difference in definition proposed is the addition of ‘information’ to the clarification of system) is provided below:

Ageing is defined as the degradation of the system (equipment, people\(^2\) or information) leading to an increased safety risk.

\(^2\) People refers to issues such as skills, knowledge, training and motivation
2.2 **AIM OF AN AGEING AIRCRAFT PROGRAMME**

There has also been significant debate within the community as to what the aims of the AAA are and what they should be. There have been concerns raised that the focus of the audit, as defined in the current MOD policy in JAP100A-01 [6], on compliance with policy and including aspects such as availability and cost of ownership run the risk of diluting the original concept of the AAA. Given the real financial constraints in place today, there is a danger that spreading the remit of the audit too widely may generate a ‘box-ticking’ approach which misses the key ageing issues and concentrated on whether measures are in place rather than whether they are effective. One might argue that much of the auditing work focussed on the PT that is currently undertaken should be covered by internal quality assurance. That said, initial attempts have clearly been made by the MAA in the latest issue of the AAA policy to redress this balance by concentrating upon the airworthiness aspects of the AAA, at the expense of addressing cost of ownership and availability issues.

However, with the ongoing changes in the way the MOD regulates airworthiness and how the responsibilities for meeting these regulations will be apportioned in the future, it is essential that the ageing aircraft programme has a clearly defined aim. This aim would then provide the basis of military airworthiness regulations with responsibility for defining the methods to be employed to meet this rule apportioned accordingly between the relevant authorities. Much of the content of the current AAA policy could then be provided as acceptable means of compliance and guidance material (see Section 2.5).

Therefore, it is recommended that a clear top-level aim for an ageing aircraft programme should be defined. A suggested top-level aim is identified below:

*The aim of an ageing aircraft programme is to identify the onset of ageing\(^3\) within a fleet and to recommend (or implement – see Recommendation 3) remedial action.*

**Recommendation 2:** In order to ensure that an ageing aircraft programme is focussed, it is recommended that a clear top-level aim should be defined in MOD policy in JAP100A-01 [6]. A suggested top-level aim is identified as:

*The aim of an ageing aircraft programme is to identify the onset of ageing within a fleet and to recommend (or implement – see Recommendation 3) remedial action.*

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\(^3\) Where ageing is defined as the degradation of the system (equipment, people or information) leading to an increased safety risk.
2.3 **AGEING AIRCRAFT AUDIT OR AGEING AIRCRAFT PROGRAMME?**

The description of an ageing aircraft programme as an audit is largely historic. However, by being described as an audit the programme of work is, by definition, constrained to audit functions. Although a large proportion of the work needed to identify the onset of ageing and identify remedial action is auditing, evidence from programmes undertaken to date suggests that a more pro-active approach is necessary. An ageing aircraft programme, which incorporates the audit function, but also introduces enhanced continued airworthiness measures, appropriate for the platform in question, is a more appropriate method of providing airworthiness assurance for fleets in their later lives.

Ageing aircraft systems programmes to date have shown a great many common issues across aircraft types, such as poor husbandry, lack of physical clearances, widespread systems corrosion, poor maintenance data, loss of knowledge and apparent insufficient or inadequate training. While these issues are being addressed currently by initiatives such as the Air Command ‘Can-Do-Safely’ Campaign, the underlying circumstances leading to these degraded conditions are likely to persist to some degree and are likely to reoccur in the future, particularly given the ongoing economic constraints within which military aviation will be forced to operate.

Therefore, by developing the scope of an AAA into an Ageing Aircraft Programme (AAP), tailored by the findings of the audit element, the end-point for the programme would be implemented remedial solutions, rather than a series of recommendations that may or may not be implemented.

**Recommendation 3:** It is recommended that the AAA should be developed into an Ageing Aircraft Programme (AAP). Recognising that degradation or ageing is likely to occur, the AAP should incorporate the audit function, using the output to tailor the solution to the specific needs of the platform, but with the programme end-point being the implementation of remedial solutions, rather than recommendations.

2.4 **STREAMLINING OF AGEING AIRCRAFT AUDIT POLICY**

The bulk of the current AAA process is common to structure, systems and propulsion and hence the current arrangement (at the time of drafting this paper) of three separate audits, under three separate sub chapters within the JAP100A-01 [6] is not helpful to PT and could add unnecessary work and cost to these programmes. It has been estimated during a recent

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4 These issues are discussed further later in this paper.
combined audit that up to 40% of the costs of the audit can be saved by combining the disciplines into a single audit. Therefore, it is recommended that there should be a single AAA with common AAA policy with additional elements peculiar to systems, structure and propulsion identified accordingly.

It is understood that the MAA has already accepted this recommendation and made the decision to streamline the approach into a single audit for structures, systems and propulsion and this will be incorporated into the JAP 100A-01 at the next amendment (understood to be AL23 and included as Appendix A) and hence this recommendation merely reinforces this decision.

**Recommendation 4:** There should be a single AAA with common policy and with additional elements particular to systems, structure and propulsion identified accordingly. This recommendation has been accepted by the MAA and a revised, single-audit approach for structure, systems and propulsion will be incorporated into the next release of JAP100A-01. [Dstl[5] Rec 1].

### 2.5 Guidance for the Conduct of Ageing Aircraft Programmes

Current MOD policy contains a combination of what civil regulators would describe as rules, Acceptable Means of Compliance (AMC) and guidance. Although the author is not privy to the detailed deliberations within the MAA, it is understood that a move towards a more-civil approach in defining regulatory material is likely. Consequently, the rules within the current or amended regulations will, most likely, be extracted from the AMC and guidance material. The initial focus for the MAA will inevitably be on ensuring that the fundamental airworthiness rules are fit for purpose and responsibilities are apportioned to the relevant authorities accordingly, with the development of AMC and guidance to follow thereafter.

Experience to date suggests that the currently available AAA acceptable means of compliance (AMC) and guidance, within the JAP100A-01 policy requires development. This is to be expected as the current systems aspects of the policy were, from necessity, written without the experience of implementing such a programme. However, over the past 2-3 years a considerable amount of experience has been gained across the community in systems AAA and CS programmes. It is now an opportune time to capture and collate this knowledge as the basis for the development of ‘guidance material’ for future programmes and to inform AMC.
Recommendation 5: It is recommended that a SAAG paper outlining guidance material for the conduct of ageing aircraft programmes should be developed.

2.6 On-aircraft Condition Surveys

There has been significant debate within several projects as to whether an AAA requires any physical survey or inspection of the aircraft. It has been argued, erroneously in the view of the author, in some quarters that an audit is purely a review of process and that this does not require verification that the process has actually been undertaken or is effective. However, the wording of the current policy (AL20) [6] is quite clear and contradicts this view; bullet 1 of the policy defines an AASysA as:

*A periodic, independent assessment of the performance of procedures, management processes, technical information and documentation put in place to assure the integrity, functionality and airworthiness of aircraft systems.*

Therefore, from this policy statement the audit is required to assess the performance of the measures put in place to maintain and assure an airworthy aircraft. However, in addition to assessing the effectiveness of the key aims of a condition survey is to identify signs of ageing (i.e. degradation). It is also suggested that part of the assessment should include an analysis to determine whether the “as flown” aircraft matches the “as prescribed” aircraft. Furthermore, undertaking a survey of the actual condition of the aircraft and its systems is considered an essential part of that comparison process, without which the performance of the integrity measures cannot be assured. UK MOD structures experience and US civil and military experience clearly illustrates that surveying aircraft is essential. The crucial aspect of this performance assessment was illustrated by Mr Stewart Miller, FAA Aging System Program Manager, in his comments in the aftermath of TWA 800 [8] that:

*“We were watching the fleet, but we did not understand that maintenance programs were not as robust as we thought.”*

The importance of the actual condition of fleets has been recognised at the highest levels in the MOD and this is illustrated by the Air Command “Can do safely” campaign. AAA provides an unrivalled opportunity to identify issues of aircraft condition. At the top level, an AAA is fundamentally about identifying degradation that can lead to an increased safety risk (as previously defined) and this cannot be done without ascertaining the condition of the fleet. Design, regulation and policy all go to define the expected condition and the actual condition needs to be assessed against this benchmark.
Therefore, to avoid future ambiguity, it is recommended that an independent aircraft condition survey should be specifically identified as a requirement of an AAA. It should be noted that following circulation of a draft of this paper, this recommendation has been accepted by the MAA and the latest revision to the AAA policy [6] mandates a condition survey.

**Recommendation 6:** An independent aircraft condition survey should be specifically identified as a requirement of an AAA, to remove any ambiguity in what is meant by assessing the performance of integrity measures. The aim of this aircraft condition survey is to look for signs of ageing (i.e. degradation), identify the effectiveness of integrity assurance measures, and determine whether the “as flown” aircraft matches the “as prescribed” aircraft. The MAA has accepted this recommendation and a condition survey has now been mandated in the revised AAA policy, to be promulgated in JAP100A-01. [R&D[4] Rec 9], [Dstl[5] Rec 2].

### 2.7 GUIDANCE FOR THE CONDUCT OF CONDITION SURVEYS

Alongside the development of this paper, the MOD/Industry Condition Survey Working Group (CSWG) (a SAAG sub-committee) has been debating issues surrounding what is meant by a condition survey and what approach should be taken. A consensus was reached across the community that there was a need for a condition survey (see Section 2.6). However, it was concluded at the CSWG meeting on 23 November 2010 that further work was required to develop guidance for undertaking condition surveys, as part of an ageing aircraft programme. This guidance should include, but not be restricted to aspects such as:

- Identifying *a priori* information for use in scoping the extent of the survey (i.e. in-service arisings, consequences of failure, previous survey experience).
- Determining and achieving representative sample sizes.
- Determining the depth of the survey.
- Providing a robust mechanism to record and communicate findings to the PT and wider community.
- Identification of the importance of sentencing observations to enable a degree of filtering.
- Development of an immediate fault reporting process to highlight immediate continued airworthiness concerns.
Recommendation 7: It is recommended that a SAAG paper should be developed to provide guidance for the conduct of an aircraft condition survey as part of an ageing aircraft programme (and to be incorporated into or referenced to the proposed AAA conduct guidance paper identified in Recommendation 5). This guidance should include, but not be restricted to aspects such as:

- Identifying a priori information for use in scoping the extent of the survey (i.e. in-service arisings, consequences of failure, previous survey experience).
- Determining and achieving representative sample sizes.
- Determining the depth of the survey.
- Providing a robust mechanism to record and communicate findings to the PT and wider community.
- Identification of the importance of sentencing observations to enable a degree of filtering.
- Development of an immediate fault reporting process to highlight immediate continued airworthiness concerns.

2.8 CONSIDERATION OF MANDATORY SYSTEMS

Identification of where to focus the efforts for an ageing systems programme has proven to be a challenging aspect of programme development and some of the methods used are discussed in Section 3 of this paper. However, from the programmes undertaken to date, it is clear that there are common systems that should be included with the programme from a “hull-loss” perspective. Rather than expecting each project to identify these systems, it is recommended that consideration should be given to identifying mandatory systems that require further investigation. However, during peer review of this paper, this recommendation sparked considerable comment, debate and some reservations from across the community and hence it is recommended that this issue should be debated further within the SAAG, with the aim of reaching a consensus.

Recommendation 8: Consideration should be given to including mandatory systems within the AAA regulations which would be considered “targeted systems” by their very function (flight control systems, hydraulics, etc) or contribution to fire/explosion hazard (fuel, environmental control systems). Following issue of a draft of this paper for peer review, this recommendation sparked considerable comment, debate and some reservations from across the community and
hence it is recommended that this issue should be debated further within the SAAG, with the aim of reaching a consensus.

2.9 SAMPLING OR FORENSIC INVESTIGATION, NOT TEARDOWN

The use of the term “teardown”, although widespread throughout integrity assurance programmes, is a legacy from the structural origins of the AAA programmes. In fact teardown is probably an inappropriate term even in the structural AAA context as it implies a rough-and-ready approach which is incorrect. It would be far more appropriate to describe the activity as sampling and forensic investigation. One might argue that this is pointless ‘word-smithing’ but perceptions are important and discussions with several PT staff found them supportive of sampling programmes yet unsupportive of a teardown programme.

**Recommendation 9:** Reference in policy to teardown of aircraft systems should be referred to as sampling, including forensic investigation, as appropriate. Teardown implies a level of imprecision which is inappropriate. [R&D[4] Rec 10], [Dstl[5] Rec 3].

2.10 SAFETY MANAGEMENT SYSTEMS FOUNDATIONS SUPPORTING AN AAA

Understanding where to focus efforts has to be one of the most important aspects of the planning phase of a systems audit or in establishing a Systems Integrity (SysI) Programme. It is impractical to undertake in-depth investigations of every component in every system throughout all the zones of the aircraft and hence a targeted approach is necessary. Although this is easily said, it is a little more challenging to undertake in practice. To a certain extent, the complexity of this targeting task is dependent largely on the foundations that are in place for the systems safety management of the aircraft.

The identification of where to look on the aircraft is one of the major differences between conduct of the structural aspects of the AAA and systems aspects. Most military aircraft have fairly well defined areas of structural interest from either static strength or fatigue strength considerations. These features are described as Structurally Significant Items (SSI) or

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5 It is expected that not all aircraft have SSIs; however, an equivalent designation such as Safety of Flight Structure, Grade A parts or Critical Parts will apply.
equivalent and will have been identified by the consequences of failure of the feature. However, for systems particularly, this may not be quite so clear cut.

Ideally, at the initiation of an audit existing information would be available that identifies all the system hazards⁶ and inter-system hazards across the aircraft, from a detailed functional safety, operational safety and physical safety perspective. This may well be the case for an aircraft certified to either civil or military regulations in relatively recent years, where such an approach would be expected. However, even for legacy platform the Designer should have identified ‘critical’ components (sometimes termed Maintenance Significant Items (MSI)) at the design and test phases or undertaken a Functional Hazard Assessment and Preliminary Systems Safety Assessment. If this has not been carried out, or this information has been lost over time, then there is a wealth of in-service data and experience that can be used to determine components to be examined, (RCM analysis, maintenance data, flight safety occurrence reporting, Modification and SI(T) records, F760 records, other type experience, etc). However, retrospective application of top-down methods, such as Fault Tree Analysis⁷ (FTA), coupled with bottom-up methods, such as Failure Modes Effects (and Criticality) Analysis (FME(C)A) and Zonal Hazard Analysis (ZHA) / Zonal Safety Analysis (ZSA) may not necessarily have been applied to all military fleets.

Therefore, the extent of the audit task will vary considerably dependent upon the system safety foundation data available; hence it is recommended that the available data should be identified three years before the first audit is scheduled, to allow sufficient time to put remedial action in place if required. Such a review should also be undertaken when establishing a SysI programme for the aircraft and should be included or referenced within the SysI policy. SAE ARP4761 [9] provides useful guidance on the processes and techniques that can be used to assemble the necessary information.

**Recommendation 10:** A review should be undertaken three years before the first scheduled AAA to identify whether sufficient data are available to identify target systems and zones for the audit. This requirement should be either included in or referenced from the SysI policy. Such a review should also be undertaken when establishing a systems integrity programme for the aircraft. SAE ARP4761 [9] provides useful guidance on the processes and techniques that can be used to assemble the necessary information. [R&D[4] Rec 13], [Dstl[5] Rec 4].

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⁶ In this context a hazard is considered to be a prerequisite condition that can develop into an accident through a sequence of failures, events and actions in the process of meeting an objective [18].

⁷ It should be remembered that FTA is not a technique for hazard identification.
2.11 VALIDATION OF EMERGENCY SYSTEMS PERFORMANCE AND ADEQUACY

Although AAA are identified within the Sustaining section of current MOD Establish-Sustain-Validate-Recover-Exploit (ESVRE) policy contained in JAP100A-01 [6], many of the functions of the audit are validation functions.

Even a cursory view of accident sequences with technical causes will clearly identify a chain of events leading to that accident, plus, often, several opportunities to break that chain and either prevent the accident occurring or lessen the consequences. The widening of the remit of AAA to include systems now brings emergency systems within the bailiwick of an audit.

Emergency systems should be subject to specific attention within an AAA. By definition, their use in anger will occur when a few steps down an accident sequence have already been taken. Furthermore, these systems figure heavily in Safety Case mitigations and Safety Case assumptions should be validated.

Therefore, the continued performance and adequacy of each emergency system should be ascertained against the system requirements. Overheat detection devices provide an excellent example to illustrate this point. Although the overheat detectors may be subject to electrical continuity checks, the actual performance of the detector may not have been checked during the life of the aircraft, particularly if these have been identified as ‘on-condition’ items. It should be noted that this recommendation has been accepted by the MAA from a draft of this paper and has been included in the latest revision of the AAA policy in the JAP100A-01.

Recommendation 11: Amendment to the MOD AAA regulation should be considered to clearly identify which systems are emergency systems and to mandate their inclusion in the AAA. This recommendation has been accepted by the MAA and has been included in the latest revision of the JAP100A-01 AAA policy.

Recommendation 12: A review of the continued performance and adequacy of emergency systems should be specifically identified as a requirement of the AAA. This recommendation has been accepted by the MAA and has been included in the latest revision of the AAA policy. [R&D[4] Rec 19], [Dstl[5] Rec 5].
2.12 Validation of Design and Usage Assumptions – OLM / ODR / FDR

The system designer must make assumptions of how a system will be used, how it will interact with the environment, and how it will interact with other systems in the aircraft. The structures community has, in the past, felt the implications of not fully appreciating the sensitivity of structural lives to changes in usage and operating environment. Validation processes, including Operational Loads Measurement\(^8\) (OLM), are therefore now entrenched within MOD Structural Integrity Policy \([6]\). Validation of design and usage assumptions can be equally critical for aircraft systems, as has been illustrated by the Nimrod loss and the MOD Systems Integrity policy now makes reference to the need to validate system usage assumptions.

Experience to date has illustrated shortfalls in the information readily available to validate these design and usage assumptions. It is important to understand the key sensitivities within a target system or zone and to be able to measure appropriate parameters to validate assumptions. For example, when considering the traditional fire triangle of oxygen, heat or ignition source, and fuel, the usual focus within a zone for an ignition source might be a spark from an electrical system. However, auto-ignition of fuels can occur without the presence of a flame or spark. The exact conditions for auto-ignition are influenced by factors such as surface geometry, closed or open environment, local air velocities and fluid residence time \([10]\). However, aviation fuels are vulnerable to auto-ignition at temperatures as low as 210°C to 300°C, depending on the air-fuel ratio, at atmospheric pressure. Therefore, validation of the temperatures seen within a fuel-containing zone is essential.

In reality, the division between managing the integrity of systems, structure and engines is purely a method of dividing the air vehicle integrity task into manageable sections. However, Operational Loads Measurement or Operational Data Recording\(^9\) (ODR) programmes already have the infrastructure in place to capture essential assumption validation data. OLM / ODR data captured are also used to understand the operating environment and this is equally important for the aircraft systems. Flying control positional data are also generally captured within OLM programmes. Therefore, the additional systems data capture requirements of parameters such as temperatures and pressures would be relatively small.

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\(^8\) Where a proportion of the fleet is instrumented with strain and parametric sensors to capture the representative structural usage of the aircraft in service

\(^9\) ODR programmes are conducted on rotary-wing aircraft where the division between structures and systems is less rigid as transmission systems have traditionally been classified as “structure”. Furthermore, rotary-wing Health and Usage Monitoring Systems (HUMS)
**Recommendation 13:** The current requirements for Operational Loads Measurement / Operational Data Recording should be extended to include the capture and analysis of data necessary to validate design and usage assumptions for target systems or zones. *[R&D[4] Rec 20], [Dstl[5] Rec 6]*.

### 2.13 IMPLICATIONS OF CHANGES IN REGULATION

Although the consideration and implications of changes in regulation since an aircraft was certified are not unique to systems, the issue is generally more significant for aircraft systems than it might be for structure. In general, changes to certification regulation within the civil and military arenas are not made retrospective. However, it is understood that changes in the management of Defence Standard 00-970 for example will force a greater consideration as to whether a change in regulation should be applied retrospectively.

Within the context of an AAA, there should be a review of the current safety-related certification regulations for target systems and zones and shortfalls in the design or practise currently invoked should be identified. For example, if the relevant latest fire protection certification requirements for an Auxiliary Power Unit (APU) bay were significantly greater than the protection mandated and applied at the time of certification of an aircraft, this should be highlighted within the AAA. Thereafter, one would expect the PT to consider remedial action or mitigation of an additional risk.

**Recommendation 14:** An AAA should include a review of the current relevant safety-related certification regulations for target systems and zones and any shortfalls in the design or practise currently in place should be identified within the audit. *[R&D[4] Rec 26], [Dstl[5] Rec 7]*.

### 2.14 PROGRAMME COST CONSTRAINTS

Current MOD policy does not address cost issues associated with meeting policy requirements. In addition, there is no guidance (to the knowledge of the author) available to PT on the likely cost of AAA programmes. In reality, the extent of the work undertaken within an AAA or CS is largely governed by the funding available to undertake the work. While this is an inescapable reality, the efficacy of an AAA or CS programme can be severely undermined if the funding is programmes may well capture most of the essential systems parameters already but these may not be analysed to any great degree currently.
insufficient to undertake the required work and this may not be clearly evident outside of the programme. Therefore, it is recommended that guidance for PTs should be developed to identify typical AAA programme costs across a range of programmes and that the cost implications of changes to policy should be considered.

**Recommendation 15:** It is recommended that guidance for PTs should be developed to identify typical AAA programme costs across a range of programmes and that the cost implications of changes to policy should be considered.

### 2.15 Programme Exclusions

As discussed in the previous section, the scope of an ageing aircraft programme will, necessarily, be constrained by a variety of factors (primarily funding). As a result, the output of the programme will be significantly shaped by exclusion or constraint decisions that are made at the outset of the programme. However, the Project Engineer (PE) is required to sentence the recommendations of the AAA report. Also, progress against the AAA report recommendations is to be monitored by the Platform Safety Working Group (PSWG) or Integrity Working Groups but a similar level of scrutiny is not required to sentence exclusions or the intended scope of the programme at the outset. Therefore, it is recommended that the scope of the AAA and any exclusions should be formally endorsed by the PE at the outset of the programme. This recommendation has been accepted by the MAA and has been included in the latest version of AAA policy in the JAP100A-01.

**Recommendation 16:** It is recommended that AAA policy should mandate that the scope of the AAA and any exclusions should be formally endorsed by the PE at the outset of the programme. This recommendation has been accepted by the MAA and has been included in the latest version of AAA policy in the JAP100A-01.

### 2.16 Review of Latest Iteration of AAA Policy

As previously discussed, MAA Tech Cert ASI has recently amended the MOD AAA policy and this will be promulgated at the next amendment of the JAP100A-01 (understood to be AL 23). This was understood to be an interim amendment which included streamlining the AAA to a

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10 Exception or deferral of the complete or structures, systems or propulsion sub-audit requires 2-Star endorsement.
single audit and implementing key recommendations made in this paper and accepted by the MAA (extracted from the draft circulated in September 2010). The MAA further identified at the 3rd SAAG meeting on 3 November 2010 that the JAP100A-01 was scheduled for a freeze of a significant length (understood to be a year) from February / March 2011. Therefore, it was agreed at the 3rd SAAG meeting to identify suggested amendments to the latest iteration of the AAA policy (to be issued at the next AL) in time to meet the JAP100A-01 freeze.

However, it was not practical to attempt a complete re-write of the policy and to segregate it into rules, AMC and guidance in the timescales necessary to meet the JAP freeze. Therefore, initial comments on the revised AAA policy, within the existing policy format, were provided to the MAA and it was agreed that thorough revision of the policy was still required.

**Recommendation 17:** It is recommended that AAA policy should be subject to a thorough review, in light of the experience gained in these ageing aircraft related programmes, and to ensure the regulation, AMC and guidance is fit for purpose.
3 AGEING AIRCRAFT PROGRAMME CONDUCT

ISSUES IDENTIFIED

3.1 PAN-ORGANISATIONAL AUDIT TEAM

AAA and CS are complex and when done well will require significant efforts from all those involved. It was immediately evident from the initial programmes that no one organisation has all the skills and knowledge needed to undertake a successful programme in isolation. The MOD policy [6] identifies that the audit should be independent. However, it should also be recognised that success is dependent upon the support of the Design Organisations, PT, Maintenance Staff, Operators and MOD Policy Branch, and the independent auditor cannot provide a successful audit without the co-operation of all these organisations. In particular, experience has shown that the Maintenance Staff can provide detailed information that is not normally available from other sources. This is particularly relevant to contracted-out maintenance where certain issues are addressed within the contract and do not necessarily come to the notice of the PT or the Designer.

Recommendation 18: It should be recognised when advising PT on AAA conduct that success is dependent upon the support of the Design Organisations (Prime and Component), PT (including Commodity), Maintenance Staff, MOD Policy Branch and Operators; the independent auditor cannot provide a successful audit without the co-operation of all these organisations. In particular, experience has shown that the Maintenance Staff can provide detailed information that is not normally available from other sources. This is particularly relevant to contracted-out maintenance where certain issues are addressed within the contract and do not necessarily come to the notice of the PT or the Designer11. [R&D[4] Rec 7], [Dstl[5] Rec 8].

3.2 PEER REVIEW

Peer review provides an invaluable opportunity to validate a proposal or a completed body of work. Within academic circles it is considered an essential element in the acceptance of ideas.

11 Specific reference to Component Design Organisations, Commodity Project Teams and the importance on information gained from Maintenance Staff has added to this recommendation – these aspects were not previously specifically identified in [4].
Over the next few years a great deal of experience will be gained in undertaking the systems aspects of AAA, to accompany the wealth of experience already gained in structural aspects of these audits. This experience should be used within a culture of continued development to provide peer review of audit plans and draft audit reports.

**Recommendation 19:** Pan-organisational peer review, within a culture of continued development, of audit plans and draft audit reports should be strongly encouraged. [R&D[4] Rec 8], [Dstl[5] Rec 9].

### 3.3 IS SAMPLING A REQUIREMENT?

The issue as to whether sampling (currently termed teardown (see Section 2.4)) should be a requirement of an AAA has been debated within several programmes and was discussed briefly under Section 2. The lead large aircraft fleets involved in the development of ageing aircraft programmes, the Nimrod, VC10 and C130K condition surveys had the opportunity to use an aircraft that was being retired from Service as part of their investigations. There is no doubt that having an example, even if it is only one aircraft and hence not a representative sample, from the fleet provides a unique opportunity to identify and understand issues. However, the activity of sampling does not necessarily require a full aircraft, nor does it necessarily have to result in the destruction of all or part of the aircraft. Additionally, the sample size, with an aim to undertake sufficient samples to be representative of the fleet, should be considered [11, 12]. Careful planning should allow necessary testing, analysis and inspection to be largely accommodated within the realms of existing maintenance programmes. The additional burden of sampling beyond the normal maintenance regime into un-inspected or undisturbed systems would generally be expected to be relatively small.

Certainly in the case of the VC10 programme, having the aircraft available and parked outside right at the outset of the programme was a disadvantage. It would have been preferable for a planning period to have been scheduled before the arrival of the aircraft.

**Recommendation 20:** Where example aircraft are retired from the fleet for use in sampling programmes (currently termed teardown), a period of planning should be scheduled before the aircraft is delivered for the programme. [R&D[4] Rec 11], [Dstl[5] Rec 10].

Sampling has been identified in MOD SI policy for many years. However, it is only in relatively recent years that the true value has been recognised in the wider aerospace community as structural sampling has providing crucial evidence to continue operating ageing aircraft fleets. As the focus shifts to the integrity of systems and lives of aircraft continue to be extended, it is
likely that sampling of systems will also prove to be an invaluable tool. It should be remembered that the use of sampling, within age exploration programme [13] is a fundamental aspect of RCM. However, systems sampling programmes are still relatively rare. Consequently, when events occur that necessitate investigations of systems lifing policy, such as the recent studies conducted by CASD-AVI (now MAA) into lifing of seals [14], flexible hoses [15] and control rods [16], definitive evidence of the specific performance of these components can be difficult to ascertain purely from component replacement or flight safety incident/occurrence report data.

It is common knowledge that many of the components within a system will deteriorate; elastomeric seals, used widely in aircraft systems, are an excellent example. The deterioration of these seals will be influenced by a great many factors, including materials, environmental and chemical attack and in many cases changes to the chemistry of the seals manufactured over time. Understanding how deviations from design assumptions (if they are known) will affect the performance of the seals is extremely complex. In cases where the consequence of failure demands, the use of sampling from in-service and possibly additional testing of sampled components\(^{12}\) could provide an invaluable insight into the integrity of these components. This would allow remedial action to be introduced before failures occur. Furthermore, ongoing programmes can be used to identify the effect of changes in usage on the systems directly.

**Recommendation 21:** The potential value of sampling of system components should be emphasised. This should be invoked where the consequences of component failure are significant and the deterioration of the component is difficult to predict accurately (such as elastomeric seals). \([R&D[4] \text{ Rec 12}], [Dstl[5] \text{ Rec 11}].\)

### 3.4 IDENTIFICATION OF TARGET SYSTEMS OR ZONES WITH LIMITED A PRIORI INFORMATION

As already discussed, for some of the MOD’s fleets the systems safety information available may be limited and hence a method of identifying where to focus efforts will have to be developed.

The approach taken within the VC10 VISSAGE (latterly termed VC10 Intrusive Condition Survey (VICS)), which was intended to be an element of the AAA programme, was to use an initial 3-

\(^{12}\) The approach of retiring components from service for sampling and the use of run-on testing is a well-used procedure within the propulsion discipline, for example, for lifing of turbine disks.
day workshop, facilitated by a highly-experienced Design Airworthiness Engineer and supported by the PT, Design Engineers, Maintenance Engineers, Maintenance Instructors, In-Service Engineering Investigation Team, experienced aircrew (STANEVAL). Within this Workshop, an initial FTA was developed but using a Hull-Loss Model (Figure 1) as a template to ensure that faults that could produce hazards and single-failure points were identified.

The success of this approach was highly dependent upon having knowledgeable representation from designers, maintainers and operators (aircrew). Each of these organisations brings an essential element of understanding and perspective; without any one of the parties the picture would have been incomplete and the understanding of the implications of a potential systems failure could have been flawed. Consideration of this approach is recommended in the absence of available information with which to identify target systems and zones for investigation. As previously discussed, SAE ARP4761 [9] provides valuable guidance for the processes and methods used to conduct safety assessments.

This lack of information can also be an issue when attempting to understand fully the implications of subtle but significant variations between marks of aircraft and of individual aircraft within a mark. Therefore, it is recommended that reference should be made to ensuring that mark variations and variations within a mark are considered within the systems integrity management and the AAA policy. The MAA has accepted this recommendation and included it in the latest issue of AAA policy.

![Figure 1. Top-level hull-loss model](image-url)
**Recommendation 22:** Where there is insufficient systems safety information initially available to identify which systems and zones should be focussed upon within an AAA, the use of a Fault Tree Analysis workshop, using a Hull-Loss Model template, with the involvement of design, maintenance, instructional staff and aircrew, with an experienced airworthiness facilitator should be considered as a starting point for systems prioritisation. \[R&D[4] Rec 14\], \[Dstl[5] Rec 12\].

**Recommendation 23:** Where a complete aircraft Zonal Hazard Analysis / Assessment of Zonal Safety Assessment is initially unavailable to identify which zones should be focussed upon within a AAA, the use of a physical review of the aircraft using experienced design and maintenance engineers should be considered as a starting point and, where possible, in conjunction with any existing Safety Case documentation or any previous limited hazard analysis undertaken. \[R&D[4] Rec 15\], \[Dstl[5] Rec 13\].

**Recommendation 24:** In additional to a physical review of the aircraft, the Topic 5A1 Master Maintenance Schedule (MMS) can provide valuable information for targeting zones by identifying which systems (by Schedule Identification Number (SIN)) are within which zone and what volume and frequency of maintenance is carried out in the zone. The volume and frequency of maintenance can be a good indicator to the criticality of the systems within a zone and hence an aid to zonal targeting.

**Recommendation 25:** Reference should be made to ensuring that mark-to-mark variations and variations within a mark are considered within the systems integrity management and the AAA policy. The MAA has accepted this recommendation and included it in the latest iteration of the AAA policy. \[R&D[4] Rec 16\], \[Dstl[5] Rec 14\].

The Hull-Loss driven FTA for the VC10 VICS programme was supplemented by identification of the systems content in each zone of the aircraft and an initial zonal hazard review undertaken by DSG St Athan (depot-maintenance organisation) and BAE Systems (design organisation).

Pending the completion of the FTA and zonal assessment work, a parallel review of the systems / zones was undertaken by the VISSAGE Team. The VISSAGE Mechanical, Electrical, Safety and Data Specialist Technical Working Groups (STWG) were drawn from the Aircraft Project Team, QinetiQ (both technical and safety specialists), BAE Systems, MOD Policy Branch (MAEI 2 (now MAA)) and Dstl, with further type-specific support from DSG St Athan.

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\[Zonal Hazard Assessment / Analysis and Zonal Safety Assessment are similar terms used to define similar techniques.\]
The approach taken within the STWGs was to consider each system in turn (using the Topic 5A1 designations) and identify which systems should be considered within the audit, based upon the consequences of each failure of that system from two separate perspective:

- The direct potential consequences of failure of the system.
- The in-direct consequences of failure of the system including system interaction or interconnection – so called “zonal” effects.

**Recommendation 26:** The formation of pan-organisation Specialist Technical Working Groups (Mechanical, Electrical, Safety and Data in this case) has provided a useful method of guiding systems investigation process, gaining peer review and stakeholder buy-in and should be considered for future audits. This is already identified in policy and hence this recommendation is included for reinforcement only. The diverse responsibilities of commodity project teams, industrial commodity providers and sub-contractors greatly increases the organisational complexity for systems audits, when compared with structural audits and this needs to be recognised and addressed within the programme. [R&D[^4] Rec 17], [Dstl[^5] Rec 15].

For the Tucano, which is a relatively simple aircraft, the approach taken to identify target zones was to use a wide range of available data, including RCM analysis, air publications, general arrangement drawings, zonal analysis, undertaken by the designer, and discussions with maintenance staff. The Tucano audit team also adapted a methodology developed to undertake ZHA on the Harrier GR9 and T12 aircraft, developed by QinetiQ [17].

As discussed earlier in this paper, it should also be noted that the Society of Automotive Engineers (SAE) has produced an Aerospace Recommended Practice (ARP) 4761 – Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment [9].

### 3.5 Avoiding the Risk Mitigation Trap

In practice, it can be quite difficult not to draw in the mitigation provided by back-up systems or emergency protection into the analysis process, as detailed previously, when considering whether a system should be identified for further investigation. The result of falling into this trap may be to exclude systems from consideration, based upon potentially un-validated mitigation. To prevent this, constant reference back to the Hull-Loss Model should be used and periodic checks that the decision logic is sound should be undertaken. This is best illustrated with an example: loss of primary flight control would generally result in a hull loss. Therefore, primary
flying control systems should be considered for investigation within an AAA, based upon the consequences of failure of that system alone. The availability of back up systems and emergency systems potentially reduces the probability of the occurrence but not the consequences of loss of control. Therefore, the presence of mitigation should not remove the primary flying controls from those systems to be considered under an AAA. Validation of the risk mitigation assumptions provided by back-up or emergency systems should be a fundamental aspect of the Systems Integrity Programme.

The importance of validating the mitigation assumed from back-up systems is based upon the risk that supposedly independent systems may in fact be vulnerable to either dormant (undetected or latent first system failures) or dependent failures. One of the most widely used assumptions in quantitative analyses is that failures of components or sub-systems are independent of any other failures. This assumption greatly simplifies the analysis and is therefore very convenient. Although most essential and critical systems employ some sort of redundant technique, closer scrutiny can reveal that these systems often have a “single element”, the failure of which will cause multiple channel failures [18]. These can either be:

- **Common-part failures** - such as multiple flying control systems merging into a single pilot's control column.

- **Common-cause failures** - such as a fire destroying multiple independent systems located in the same bay.

- **Cascade failures** – this is a particular type of common-mode failure where a single failure may overload the remaining systems or channels.

The need to separate the consequence of failure from the probability of occurrence was recognised within the VC10 programme and hence the term “Target” systems or zones rather than “Critical” systems or zones was used because “Critical” implies a combination of failure consequence and probability of occurrence.

**Recommendation 27:** Care should be taken to ensure that the consequence of failure is used to identify systems and zones for further investigation under an AAA and that perceived mitigation, such as redundancy or back-up systems, should not be used to exclude these areas from further investigation within the Audit. [Dstl[5] Rec 16].
3.6 TARGET SYSTEM PERFORMANCE ASSESSMENT

One of the areas where there may well be a significant difference between systems and structural audits is in understanding the performance of the system and the significance of survey or sampling observations. Failure criteria in structural components are generally fairly well understood. For example, the residual strength of a structure in the presence of a crack would be identified and assessed against failure criteria, such as the structure being able to support 120% limit load or meet a stiffness or deflection limit. Therefore, a reasonably reliable estimate of the effect on the overall structural integrity of the aircraft can be identified from a disassembled component.

For a system, however, the link between damage found in a component and the capability of the system to perform its required function or the effect on safety of the aircraft can be less clear. Equally, the performance of the system may well have degraded without readily identifiable physical evidence.

Therefore, where condition surveys or sampling programmes are being carried out, detailed functional checks of the performance of target systems before undertaking survey or sampling can provide an extremely useful yard stick. Such checks can identify degraded performance and assist in the understanding of the significance of any observations found during survey or sampling. Such an approach is invaluable in prioritising recovery actions following the identification of observations. Once a system is disturbed, if this approach is to be taken, this information is potentially lost.

For many systems (such as flying control systems), there will already be detailed functional checks in the Air Publications. However, many of the checks will be pass/fail in nature. It is useful to identify greater resolution than just pass/fail in order to determine whether the system performance is degrading and whether any observations found are related to a degradation of performance. For systems without extant functional checks, reference to any certification testing or release-to-service test schedules can provide a valuable comparison of performance.

In addition, maintenance staff with significant experience on the aircraft type should be consulted to identify target systems where there are difficulties meeting the required tolerances. Maintenance data will also show where systems are failing functional checks.

**Recommendation 28:** The use of functional performance checks of target systems should be considered before condition surveys or sampling programmes are undertaken. Such checks will identify degraded system performance and assist in ascertaining the significance of observations found during the condition surveys or sampling programme. [*R&D[4] Rec 18*, *Dstl[5] Rec 17*].
Recommendation 29: The performing of functional testing before a condition survey can also provide a valuable check of the adequacy of the tests carried out in-service, by correlating faults found during the condition survey with test reports.

Recommendation 30: Maintenance staff with significant experience on the aircraft type should be consulted to identify target systems where there are difficulties meeting the required tolerances. Maintenance data should also show where systems are failing functional checks.

3.7 TRENDING OF SYSTEM PERFORMANCE

Trending of accurate fault and incident reporting data can provide a valuable early-warning system and can have knock on benefits for Reliability and Maintainability (R&M). Conversely, systems R&M information can directly benefit integrity. An excellent example is demonstrated by the work ongoing within the Tornado programme at RAF Marham where the reliability of aircraft systems on an aircraft-by-aircraft basis is being investigated to capture the R&M drivers for each system (a similar approach is in place within the Tucano Support Contract). Moreover, the work undertaken during an RCM review can provide valuable information to support the AAA, particularly where changes have been made to the Topic 5A1 as a result of the review.

Recommendation 31: Prior to using any R&M data, the availability and age of any RCM study should be considered as a useful source. If RCM has recently been carried out then the issues highlighted during trend monitoring of R&M data would have been captured by RCM and reflected in the Topic 5A1 up-issue. Hence a relatively quick review of the 5A1 amendments can save a significant amount of time compared with reviewing R&M data.

Recommendation 32: Trending of fault, incident report and reliability and maintainability (R&M) data should be undertaken on target systems and zones to provide early-warning of emergent systems integrity issues. [R&D/4 Rec 22], [Dstl/5 Rec 18].

3.8 AUDIT DATA MANAGEMENT AND DATA AVAILABILITY

The issues of managing audit data for a systems audit is fundamentally no different to those faced in previous audits. However, the sheer magnitude of data and data sources and the need to have a rigorous audit trail of process and decisions has highlighted the necessity to apply specific attention to data management. The choice of tool should be down to the auditor; however, the need to have a data management process and tools in place at the outset of an AAA should be emphasised and reinforced for all projects.
**Recommendation 33:** The data management requirements for an AAA are significant and a robust, auditable mechanism for tracking issues, references and decisions and preserving the data should be in place at the outset of the audit. The importance of establishing a data management process and procedures should be emphasised for all AAA projects. \([R&D[4] \text{ Rec 23}], [Dstl[5] \text{ Rec 19}].\)

The importance of forming a pan-organisational team with inclusion of designers, maintainers etc, has been emphasised several times within this paper. However, the practical obstructions to achieving this ideal can be significant but most of these problems can be overcome with a suitable will. Establishing a method for ‘real time’ access by all parties to common data sources, such as databases or test plan procedures is an aspect that should be planned at the outset of the audit. Without access to common data sources the effectiveness of the joint team will be diminished.

**Recommendation 34:** A mechanism for allowing real-time access to common data sources for parties from all organisations involved in the conduct of the AAA should be planned for at the outset of the audit. Without access to common data sources the effectiveness of the joint team could be significantly diminished. \([R&D[4] \text{ Rec 24}], [Dstl[5] \text{ Rec 20}].\)

### 3.9 Revision of Maintenance Policy, Support Policy and Practices

The systems aspects of AAA and related programmes undertaken to date have made significant recommendations for changes in specific aircraft maintenance and support policies and trade practices. However, there has been some debate as to where the remit of the AAA ends. There is a concern that audits could fall short of providing the direct recommendations needed to assure continued airworthiness and this aspects should be specifically identified within regulations \([6].\) This recommendation has been accepted by the MAA and will be included in the latest iteration of the AAA policy.

**Recommendation 35:** AAA regulation should include specific reference to recommendations for changes to aircraft maintenance policy, support policy and practices, based upon audit findings. A suggested wording is as follows: … through analysis of the results, make specific recommendations for changes to the aircraft maintenance and support policy and practises. This recommendation has been accepted by the MAA and will be included in the latest iteration of the AAA policy.
3.10 **FOCUS ON COMPONENTS WITHIN SYSTEMS**

Much of the focus within the initial programmes has been placed on identifying which systems should be targeted within the audit. However, it is more usually within individual components within a system, rather than in the entire system, where airworthiness concerns lie. Therefore, there is a need for guidance as to how to focus attention on those components within a system that require attention within the audit.

**Recommendation 36:** It is recommended that there should be greater guidance within the regulatory framework to identify which components within a system require further investigation within an audit.

3.11 **SYSTEM INTERCONNECTION ISSUES**

A significant proportion of the observations found during the aircraft condition surveys undertaken have been related to interconnecting elements of the systems (pipes, cables, linkages, control rods, wiring) rather than Line Replaceable Units (LRU) or equipment. The regulation should emphasise the importance of these components within the system. This aspect is discussed further in Section 4 of this paper. This recommendation has been accepted by the MAA and reference to interconnections has been included in the latest iteration of AAA policy.

**Recommendation 37:** It is recommended that the AAA regulation should identify the significance of interconnecting elements (such as pipes, cables, linkages, control rods and wiring) within the audit. This recommendation has been accepted by the MAA and reference to interconnections has been included in the latest iteration of AAA policy.

3.12 **RISK-BASED REPORTING**

UK military aviation is managed using a risk-based approach. In order for the observations identified in an AAA and CS to be afforded appropriate priority among the myriad of other issues being dealt with by the PT, they need to be assessed in terms of risk. In most cases the consequences of failure from the hazard can be identified relatively simply. However, often gaining a reasonable assessment of the probability of occurrence can be problematic and hence an indication of the level of confidence in any assessment should be identified.
**Recommendation 38:** It is recommended that the AAA regulation should identify that observations identified in AAA and CS should be assessed in terms of risk, to allow an appropriate priority to be afforded to the accompanying recommendation.
4 WIDER AIRWORTHINESS ISSUES

4.1 ELECTRICAL WIRING AND INTERCONNECTION SYSTEMS INTEGRITY

In recent years, the MOD’s focus has, understandably, been on the issues identified by the Nimrod accident. However, the issues and risks associated with ageing wiring are also well known within the aviation community and are highly generic. The assurance of wiring integrity is largely based upon visual inspection. However, ageing systems programmes to date have identified significant issues with wiring husbandry, despite detailed MOD wiring husbandry policy [19]. Moreover, large sections of wiring are often inaccessible visually. Furthermore, it is unclear as to whether visual inspection is always sufficient to identify areas where wiring integrity has been compromised. Forensic capability for wiring integrity is also limited. Hence, a greater focus on understanding the key wiring integrity issues relevant to MOD aircraft is needed and a community-wide approach to resolving these issues should be taken.

**Recommendation 39:** The MOD should undertake an investigation into in-service Electrical Wiring Interconnection System (EWIS) integrity, to capture the generic EWIS integrity issues and to identify measures to address these issues. This recommendation is being addressed by SAAG Paper 002 – In-Service EWIS Integrity. [R&D[4] Rec 3], [Dstl[5] Rec 21]

Within the European civil aviation arena, the threats to EWIS are identified in EASA Part 21. AMCs 20-21, 20-22 and 20-23 [20-22] that address EWIS, warns of the threats to wiring integrity by actions such as, aircraft de-icing, the application of corrosion prevention compounds and pressure washing, the latter often being carried by personnel who might not be included in any EWIS husbandry training. Some of the EASA guidance appears in the MOD publication, particularly the wiring survey guide. However, there is further valuable information within the EASA that should be either referenced or included in MOD guidance and best practice.

**Recommendation 40:** It is recommended that the EASA EWIS AMCs 20-21, 20-22 and 20-23 [20-22] should be either referenced from MOD policy or included in MOD guidance and best practice.
4.2 FORMATION OF A KNOWLEDGE STORE

The quantity of data freely available on ageing aircraft issues and systems integrity, particularly originating in US, is staggering. Much of these data are potentially useful for UK programmes. Furthermore, MOD audits have already been undertaken and a significant number of discrete studies into areas such as seals and control cables have been conducted. This information may well have relevance across all ageing aircraft programmes, even if they were specific-to-type studies initially. However, there is currently no ageing aircraft or systems integrity knowledge store, where these data are identified, collated and can be easily located by those involved in the conduct of ageing aircraft programmes. The risk of not having such a system in place is that valuable, relevant information may not be included in a decision-making process as it is not known about and also studies may, in effect, be repeated unnecessarily. Therefore, a properly established, on-line, knowledge store, accessible by all those involved in ageing aircraft programmes should be established and parties involved in programmes to date should be strongly encouraged to add known information to the store. If there are concerns over information release then reference to the relevant information should be made with the knowledge store and a contact in the originating organisation identified for release permissions.

**Recommendation 41:** An on-line ageing aircraft knowledge store with access provided to all parties involved in ageing aircraft programmes should be established. Known data should be added to the knowledge store and it should be formally maintained. Its availability should be publicised and agencies involved in ageing programmes should be strongly encouraged to supply information. If there are concerns over information release then reference to the relevant information should be made with a contact in the originating organisation identified, for release permissions. An Ageing Aircraft Sustainment Knowledge Store (AASKS) system is being developed within the Understanding Ageing Aircraft R&D programme. This system will meet the requirements detailed in this recommendation and will be accessible to all SAAG members, initially through the RLI. [R&D[4] Rec 25], [Dstl[5] Rec 22].

4.3 ZONAL INSPECTIONS

As a result of the large number of discrepancies identified during the Nimrod ageing systems investigation, the focus of the work shifted heavily towards maintenance issues, possibly at the expense of some of the wider ageing aircraft aspects. Although the quantity of anomalies or discrepancies found during condition surveys and visual inspection on other audits and condition surveys has generally been less, some significant maintenance issues have been identified on these programmes. It is easy to apportion blame onto those undertaking
maintenance inspections in the field in such cases and to state that these issues should have been identified. In some cases this criticism can be justified but the wider aspects also should be considered.

The MOD is heavily reliant during its day-to-day operations upon zonal inspections to identify discrepancies that are thereafter subject to rectification action, if deemed necessary. However, the body of evidence to date suggests that the zonal inspection training should be reviewed.

**Recommendation 42:** The large number of maintenance observations identified in AAA and CS performed to date suggests that the effectiveness of zonal inspection training should be reviewed. [Dstl[5] Rec 23].

### 4.4 MAINTENANCE SCHEDULE REVIEWS

The maintenance policy for MOD aircraft has, for many years, been based upon a RCM philosophy, currently based upon the output from Maintenance Steering Group-3 (MSG-3) [13]. Moreover, adherence to the RCM philosophy is often quoted as the foundation for the use of an “on-condition” maintenance policy for a particular equipment or item. However, RCM should be based upon sound foundations, including a detailed understanding of the design of the aircraft. Hence, the apparent lack of foundation information, such as FTA, FME(C)A and ZHA/ZSA, identified on several of these AAA and CS programmes, appears is at odds with a coherent application of RCM.

Without this design knowledge one might suggest that the RCM analysis has been “partial” and largely focussed a pre-determined list of components and on in-service fault data and engineering judgement and may not have included a full understanding of the consequence of failure of system components. While this may be a pragmatic approach, it is essential that the implications of this are understood, including and understanding of the role of Functionally Significant Items (FSI), or equivalent. As RCM falls within the bailiwick of the MAA, it is most likely that this issue has already been considered. However, assumptions are unwise and hence this potential concern has been added to this paper.

**Recommendation 43:** The basis of the MSG-3 based RCM analysis used to determine maintenance schedules for each aircraft should be understood and remedial action initiated where shortfalls in the design data (e.g. FTA, FME(C)A, ZHA/ZSA) used within the analysis are identified. [Dstl[5] Rec 25].
**Recommendation 44:** The use, designation and intention for Functionally Significant Items (FSI) within the maintenance schedule development should be clearly identified within the regulatory framework.

### 4.5 DATA QUALITY AND MANAGEMENT

Once again, the AAA programmes have highlighted significant issues with quality and management of data. Essential airworthiness information, relating to certification of the aircraft, is no longer available. Furthermore, the quality of data (such as fault reporting information) used to support airworthiness decisions is often considered suspect. There appears often to be a resignation and acceptance of this situation. In some cases those entering data may not be aware that it can be used to support airworthiness decisions and simple education may suffice. Data that are potentially used to support airworthiness decisions should be identified and accorded appropriate integrity procedures.

**Recommendation 45:** Data that are potentially to be used to support airworthiness decisions should be annotated as such and accorded appropriate integrity procedures. [Dstl[5] Rec 25].

Relevant data, or information, falls broadly into two categories, the data the PT should hold and the data the Designer should hold. In the case of PT data, changes in organisation are often accompanied by a change in file references. Therefore, files that have been archived can often no longer be located simply because the references are no longer known. There is also a further complication with the retention of maintenance data. MOD policy in the JAP100A-02 suggests that maintenance work orders be kept until the next Major, SBM or Depth maintenance, though the final decision on what records should be retained rests with the PT. This means that corrective maintenance data which may have through-life airworthiness implications for an individual aircraft could be lost. Maintenance records that have airworthiness implications, such as corrective maintenance records, should be retained for the life of the aircraft fleet.

**Recommendation 46:** It is recommended that MOD JAP100A-02 policy should be amended to ensure that maintenance records that have airworthiness implications, such as corrective maintenance records, should be retained for the life of the aircraft.

In the case of Designer held data, the case is rather more complex but clear examples have been identified in AAA where the Designer Organisation (DO) has not been able to provide information that a PT would expect to be held by the DO. This issue could be addressed by the DO having a similar responsibility to that of a civil Type Certificate Holder (TCH) who is
mandated to keep all information for the life of the aircraft type. Although this is clearly straying outside the bounds of an AAA, the inadequate retention of airworthiness-related documentation has had clear implications for AAA and CS programmes.

**Recommendation 47:** It is recommended that requirements for Design Organisations to retain airworthiness-related information should be reviewed to ensure this information is available throughout the life of the aircraft. This issue could be addressed by the DO having a similar responsibility to that of a civil Type Certificate Holder (TCH) who is mandated to keep all information for the life of the aircraft type.

### 4.6 Tools to Implement Policy

It has been apparent across the initial systems AAA and CS programmes that there is a significant gulf in some areas between policy (or regulation) and the ability or capability to implement that policy effectively. Informal discussions with PT staff across a wide range of aircraft programmes, from those with all-encompassing availability contracts to small teams managing a range of aircraft fleets with little or no design organisation support revealed many of the same issues. As one might expect, manpower and funding ranked at the top of impediments to compliance. However, the lack of tools with which to allow compliance with policy was also identified as a significant issue. The requirement to maintain configuration control provides an excellent example to illustrate this point. PT are mandated to maintain configuration control of their aircraft and an AAA is required to audit compliance with this policy. This is a universally understood requirement which is fully supported within the community, many of whom have seen the implications of loss of configuration control first hand. However, the MOD has no universal tools to support control of configuration and hence it is suggested that compliance with this requirement is probably ‘patchy’ at best.

Configuration control is just one example which clearly illustrates clearly the gap between policy and the capability to comply with that policy. Therefore, there is a clear need to identify these policy-compliance capability gaps and provide tools to facilitate compliance. Additionally, it is recommended that there should be consideration of the capability to comply with policy before it is promulgated and measures should be initiated to plug capability gaps coincident with policy publication.

**Recommendation 48:** Shortfalls in the capability to comply with integrity policy should be identified and measures should be initiated to provide tools and capabilities to facilitate compliance, including published AMC and guidance. Additionally, there should be consideration
of the capability to comply with policy before it is promulgated and measures should be initiated to plug capability gaps. \([R&D]\text{[4]} \text{Rec 27}], \[Dstl]\text{[5]} \text{Rec 26}].

### 4.7 Corrosion of System Components

Widespread corrosion, across a plethora of mechanical and electrical systems (such as hydraulic pipe end fittings and electrical connectors), was identified within the initial systems AAA and CS programmes. In many cases it was difficult, if not impossible to identify the extent of corrosion damage from visual inspection in situ. Little evidence of remedial action or recording of corrosion was apparent. Many of these corrosion sites are known problems but there was little evidence of these issues being addressed.

**Recommendation 49:** Areas of the aircraft where there are systems corrosion issues should be identified, collated and managed within the Systems Integrity Working Group. Clear limits should be identified and promulgated in a consistent manner in aircraft documentation.

**Recommendation 50:** Corrosion protection and reapplication of protective coatings, particularly for aircraft systems, should also be investigated to identify whether improvements in methods and practices can be developed.

### 4.8 Cadmium Corrosion

The occurrence of Cadmium corrosion, particularly around electrical connectors has been identified as a concern. Cadmium is identified under the European Community Restriction of Hazardous Substances (RoHS) directive. However, the corrosion products appear very similar to salt crystals and tradesmen are not necessarily aware initially that Cadmium corrosion is present. It is understood that there is no simple test for Cadmium corrosion products available in service and hence tradesmen may be exposed to these products inadvertently. There is a clear need to develop a simple on-aircraft or near-aircraft test for Cadmium corrosion for in-service use.

**Recommendation 51:** It is recommended that a simple on-aircraft or near-aircraft test for Cadmium corrosion for in-service use should be developed.
4.9 POLYMER DEGRADATION

The issues associated with elastomeric fuel seals have already been discussed within this paper. However, this was in the context of sampling within an AAA (Section 3.3) rather than the direct airworthiness concerns. The initial systems AAA and CS programmes have identified widespread issues with the degradation of a whole range of polymers, including seals, sealants, electrical wiring insulation, paints and coatings. Many of these polymers are operating well beyond their intended service life and often in hostile environments, such as in undercarriage bays. The majority of these polymers are effectively retained in service ‘on-condition’, irrespective of whether the original manufacturer identified a recommended service life. Moreover, in some applications, such as structural fuel tank sealants, whole-scale replacement would be prohibitively costly and could only be justified on risk grounds, based upon a sound understanding of the degradation of the polymer. Understanding ageing polymers is an issue far wider than just aerospace and these issues are being tackled in a range of safety-related applications. These issues are often further complicated by insufficient understanding of the effects of changes in the chemical constituents within the polymer over time and limited understanding of the operating environment.

However, the complexity of the issue does not lessen the implications and hence there is a need to have a greater understanding of the degradation of polymers when used in safety-related applications\textsuperscript{14}, with an aim of developing life assessments.

Recommendation 52: it is recommended that methods and processes are developed to support life assessment of polymers used in safety-related applications.

4.10 PHYSICAL CLEARANCES

Lack of adequate clearance and fouling between systems, particularly pipes, but including a wide range of electrical and mechanical interconnection components was a clearly identifiable, common issue across aircraft types. Moreover, many of the clearance issues were known problems on the aircraft and in some cases local attempts had been made to alleviate the situation. However, very few, if any, of these issues were documented and consequently no co-ordinated remedial action had been taken. Moreover, being a known problem that had not been formally addressed meant that there were no follow-on limits established to identify when more significant action was required (such as component replacement).

\textsuperscript{14} The restriction to safety-related applications has been made to attempt to bound the problem.
**Recommendation 53:** Areas of the aircraft where there are clearance issues should be identified, collated and managed. Clear limits should be identified and promulgated in a consistent manner in aircraft documentation. Where required clearances cannot be obtained then suitable mitigation should be established, such as directed inspections, antifouling protection etc.

### 4.11 Electrical Bonding in Fuel Systems

A recent CS programme has identified occurrences of inadequate electrical bonding within fuel systems components (such as fuel pipes). In this example, the shortfall was generally associated with Class S bonding, used to protect against electrostatic discharge (rather than Class L bonding, to protect against lightning strike). Bonding straps were either missing, poorly connected, leading to corrosion, or installed without surface finish being removed from the bonded component, causing an excessive resistance to the electrical bonding path. Although the design of the electrical bonding system, on the aircraft under investigation, was tolerant to a level of ineffective bonding, the extent of the inadequate bonding identified raised significant airworthiness concerns. Also, it was most likely that the degradation in the electrical bonding of the fuel system components occurred gradually and had remained undetected in service.

Therefore, the importance of retaining effective electrical bonding to protect the aircraft from threats, such as lightning strikes and electrostatic discharge, should be emphasised within systems integrity policy and AAA guidance material.

**Recommendation 54:** The importance of retaining effective electrical bonding to protect the aircraft from threats, such as lightning strikes and electrostatic discharge, should be emphasised within systems integrity policy and AAA guidance material.

### 4.12 Husbandry

The level of husbandry afforded the aircraft surveyed during the initial systems AAA and CS programmes was generally below that expected. With a maintenance philosophy largely dependent upon zonal inspections, it is essential that the condition of the aircraft allows the tradesmen to identify anomalies easily. However, once the general condition deteriorates, this greatly impairs the ability to identify problems before they become significant and also allows the “they are all like that” approach to take hold.
It is understood that the Air Command ‘Can Do Safely’ programme is addressing this issue and it would be valuable for feedback from Air Command to be provided to those undertaking AAA as to the progress being made. This would also help benchmark the observations identified by the AAA teams.

**Recommendation 55:** The general level of husbandry seen on the system AAA and CS programmes to date raises concerns. It is understood that husbandry issues are being addressed by the Air Command ‘Can Do Safely’ campaign. Therefore, it would be extremely valuable for progress in this campaign to be fed back to those undertaking AAA and CS. This would also help benchmark the observations identified by the AAA teams.
5 CONCLUSIONS

The inclusion of systems aspects within the AAA has provided a potentially significant step forward in assuring the continued airworthiness of ageing military aircraft. Many lessons have been identified during the initial systems audit and condition survey programmes and a continual-improvement approach to policies and practice should allow maximum benefit to be gained from future audit programmes.
6 RECOMMENDATIONS

The recommendations made within this paper are summarised as follows:

6.1 POLICY RECOMMENDATIONS

**Recommendation 1:** It is recommended that a clear definition of ageing should be incorporated into the MOD policy in the JAP100A-01. A suggested definition, which directly links degradation with the consequences of that degradation, is detailed below. This definition is based very closely on that used by the Defence Scientific Advisory Council (DSAC) in its recent cross-domain review of ageing issues [7] (the difference in definition proposed is the addition of ‘information’ to the clarification of system) is provided below:

> Ageing is defined as the degradation of the system (equipment, people or information) leading to an increased safety risk

**Recommendation 2:** In order to ensure that an ageing aircraft programme is focussed, it is recommended that a clear top-level aim should be defined in MOD policy [6]. A suggested top-level aim is identified as:

> The aim of an ageing aircraft programme is to identify the onset of ageing within a fleet and to recommend (or implement – see Recommendation 3) remedial action.

**Recommendation 3:** It is recommended that the AAA should be developed into an Ageing Aircraft Programme (AAP). Recognising that degradation or ageing is likely to occur, the AAP should incorporate the audit function, using the output to tailor the solution to the specific needs of the platform, but with the programme end-point being the implementation of remedial solutions, rather than recommendations.

**Recommendation 4:** There should be a single AAA with common policy and with additional elements particular to systems, structure and propulsion identified accordingly. This recommendation has been accepted by the MAA and a revised, single-audit approach for structure, systems and propulsion will be incorporated into the next release of JAP100A-01. [Dstl[5] Rec 1].

**Recommendation 5:** It is recommended that a SAAG paper outlining guidance material for the conduct of ageing aircraft programmes should be developed.
**Recommendation 6:** An independent aircraft condition survey should be specifically identified as a requirement of an AAA, to remove any ambiguity in what is meant by assessing the performance of integrity measures. The aim of this aircraft condition survey is to look for signs of ageing (i.e. degradation), identify the effectiveness of integrity assurance measures, and determine whether the “as flown” aircraft matches the “as prescribed” aircraft. It should be noted that the MAA has accepted this recommendation and a condition survey has now been mandated in the revised AAA policy, to be promulgated in JAP100A-01. [R&D(4) Rec 9], [Dstl(5) Rec 2].

**Recommendation 7:** It is recommended that a SAAG paper should be developed to provide guidance for the conduct of an aircraft condition survey as part of an ageing aircraft programme (and to be incorporated into or referenced to the proposed AAA conduct guidance paper identified in Recommendation 5). This guidance should include, but not be restricted to aspects such as:

- Identifying a priori information for use in scoping the extent of the survey (i.e. in-service arisings, consequences of failure, previous survey experience).
- Determining and achieving representative sample sizes.
- Determining the depth of the survey.
- Providing a robust mechanism to record and communicate findings to PT and wider community.
- Identification of the importance of sentencing observations to enable a degree of filtering.
- Development of an immediate fault reporting process to highlight immediate continued airworthiness concerns.

**Recommendation 8:** Consideration should be given to including mandatory systems within the AAA regulations which would be considered “targeted systems” by their very function (flight control systems, hydraulics, etc) or contribution to fire/explosion hazard (fuel, environmental control systems). Following issue of a draft of this paper for peer review, this recommendation sparked considerable comment, debate and some reservations from across the community and hence it is recommended that this issue should be debated further within the SAAG, with an aim of reaching a consensus.
Recommendation 9: Reference in policy to teardown of aircraft systems should be referred to as sampling, including forensic investigation, as appropriate. Teardown implies a level of imprecision which is inappropriate. [R&D[4] Rec 10], [Dstl[5] Rec 3].

Recommendation 10: A review should be undertaken three years before the first scheduled AAA to identify whether sufficient data are available to identify target systems and zones for the audit. This requirement should be either included in or referenced from the Systems Integrity policy. Such a review should also be undertaken when establishing a Systems Integrity programme for the aircraft. SAE ARP4761 [9] provides useful guidance on the processes and techniques that can be used to assemble the necessary information. [R&D[4] Rec 13], [Dstl[5] Rec 4].

Recommendation 11: Amendment to the MOD AAA regulation should be considered to clearly identify which systems are emergency systems and to mandate their inclusion in the AAA. This recommendation has been accepted by the MAA and has been included in the latest revision of the JAP100A-01 AAA policy.

Recommendation 12: A review of the continued performance and adequacy of emergency systems should be specifically identified as a requirement of the AAA. This recommendation has been accepted by the MAA and has been included in the latest revision of the AAA policy. [R&D[4] Rec 19], [Dstl[5] Rec 5].

Recommendation 13: The current requirements for Operational Loads Measurement / Operational Data Recording should be extended to include the capture and analysis of data necessary to validate design and usage assumptions for target systems or zones. [R&D[4] Rec 20], [Dstl[5] Rec 6].

Recommendation 14: An AAA should include a review of the current relevant safety-related certification regulations for target systems and zones and any shortfalls in the design or practise currently in place should be identified within the audit. [R&D[4] Rec 26], [Dstl[5] Rec 7].

Recommendation 15: It is recommended that guidance for PT should be developed to identify typical AAA programme costs across a range of programmes and that the cost implications of changes to policy should be considered.

Recommendation 16: It is recommended that AAA policy should mandate that the scope of the AAA and any exclusions should be formally endorsed by the PE at the outset of the programme. This recommendation has been accepted by the MAA and has been included in the latest version of AAA policy in the JAP100A-01.
**Recommendation 17:** It is recommended that AAA policy should be subject to a thorough review, in light of the experience gained in these ageing aircraft related programmes, and to ensure the regulation, AMC and guidance is fit for purpose.

### 6.2 Audit Conduct Recommendations

**Recommendation 18:** It should be recognised when advising Project Teams on AAA conduct that success is dependent upon the support of the Design Organisations (Prime and Component), Project Teams (including Commodity), Maintenance Staff, MOD Policy Branch and Operators; the independent auditor cannot provide a successful audit without the cooperation of all these organisations. In particular, experience has shown that the Maintenance Staff can provide detailed information that is not normally available from other sources. This is particularly relevant to contracted-out maintenance where certain issues are addressed within the contract and do not necessarily come to the notice of the PT or the Designer.  


**Recommendation 19:** Pan-organisational peer review, within a culture of continued development, of audit plans and draft audit reports should be strongly encouraged.  


**Recommendation 20:** Where example aircraft are retired from the fleet for use in sampling programmes (currently termed teardown), a period of planning should be scheduled before the aircraft is delivered for the programme.  


**Recommendation 21:** The potential value of sampling of system components should be emphasised. This should be invoked where the consequences of component failure are significant and the deterioration of the component is difficult to predict accurately (such as elastomeric seals).  


**Recommendation 22:** Where there is insufficient systems safety information initially available to identify which systems and zones should be focussed upon within an AAA, the use of a Fault Tree Analysis workshop, using a Hull-Loss Model template, with the involvement of design, maintenance, instructional staff and aircrew, with an experienced airworthiness facilitator should be considered as a starting point for systems prioritisation.  


**Recommendation 23:** Where a complete aircraft Zonal Hazard Analysis / Assessment of Zonal Safety Assessment is initially unavailable to identify which zones should be focussed upon within a AAA, the use of a physical review of the aircraft using experienced design and maintenance engineers should be considered as a starting point and, where possible, in
conjunction with any existing Safety Case documentation or any previous limited hazard analysis undertaken.  [R&D[4] Rec 15], [Dstl[5] Rec 13].

**Recommendation 24:** In additional to a physical review of the aircraft, the Topic 5A1 Master Maintenance Schedule (MMS) can provide valuable information for targeting zones by identifying which systems (by Schedule Identification Number (SIN)) are within which zone and what volume and frequency of maintenance is carried out in the zone. The volume and frequency of maintenance can be a good indicator to the criticality of the systems within a zone and hence an aid to zonal targeting.

**Recommendation 25:** Reference should be made to ensuring that mark-to-mark variations and variations within a mark are considered within the systems integrity management and the AAA policy. The MAA has accepted this recommendation and included it in the latest iteration of the AAA policy.  [R&D[4] Rec 16], [Dstl[5] Rec 14].

**Recommendation 26:** The formation of pan-organisation Specialist Technical Working Groups (Mechanical, Electrical, Safety and Data in this case) has provided a useful method of guiding systems investigation process, gaining peer review and stakeholder buy-in and should be considered for future audits. This is already identified in policy and hence this recommendation is included for reinforcement only. The diverse responsibilities of commodity project teams, industrial commodity providers and sub-contractors greatly increases the organisational complexity for systems audits, when compared with structural audits and this needs to be recognised and addressed within the programme.  [R&D[4] Rec 17], [Dstl[5] Rec 15].

**Recommendation 27:** Care should be taken to ensure that the consequence of failure is used to identify systems and zones for further investigation under an AAA and that perceived mitigation, such as redundancy or back-up systems, should not be used to exclude these areas from further investigation within the Audit.  [Dstl[5] Rec 16].

**Recommendation 28:** The use of functional performance checks of target systems should be considered before condition surveys or sampling programmes are undertaken. Such checks will identify degraded system performance and assist in ascertaining the significance of observations found during the condition surveys or sampling programme.  [R&D[4] Rec 18], [Dstl[5] Rec 17].

**Recommendation 29:** The performing of functional testing before a condition survey can also provide a valuable check of the adequacy of the tests carried out in-service, by correlating faults found during the condition survey with test reports.
**Recommendation 30:** Maintenance staff with significant experience on the aircraft type should be consulted to identify target systems where there are difficulties meeting the required tolerances. Maintenance data should also show where systems are failing functional checks.

**Recommendation 31:** Prior to using any R&M data, the availability and age of any RCM study should be considered as a useful source. If RCM has recently been carried out then the issues highlighted during trend monitoring of R&M data would have been captured by RCM and reflected in the Topic 5A1 up-issue. Hence a relatively quick review of the 5A1 amendments can save a significant amount of time compared with reviewing R&M data.

**Recommendation 32:** Trending of fault, incident report and reliability and maintainability data should be undertaken on target systems and zones to provide early-warning of emergent systems integrity issues. [R&D[4] Rec 22], [Dstl[5] Rec 18].

**Recommendation 33:** The data management requirements for an AAA are significant and a robust, auditable mechanism for tracking issues, references and decisions and preserving the data should be in place at the outset of the audit. The importance of establishing a data management process and procedures should be emphasised for all AAA projects. [R&D[4] Rec 23], [Dstl[5] Rec 19].

**Recommendation 34:** A mechanism for allowing real-time access to common data sources for parties from all organisations involved in the conduct of the AAA should be planned for at the outset of the audit. Without access to common data sources the effectiveness of the joint team could be significantly diminished. [R&D[4] Rec 24], [Dstl[5] Rec 20].

**Recommendation 35:** AAA regulation should include specific reference to recommendations for changes to aircraft maintenance policy, support policy and practices, based upon audit findings. A suggested wording is as follows: … through analysis of the results, make specific recommendations for changes to the aircraft maintenance and support policy and practises. This recommendation has been accepted by the MAA and will be included in the latest iteration of the AAA policy.

**Recommendation 36:** It is recommended that there should be greater guidance within the regulatory framework to identify which components within a system require further investigation within an audit.

**_recommendation 37:** It is recommended that the AAA regulation should identify the significance of interconnecting elements (such as pipes, cables, linkages, control rods and wiring) within the audit. This recommendation has been accepted by the MAA and reference to interconnections has been included in the latest iteration of AAA policy.
**Recommendation 38:** It is recommended that the AAA regulation should identify that observations identified in AAA and CS should be assessed in terms of risk, to allow an appropriate priority to be afforded to the accompanying recommendation.

### 6.3 WIDER AIRWORTHINESS RECOMMENDATIONS

**Recommendation 39:** The MOD should undertake an investigation into in-service Electrical Wiring Interconnection System (EWIS) integrity, to capture the generic EWIS integrity issues and to identify measures to address these issues. This recommendation is being addressed by SAAG Paper 002 – In-Service EWIS Integrity. [R&D[4] Rec 3], [Dstl[5] Rec 21].

**Recommendation 40:** It is recommended that the EASA EWIS AMCs 20-21, 20-22 and 20-23 [20-22] should be either referenced from MOD policy or included in MOD guidance and best practice.

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Recommendation **45**: Data that are potentially to be used to support airworthiness decisions should be annotated as such and accorded appropriate integrity procedures. [Dstl[5] Rec 25].

Recommendation **46**: It is recommended that MOD JAP100A-02 policy should be amended to ensure that maintenance records that have airworthiness implications, such as corrective maintenance records, should be retained for the life of the aircraft.

Recommendation **47**: It is recommended that requirements for Design Organisations to retain airworthiness-related information should be reviewed to ensure this information is available throughout the life of the aircraft. This issue could be addressed by the DO having a similar responsibility to that of a civil Type Certificate Holder (TCH) who is mandated to keep all information for the life of the aircraft type.

Recommendation **48**: Shortfalls in the capability to comply with integrity policy should be identified and measures should be initiated to provide tools and capabilities to facilitate compliance, including published AMC and guidance. Additionally, there should be consideration of the capability to comply with policy before it is promulgated and measures should be initiated to plug capability gaps. [R&D[4] Rec 27], [Dstl[5] Rec 26].

Recommendation **49**: Areas of the aircraft where there are systems corrosion issues should be identified, collated and managed within the Systems Integrity Working Group. Clear limits should be identified and promulgated in a consistent manner in aircraft documentation.

Recommendation **50**: Corrosion protection and reapplication of protective coatings, particularly for aircraft systems, should also be investigated to identify whether improvements in methods and practices can be developed.

Recommendation **51**: It is recommended that a simple on-aircraft or near-aircraft test for Cadmium corrosion for in-service use should be developed.

Recommendation **52**: It is recommended that methods and processes are developed to support life assessment of polymers used in safety-related applications.

Recommendation **53**: Areas of the aircraft where there are clearance issues should be identified, collated and managed. Clear limits should be identified and promulgated in a consistent manner in aircraft documentation. Where required clearances cannot be obtained then suitable mitigation should be established, such as directed inspections, antifouling protection etc.
**Recommendation 54:** The importance of retaining effective electrical bonding to protect the aircraft from threats, such as lightning strikes and electrostatic discharge, should be emphasised within systems integrity policy and AAA guidance material.

**Recommendation 55:** The general level of husbandry seen on the system AAA and CS programmes to date raises concerns. It is understood that husbandry issues are being addressed by the Air Command ‘Can Do Safely’ campaign. Therefore, it would be extremely valuable for progress in this campaign to be fed back to those undertaking AAA and CS. This would also help benchmark the observations identified by the AAA teams.
REFERENCES


[6]. UK MINISTRY OF DEFENCE, (2009), Military Aviation Engineering Policy and Regulation, Joint Air Publication JAP100A-01, Chapter 16.


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Lessons identified from initial Ageing Aircraft Systems Audits and Condition Survey Programmes

Within this paper, lessons from the initial Ageing Aircraft Systems Audits and Condition Survey programmes undertaken within the MOD, including VC10, Nimrod, C130, Sentry, Tucano and Historic Aircraft are detailed. The background to each lesson is described and conclusions and recommendations are made. Recommendations made have been divided into three sections: AAA policy issues, AAA audit conduct issues and wider airworthiness issues.

Aircraft Systems, Ageing Aircraft Audit, Condition Survey, Airworthiness, Safety