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Manual of Air System Integrity Management (MASIM)

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FOREWORD

1. The purpose of this Manual of Air System Integrity Management (MASIM) is to provide guidance to those organizations required to manage Air System Integrity in accordance with (iaw) the MAA's Regulatory Articles (RA) 5700-series[1].

2. The techniques and processes described in this Manual have evolved over many years, informed by best practice from civil aerospace and the lessons from numerous accidents and incidents. Further, this single Manual brings together information formerly contained within; the discipline-specific Integrity Management (IM) Handbooks, much of the Guidance Material (GM) from 5700-series RAs, information published previously in the MAA's Air System Usage Validation Programme (AUVP) Guidance Document and information from the removed MAP-01 Chapters. As a result, this Manual now presents a single, comprehensive resource to all aspects of IM and is thus an excellent source of GM to the 5700-series RAs. However, no single approach will suit every Air System and effective IM requires individuals to act on an informed assessment of the risks under consideration for their Air System.

3. The Structure of the MASIM is designed that the early chapters provide the context and generic guidance, before moving to discipline-specific guidance and finally more in-depth guidance regarding specific IM processes. Accordingly, the MASIM chapters are as follows:

a. **Chapters 1-9** provide guidance to support RA 5726 – Integrity Management.

(1) **Chapter 1** provides the context and background as to why effective IM is fundamental to Airworthiness.

(2) **Chapter 2** provides the pan-discipline IM guidance.

(3) **Chapter 3** describes the various Systems of IM, ie the programmes, tools and processes that those responsible for the management of Type Airworthiness[2] will need to undertake effective IM.

(4) **Chapters 4-6** contains the discipline-specific guidance for Structures, Systems and Propulsion IM respectively.

(5) **Chapter 7** provides guidance for the Environmental Damage Prevention and Control (EDPC) Programme.

(6) **Chapter 8** provides guidance for the AUVP.

(7) **Chapter 9** contains the specific guidance for Electrical Wiring Interconnect System (EWIS) IM.

b. **Chapter 10** provides guidance for undertaking an Ageing Air System Audit (AAA), in support of RA 5723 – Ageing Air System Audit.

c. **Chapter 11** provides guidance for undertaking a Life Extension Programme (LEP), in support of RA 5724 – Life Extension Programme.

d. **Chapter 12** provides guidance for undertaking an Out of Service Date (OSD) Extension Programme, in support of RA 5725 – Out of Service Date Extension Programme.

e. **Chapter 13** is an index of the Airworthiness Advisory Group Papers.

4. The MASIM does not include a separate glossary; any terms or abbreviations not contained within the MAA Master Glossary (MAA02) are explained in full.

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[1] Refer to RA 5723 – Ageing Air System Audit; RA 5724 – Life Extension Programme; RA 5725 – Out of Service Date Extension Programmme and RA 5726 – Integrity Management.

[2] Where the Air System is Civilian-Owned, ownership of regulatory responsibility by either the Type Airworthiness Authority (TAA) or Type Airworthiness Manager (TAM) needs to be agreed within the Sponsor's approved model for Type Airworthiness (TAw) management; refer to RA 1162 - Air Safety Governance Arrangements for Civilian Operated (Development) and (In-Service) Air Systems, or refer to RA 1163 - Air Safety Governance Arrangements for Special Case Flying Air Systems. Dependant on the agreed delegation of TAw responsibilities TAM may be read in place of TAA as appropriate.

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Chapter 1: Introduction

1. This Manual is applicable to ►crewed◄ Air Systems, and Remotely Piloted Air System (RPAS) Certified Category. Whilst this Manual is directly applicable to the Structures, Systems and Propulsion disciplines, the principles laid out in this Manual may be adopted for other disciplines such as; Weapons, Programmable Elements (both software and hardware), low observable technology and also to RPAS Specific S2 sub-category[3]. It provides guidance on how to integrate the IM, tools and processes, resulting in a more efficient and cohesive approach to Air System engineering. Thus, the aim of this document is to: describe Air System Integrity and associated threats; explain the use of IM and tools within the Establish-Sustain-Validate-Recover-Exploit (ESVRE) Framework; and provide guidance for processes mandated in the 5700-series RAs.

Applicable documents

2. **Specifications, Standards and Processes.**

Defence Standard 00-970 (DS970) Certification Specifications for Airworthiness

Manual of Airworthiness Maintenance - Processes (MAM-P)

3. **Regulatory Articles**

RA 1002	Airworthiness Competent Persons
RA 1003	Delegation of Airworthiness Authority and Notification of Air Safety Responsibility
RA 1005	Contracting with Competent Organizations
RA 1006	Delegation of Engineering Authorizations
RA 1014	Design Organization and Co-ordinating Design Organizations – Airworthiness Responsibilities
RA 1015	Type Airworthiness Management – Role and Responsibilities
RA 1016	Military Continuing Airworthiness Management
RA 1020	Aviation Duty Holder and Aviation Duty Holder Facing Organizations – Role and Responsibilities
RA 1024	Accountable Manager (Military Flying)
RA 1160	The Defence Air Environment Operating Framework
RA 1207	Air Safety Data Management and Exploitation
RA 1605	Remotely Piloted Air Systems – Specific S2 Sub-Category
RA 1606	Remotely Piloted Air Systems – Certified Category
RA 5723	Ageing Air System Audit
RA 5724	Life Extension Programme
RA 5725	Out of Service Date Extension Programme
RA 5726	Integrity Management
RA 5810	Military Type Certificate (MRP Part 21 Subpart B)
RA 5820	Changes to Type Design (MRP Part 21 Subpart D)

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[3] Refer to RA 1605 - Remotely Piloted Air Systems Specific S2 Sub-Category for tailored IM for S2 Sub-Category RPAS.

4. **Handbooks.**

MIL-HDBK-87244	Avionics / Electronics Integrity
MIL-HDBK-513	Low Observable Integrity Programme (LOIP)
MIL-HDBK-525	Electrical Wiring Interconnect System (EWIS) Integrity Program
MIL-STD-1530D	Aircraft Structural Integrity Program (ASIP)
MIL-STD-1796A	Avionics Integrity Program
MIL-STD-3024	Propulsion System Integrity Program

5. **Airworthiness Advisory Group (AAG) Papers.** The role of the MAA's AAGs is to develop and promote best practice, and to inform and evolve Regulation and governance, in the support of MOD Air Systems. The 5 AAGs'[4] remit extends across the 3 traditional IM disciplines and includes specific meetings for ageing Air System and fuels and lubricants. As part of their remit, many of the AAGs publish Papers to inform MAA Regulation and provide background information to the Regulated Community; AAG Papers applicable to IM are detailed in Chapter 13.

6. **Other References.**

Corrosion Prevention and Control Planning Guidebook for Military Systems and Equipment; Office of DoD Corrosion Policy and Oversight; Spiral 4; 2/4/2014.

Challenges and Issues with the Further Ageing of U.S. Air Force Aircraft: policy options for effective life-cycle management of resources; Gebman, JR; RAND Corporation; 2009.

Corrosion Engineering; FONTANA, MG; Third Edition.

Materials for Engineers; KEMPSTER, MHA; Third Edition.

7. **Order of precedence.** In the event of a conflict between the text of this document and the references cited herein, applicable laws and regulations takes precedence followed by the text of this document.

Introduction to IM

8. **Overview.** Any failure within the Air System will compromise the Air System's Integrity. Operations within military aviation present a complex range of Airworthiness Hazards, and with lessons learned from decades of experience including some high-profile Accidents, the MOD have prescribed a dedicated framework to manage Risks associated with the through-life management of an Air System.

9. **Roles and responsibilities.**

a. **Aviation Duty Holder (ADH) / ►Accountable Manager (Military Flying) (AM(MF))[5]◄**. The ADH ►/ AM(MF)◄ is legally accountable for the safe operation of Air Systems within their Area of Responsibility (AoR) and for ensuring that Risk to Life (RtL) is both As Low As Reasonably Practicable (ALARP) and Tolerable[6]; a key component of this is the Airworthiness of the Air System and the sustainment of its Integrity. Whilst support from various stakeholders is needed to manage the Air System Integrity, the overall responsibility is assigned to the TAA ►/ TAM◄[7,8]. ►Specifically, for IM, the ADH / AM(MF) has responsibility for validating the Statement of Operational Intent and Usage (SOIU) Chapter 8 refers.◄

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[4] The 5 AAGs are: Military Aircraft Structural Airworthiness Advisory Group (MASAAG), Systems Airworthiness Advisory Group (SAAG), Propulsion Airworthiness Advisory Group (PAAG), Ageing Audit Programme Working Group (AAPWG) and the Fuels and Lubricants Airworthiness Advisory Group (FLAAG). Note, the SAAG is held on an 'as required' basis rather than biennial.

[5] ►Refer to RA 1024 – Accoutable Manager (Military Flying)◄

[6] Refer to RA 1210 – Ownership and Management of Operating Risk (Risk to Life).

[7] Refer to RA 5726 – Integrity Management.

[8] Refer to RA 1015 – Type Airworthiness Management – Roles and Responsibilities.

b. ►◄

c. **TAA**. The TAA uses IM and associated tools / activities to ensure an Air System Type retains its Integrity through-life. At root, this is efficient management of a multitude of interdependent activities related to design, Maintenance and operation throughout the Concept, Assessment, Demonstration, Manufacture, In-Service and Disposal (CADMID) cycle. The specific activities follow the mandated ESVRE overarching framework for IM, which is applicable to both Type and Continuing Airworthiness (CAw).

d. **TAM**. For Civilian-Owned / Civilian Operated Air Systems the Air System Sponsor has the opportunity to split TAw responsibility between a TAA and a TAM who is a MAA-approved individual within an Approved Design Organization. However, a number of responsibilities are non-delegable[9]; therefore, dependant on the agreed split of TAw responsibilities, TAM may be read in place of TAA as appropriate throughout this Manual.

e. **Commodity Delivery Team Chief Engineer (DT CE)**. A Commodity DT CE will have comparable responsibility to the TAA for commodity items.

f. **Military Continuing Airworthiness Manager (Mil CAM).** The Mil CAM is responsible for the collection and reporting of operational occurrences iaw RA 1207[10] to the Integrity Working Groups (IWG).

10. **Threats to Air System Integrity.** Integrity may be compromized at any stage of an Air System's life by one or a combination of threats that may invalidate the Integrity Baseline. Usage outside the Design Spectrum and associated environments, or any failure of critical systems to Air Safety, are all potential threats to Air System Integrity. In addition to having an impact on the Integrity of the Air System, these threats can adversely affect the ADH's RtL position and the operational capability of the Air System. Typical types of threats, subdivided by the traditional 3 IM disciplines[11], are described in Table 1.

11. Where a threat to Integrity is identified and is assessed to have potential to affect RtL, then collaboration[12] between the TAA, ADHs and AM(MF) is necessary to ensure the overall Risk is ALARP and Tolerable.

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[9] Refer to RA 1162 – Air Safety Governance Arrangements for Civilian Operated (Development) and (In-Service) Air Systems. Non-Delegable TAw responsibilities include: approval of Major Type Design changes and repairs; holding a Military Type Certificate; validating the Statement of Operating Intent and Usage (SOIU); approve the issue of an Military Permit to Fly; and approve the initial issue of the Air System Document Set (ADS), approve Special Instructions (Technical) (SI(T)) and change the Master Maintenance Schedule.

[10] Refer to RA 1207 – Air System Data Management and Exploitation.

[11] Traditionally, the UK has used Structures, Systems (both mechanical and electrical) and Propulsion as the 3 key IM disciplines. However, emerging technology may result in further disciplines being required, such as Programmable Elements (Software and Hardware) and Low Observable technology.

[12] Refer to RA 1020 – Aviation Duty Holder and Aviation Duty Holder-Facing Organizations - Roles and Responsibilities.

Table 1 - Threats to Integrity

Type of Threats	Structures	Systems	Propulsion
Overload	*Fixed Wing (FW)* An Air System encounters overload when it is subjected to forces that are above the Design Limit Load (DLL) for its Structure. The DLL is the maximum and most critical combination of loads and environmental conditions likely to occur during the Service Life of an Air System Type. Overload could be a result of extreme conditions such as gusts and turbulence, heavy landings, excessive manoeuvring or divergent flutter; it could also be caused by the crew or flight control system exceeding the Release To Service (RTS) limitations. *Rotary Wing (RW)* The Air System Structure is subjected to a large variety and magnitude of loads where overload can be of static or dynamic nature. This is due to the lift being generated via the rotors, resulting in different loading conditions at the airframe and at the rotor / rotor attachment. These loads can be categorised as high or low cycle and may include: a. High Cycle: vibration caused by acoustic loading, non-divergent flutter, manoeuvre buffet, blade passing frequencies and rotating components in an Air System's dynamic systems. b. Low Cycle: manoeuvres, gusts, the ground-air-ground cycle, autorotation, cockpit or cabin pressurisations, landings, retractions, taxiing, rotor start / stop, changes in engine power, thermal changes, hydraulic / fuel system pressurisation and deck lock use, load lifting and hoisting.	Overload may occur in any mechanical or avionic system when an item or system exceeds one or more of its designed parameters. The consequence of overload may result in the deformation or degradation of an item or system; the subsequent effects may be temporary or permanent. For electrical systems, the overload may be due to external influence or unintended system interaction, such as High Intensity Radiated Field or Electro-Magnetic Compatibility effects. These effects will also be influenced by environmental and other change of use threats.	Overload may occur within the Propulsion System when an element of the system exceeds one or more of its design parameters. Since the Propulsion System is designed to work close to the material allowable limits, the consequence of overload can be severe. Examples of Propulsion System overload include over-speed, over-temperature, over-torque, exceeding aeroengine 'g' limits and the over-stress of engine mounting components.

<table>
<tr><th>Type of Threats</th><th>Structures</th><th>Systems</th><th>Propulsion</th></tr>
<tr><td rowspan="2">Fatigue</td><td colspan="3">Fatigue is the process of progressive, permanent degradation of a material when subjected to repeated loads and environmental conditions. Fatigue cracking type failures in metallic Structural components are common to Structures, Systems and Propulsion disciplines. The mechanism is often considered in two phases, initiation and propagation, which are managed through Safe Life (crack initiation) and Damage Tolerance (crack propagation) design philosophies respectively.
In the ***crack initiation phase***, the material changes at microscopic level where dislocations are piled up to form persistent slip bands due to movement of material along slip planes and serve as stress risers where fatigue cracks can initiate. Once a nominated crack threshold is reached, the fatigue crack enters the ***propagation phase*** and crack growth is the geometrical consequence of slip and crack tip blunting (slow crack growth) until the residual strength, that is the remaining strength under the presence of a crack, cannot withstand the applied load (unstable crack growth leading to failure). Crack initiation is dependent on stress concentration while crack propagation is dependent on stress intensity; and both are dependent on component geometry, material properties, the maximum / minimum (or mean / alternate) and frequency of cyclic loads, the number of load cycles and the environmental conditions.
High-life metallic components are susceptible to Widespread Fatigue Damage (WFD) when multiple cracks, at multiple similar Structural details with similar stress levels, have developed sufficient size and density to prevent the Structure from achieving its residual strength requirements. The presence of multiple fatigue cracks in the same Structural element is termed Multiple Site Damage (MSD); multiple cracks in several similar Structural elements is termed Multiple Element Damage (MED).
For RW, there is an added complexity where the occurrence of Low Cycle Fatigue (LCF) loads can cause the High Cycle Fatigue (HCF) loads to become more damaging than predicted; and inherent or induced material and / or manufacturing defects can allow HCF loads to cause fatigue failures much earlier than expected.</td></tr>
<tr><td>For composite Structures, fatigue is dependent on the type of material (prepreg or dry fibre / epoxy), manufacturing process (wet layup, prepreg layup or Resin Transfer Moulding), assembling process (co-cure, post-cure or mechanically fastened) and the thermal environment. As a result, the fatigue failure modes are ►different◄ to those found in metallic Structures: dis-bond, local delamination or matrix degradation as primary failures; moisture penetration, laminate delamination or cracking as secondary failures; leading to component failure when the residual strength cannot sustain the applied load.</td><td>Fatigue may affect systems such as:
a. Load-bearing Structures.
b. EWIS.
c. Pipework and hoses.
d. Mechanical control cables.
The impact of fatigue may be exacerbated by environmental factors, ageing and Accidental Damage (AD), particularly where there is a presumption that the system elements are fitted for the life of the Air System.</td><td>The Propulsion System is sensitive to interaction of fatigue with other threats due to the vibratory and thermal environments, such as:
a. AD causing stress concentration that increases the vibratory stress leading to High Cycle Fatigue failure.
b. Creep resulting in a solid material to gradually deform under steady stress and fracture well below the allowable determined from typical static tests, especially at prolonged elevated temperatures, or at temperatures approaching the recrystallisation temperature.</td></tr>
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<table>
<tr><th>Type of Threats</th><th>Structures</th><th>Systems</th><th>Propulsion</th></tr>
<tr><td rowspan="2">Fretting</td><td colspan="3">Fretting is a wear process that occurs at the contact area between two materials under load and subject to minute relative motion by vibration or some other force. In the presence of an aggressive environment, the contact movement causes wear and material transfer at the surface, often followed by oxidation of the debris at exposed surfaces. The oxidised debris can further act as an abrasive and such degradation is known as fretting corrosion.
Fretting increases the threat of initiating fatigue cracking, resulting in fretting fatigue, and can be exacerbated by environmental factors, ageing and AD; impacting elements presumed to be fitted for the life of the Air System.</td></tr>
<tr><td></td><td>Apart from load bearing Structures, fretting may affect systems such as EWIS; pipework and hoses; and mechanical control cables.</td><td></td></tr>
<tr><td>Wear</td><td colspan="3">Wear (or erosion) is the cumulative change in dimensions brought about by the gradual removal of discrete particles from contacting surfaces in relative motion, usually sliding, predominantly as a result of mechanical action. Wear is not a single process, but a number of different processes that can take place independently or in a combination, resulting in material removal from contacting surfaces causing dimensional reduction through a complex combination of local shearing, ploughing, gouging, welding, tearing and other actions. The outcome of wear may result in the cumulative loss of material, and ultimately Structural failure, when the residual strength of the Structure cannot sustain the applied loads.</td></tr>
<tr><td>Accidental Damage (AD)</td><td colspan="3">AD is the physical alteration of an item (or its surface protection where applicable) caused by contact, impact or interaction with an object that is not part of the Air System, or by human error during manufacture, operation or Maintenance of the Air System. AD may be caused by external impact in the air (for example: mid-air collision, bird strike, wire strike, lightning strike, severe hail, weapons release self-damage or ricochet damage) or on the ground (such as Foreign Object Damage, Maintenance activities, ground handling, freight loading or vehicle movements).
Less obvious AD may arise from occupant / maintainer accidents or from overheating metallic or composite Structure. AD may manifest itself as distorted, torn, punctured or otherwise distressed Structure or surface protection, or as delamination or debonding; and in less visible forms such as a change in heat treatment condition in metals or ‘barely visible damage’ in composites.</td></tr>
<tr><td>Environmental Damage (ED)</td><td colspan="3">ED can be in the form of erosion or corrosion and can be affected by the severity and duration (calendar time or usage) of exposure to the environment. Often, erosion is a contributing factor to corrosion when erosion by sand and / or rain removes surface protective films thus allowing corrosive attack of the underlying material.
Corrosion is the degradation of a material or its properties due to a reaction of the material with its chemical environment or electrochemical agents and is accelerated in higher temperature environments. It can be in form of uniform corrosion, galvanic corrosion, crevice corrosion, pitting corrosion, intergranular corrosion, leaching corrosion or stress corrosion.
A major contributing factor to Air System corrosion is the climate. While water vapour has a corrosive effect, water vapour and salt combination found in marine climates is a powerful corrosive agent hence Air Systems that operate in marine climates are particularly susceptible to corrosion. Other typical causes are fluid / gas absorption, thermal cycling and radiation. In addition, the presence of micro-organisms will accelerate corrosion by producing oxidizing compounds, resulting in chemical reactions that will lead to corrosion. For further guidance on ED refer to Chapter 7.</td></tr>
</table>

Type of Threats	Structures	Systems	Propulsion
	ED may manifest itself as corrosion, stress-corrosion cracking, environmental embrittlement and loss of surface finish for metals; softening of composite material matrices (including adhesives used in laminated wood), debonding or delamination for composites; with both resulting in degradation of static, fatigue and residual strength properties.	ED may manifest itself as corrosion, loss of surface finish, electrical insulation degradation or softening of materials and other types of degradation. It can be brought on or exacerbated by changes in system use and geographical area of operation; especially if the changes were not originally considered in the design assumptions.	
Lack of Configuration Control (CC)	Effective CC is essential in supporting the Air System Safety Case and to inform Airworthiness decision-making, which will ensure confidence in the Integrity of the Air System. A lack of CC may result incorrect IM decisions being made, such as: a. Type Design Changes or repair schemes being designed to incorrect dimensions, components or assumptions. b. Erroneous lifing decisions, such as life extension or component replacement, being made based on data that does not represent the as-flown configuration.		
Procedural Error- Design	Design errors can result from failure to adhere to recognized design standards, design best practice or qualification evidence methodology. It can be countered by applying RA 5810[13] and by following the system engineering principles in the Knowledge in Defence[14]; ensuring validation and verification activities, critical in the design process, are articulated in an agreed test and evaluation plan. The TAA will agree the certification basis for the Air System, that defines the Airworthiness requirements, with the Design Organization (DO)[15,16] and the MAA, and direct the means of compliance.		
	Examples of design error include: a. Underestimating local loads or overestimating of material properties; incorrect load path assumptions; b. Failing to address the potential for incorrect assembly; or c. Specifying inappropriate material and manufacturing processes.	Examples of design error include: a. Failing to generate sufficient evidence of material properties; b. Failing to address potential for incorrect assembly; c. Specifying inappropriate material and manufacturing processes; d. Failing to design an assembly that can correctly perform its required functions; e. Failing to produce reliable software; f. Failing to consider user requirements and Statement of Operating Intent (SOI); or g. failing to identify and accommodate system interactions in complex systems.	

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[13] Refer to RA 5810 – Military Type Certificate (MRP Part 21 Subpart B).

[14] Formerly Acquisition System Guidance (ASG).

[15] Refer to RA 5850 – Military Design Approved Organization (MRP Part 21 Subpart J).

[16] Refer to RA 1005 – Contracting with Competent Organizations.

Type of Threats	Structures	Systems	Propulsion
Procedural Error - Manufacturing	Manufacturing error is when outputs from a manufacturing process fail to meet the design specification. They are often driven by issues arising from: a. Inadequate quality control; b. Insufficient design information; c. Incorrect dimensioning and feature location; d. Use of inappropriate jigs, fixtures or tooling; e. Inappropriate materials and standards; f. Failure to adhere to standards / specifications / procedures; or g. Incorrect routing or assembly of components, including cable ducts, pipes or looms. This threat can be the prime source of common mode failures thereby invalidating the design and the safety target. The TAA has no direct means to counter manufacturing error; the mitigation process is through the DO's subcontracts with equipment suppliers and through the quality measures in the acceptance process carried out by the local Project Officer and / or Defence Quality Assurance Field Force personnel. The Delivery Team (DT) can identify manufacturing errors through analysis of fault data and equipment test; and if manufacturing error is suspected, MOD Form 760 action is required as part of the investigation and to initiate recovery activities.		
Procedural Error - Maintenance	Maintenance error is the outcome of an unsatisfactory Maintenance process on an Air System. Factors leading to Maintenance error may include: a. Inadequate training or supervision; b. Inadequate resources; c. Incorrect technical information; d. Use of unauthorized jigs, fixtures or tooling; or e. Human Factors. The threat can be countered by ensuring authorized tools are used; necessary support equipment is calibrated and available; procedures are in place and effective, considering Human Factors that support Maintenance personnel in their working environment and their frame of mind; and ensuring that all personnel are trained to an appropriate level and hold appropriate authorizations. This requires an ADS that is up-to-date, correct and appropriate for the activities carried out. The ADS will be supported by timely MOD Form 765 activities, which may require the application of contracts, Internal Business Agreements (IBAs) and Service Level Agreements with other IM stakeholders. The use of a Maintenance error management system will identify potential requirements for recovery activities, such as Quality ►◄ System and a system to ensure an appropriate level of supervision and inspection are in place.		
Procedural Error - Supply	Supply error is the release of a component or product that does not meet the design specification of the Air System. Factors leading to supply errors may include: a. Non-conforming components or products; b. Unapproved supplier; c. Incorrectly labelled or codified components; or		

Type of Threats	Structures	Systems	Propulsion
	d. Incorrectly identified components. Some DTs have Performance Based Logistics supply systems where DT input is minimal and greater reliance is on the contract holder to procure the correct components. This requires a thorough understanding and application of the appropriate contract requirements[16], and effective management during the contract period. Other DTs rely on the MOD procurement against a stated demand iaw the Defence Logistics Framework. In both cases, any changes in the ADS and therefore the requirements, are implemented in the supply chain and an assurance system will be in place to ensure only correct items are available.		
Obsolescence	Obsolescence is the loss, or impending loss, of manufacturers or suppliers of components, or shortages of materials / sub-components. Obsolescence does not directly impact the Air System Integrity, but it could impose a component design change that may have an impact on the Air System Integrity. DTs are required to maintain an obsolescence management plan as part of ►the ADS◄ to indicate the contingencies in place. From a systems perspective, software and Complex Electronic Hardware are to be carefully considered.		
Legislation Change	Throughout the life of a system or Air System, legislation changes may have an impact on the Air System Integrity due to enforced design changes in order to meet the new requirements. It is the TAA's responsibility to ensure the effects of legislation changes are addressed early for their Air System to reduce the impact when the change is realised. An example is the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) programme, where changes to legislation restrict the use of hazardous and environmentally damaging substances. The impact of REACH may mean that future chemicals and protective coatings are not as effective as those that they replaced; this may have wide-ranging implications for Air System Maintenance policies. Consequently, IM stakeholders have a responsibility to proactively assess the potential impact, and validate through-life, the impact of REACH legislation on Air System Integrity.		
Fuel and Fuel System Hazard including Sodium Contamination		Fuel contamination can be in the form of absorbed water, incorrect fuel types, oils, foreign particulates, Fatty Acid Methyl Esters or microbiological organisms. Fuel sulphidation[17] occurs when the sulphur in the fuel combines with sodium during burn, to produce sodium sulphate which can lead to the oxidation of superalloys. Also, de-icing fluid contains sodium compounds and can increase the risk of sulphidation. It is the responsibility of the supply chain to provide uncontaminated fuel and the responsibility of the maintainer to ensure fuel quality is iaw the ADS, and that any remedial actions comply with a Technical Instruction. Refer RA 5815[18] and JSP 317[19].	
Petrol, Oil and Lubricants (POL)		The supply chain is responsible for the provision of uncontaminated POL; and the maintainer is responsible for ensuring the POL quality is iaw the ADS.	

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[17] For details, refer Pratt & Whitney Canada Service Information Letter PT6A-206.

[18] Refer to RA 5815 – Instructions for Sustaining Type Airworthiness.

[19] JSP 317 Defence Fuels Policy, Organization and Safety Regulations.

Type of Threats	Structures	Systems	Propulsion
Human Factors	The Integrity of an Air System can be affected by Human Factors through-life in many ways. All Maintenance and operating procedures are to make allowance for the likelihood of human error and be written such that there is no ambiguity. Human Factors training will be in place to ensure the personnel are aware of their potential contribution to the threats that may have an impact on safety and Air System Integrity. DTs are to ensure error management systems are in place to monitor and take forward the lessons learnt.		
Change in Usage or Unmonitored Operation	Any period of unmonitored operation or any change in usage will have an impact on Air System Integrity due to the potential of operating outside the design intent. Causes may include inadequate validation of usage assumption hence incorrect recording of usage and critical part lifing assumptions; lack of monitoring or analysis of usage; different operating environments to the design intent; new working practices or changes to Maintenance regimes; or new operational roles.		

Chapter 2: Pan-Discipline Integrity Management Guidance

Overview

1. Potential threats will be identified early in the life cycle to minimize the RtL and the impact on operational capability. A Preventive Maintenance schedule[20] will be determined to provide an orderly scheduling of inspections and replacement or repair of life-items within the Air System Type. In addition, the actual usage with respect to the intended usage will be assessed to validate the design life of an Air System Type. The overall programme to manage such multitude of activities is the IM of the Air System and the primary purposes are to:

   a. Establish, evaluate and substantiate the Integrity of an Air System;

   b. Acquire, evaluate and apply usage data to provide a continual update of the Integrity of the Air System;

   c. Provide quantitative information for decisions on planning, inspection regime, Type Design changes and operational and support decisions;

   d. Provide a basis to improve the Integrity Baseline in terms of methods of design, evaluation and substantiation for future Type Design changes and / or Air System Types.

2. TAAs will need to consider the most appropriate scope and arrangements to cover the IM of their Air Systems. Specific disciplines other than those considered mainstream (Structure, system and propulsion), may also benefit from the IM process (eg Programmable Elements (both software and hardware), low observable technology and weapons system).

3. The TAA will need to regularly review and plan activities that form part of the IM. These activities are likely to include, but not be limited to, the following:

   a. Establish and maintain the Integrity Governance, Integrity Baseline and IM Systems.

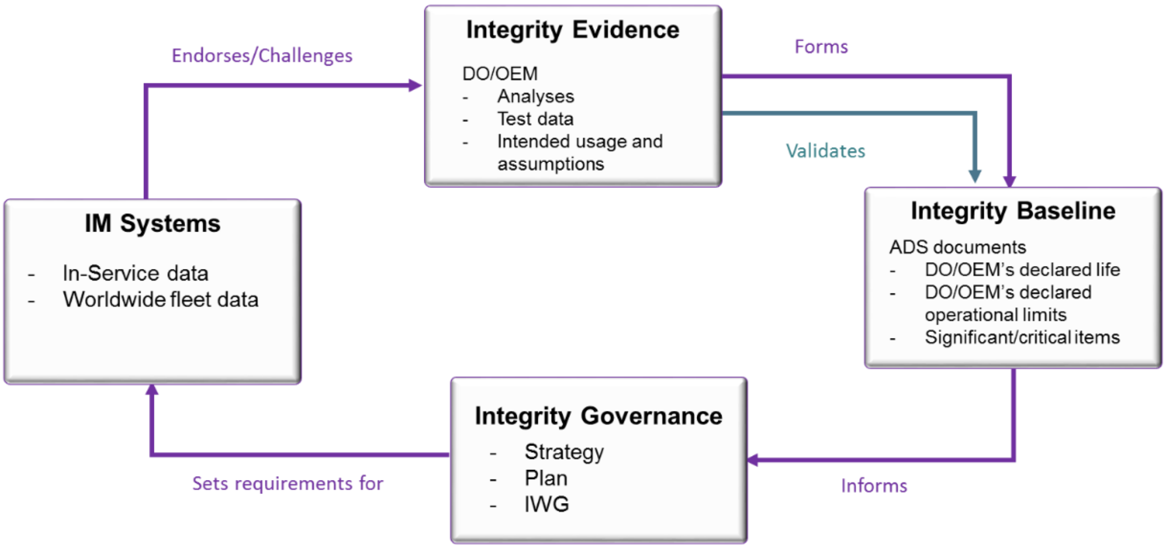
   b. Identify requirements for DO / Independent / Specialist support.

   c. Arrange financial provision for support.

   d. Establish and maintain service level agreements for support.

4. Within the ESVRE framework there are 4 key groups of artefacts, representing Integrity products, that support the IM cycle as shown in Figure 1:

Figure 1 - Artefacts within the IM cycle



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[20] Refer to RA 5320 – Air System Maintenance Schedule – Design and Validation.

5. The Integrity Evidence and Integrity Baseline underpin the Integrity; IM Systems are used to capture Service Data to pro-actively validate the Integrity Evidence and Integrity Baseline; the outcome of the validation, confirmed at the IWG, is the fundamental indicator of Air System Integrity that can be used to counter threats and to assure the arguments contained in the Type Airworthiness Safety Assessment (TASA).

Integrity Evidence

6. Integrity Evidence is produced during the Design and Certification phase for a Military Type Certificate[13] or an Approved Design Change Certificate[21]. The TAA is required to demonstrate compliance against the Air System's Type Certification Basis (TCB), and in determining the TCB, an assessment will be conducted against the MAA's benchmark Def Stan 00-970. Given that qualification testing required to achieve full clearances, typically the full-scale fatigue testing, may continue for some time after the Air System In-Service Date (ISD), the Integrity Evidence is revised subsequent to the completion of such qualification testing. It is used by the DO or Original Equipment Manufacturer (OEM) to support the Air System Type characteristics as documented in the ADS, forming the Integrity Baseline.

7. Once the Air System is In-Service, the Integrity Evidence is updated[22] continuously by assessing In-Service data and, if available, worldwide fleet data. It is captured in an Integrity Evidence Record.

Integrity Baseline

8. The Integrity Baseline is a group of artefacts that defines the characteristics of an Air System Type. Once the Air System is In-Service, the operating conditions, usage and configuration assumed by the DO during design development may change and may require recertification. The implications of any changes are assessed, and the Integrity Baseline is updated accordingly throughout the life of the Air System Type. Similarly, IM activity may result in a need to change component lives, thresholds or intervals. Authorizing the life of Air System components is the responsibility of the TAA for the Air System on which the component is installed. The IWG will need to be made aware of the extensions in place.

Integrity Governance

9. Integrity Governance is the strategic intent established by the TAA in the form of governing processes[23] stated in the Air System Integrity Strategy Document (AISD) and the Integrity Management Plan (IMP), and is supported by an IWG to provide the fundamental governance of the through-life of the Air System Type.

10. The AISD and IMP form part of the document hierarchy as shown in Figure 2, noting that individual, discipline-specific, strategy documents and management plans may be more appropriate to complex Air Systems that would benefit from the increased focus that a more-defined approach would give.

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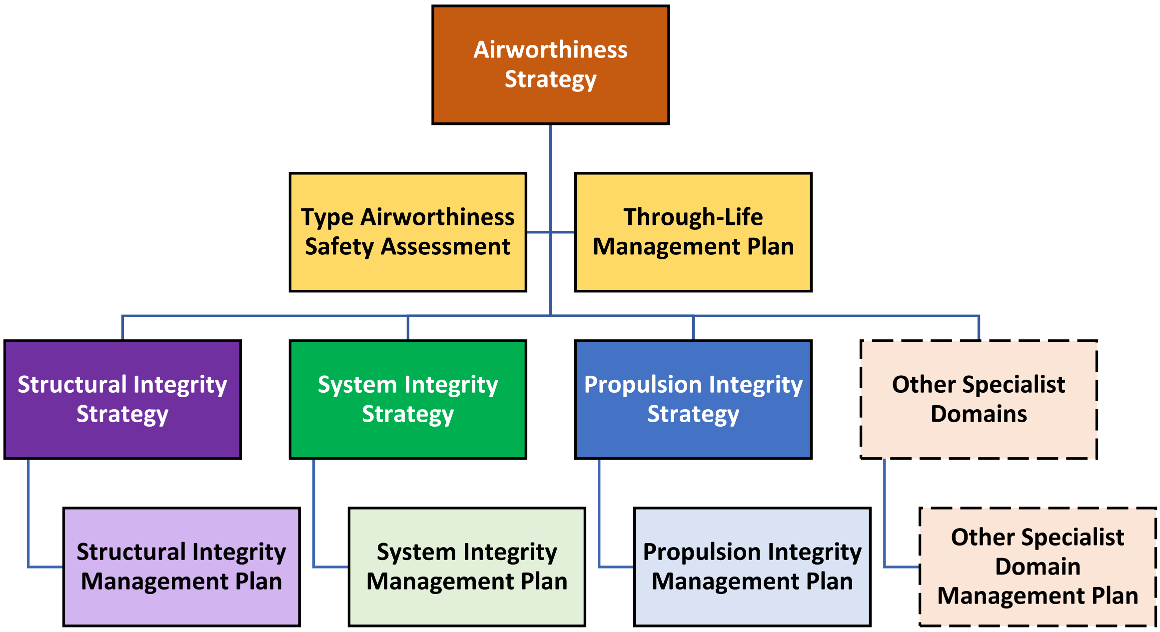
[21] Refer to RA 5820 – Changes in Type Design (MRP Part 21 Subpart D).

[22] Elements of Integrity Evidence and their subsequent updates will need to comply with RA 5815 – Instructions for Sustaining Type Airworthiness.

[23] Processes include the oversight, decision making and the regular review framework.

Figure 2 - Integrity Document Hierarchy



11. The purpose of the AISD is to maintain and promulgate the TAA's intended approach, early in the acquisition cycle and prior to Main Gate (or equivalent), to implementing the required acquisition cycle and through-life IM activities for an Air System Type in terms of methodology, timescale and requirements; covering the aspects below.

a. Details of overarching approach: the measures considered necessary to support the fleet throughout its life and to address ESVRE activities, and details of any necessary deviations from MOD Regulation.

b. Details of strategy implementation: an introduction, implementation of the strategy to ESVRE principles, the IM meetings including frequency and membership, the IMP and a record of historic IM activities and decisions.

c. Relevant items such as design philosophy, verification and validation approach, major Type Design change and capability upgrade programmes, integration of new stores and OSD.

12. The AISD is particularly important as, apart from forming part of the Air System's Through Life Management activities and associated Safety Assessment[24], it will detail the activities required to implement and maintain UK MOD IM Regulation and will act as a record of the evidence and rationale behind the IM decisions taken throughout the life of the Air System[25]. A Condition Survey (CS) of the 'as flown' condition of the fleet can be used in the ongoing development of the AISD.

13. The AISD will be reviewed prior to each IWG and endorsed by all stakeholders at the IWG. To facilitate this review, documents including any amendments, will be sent to relevant stakeholders with the IWG calling notice to allow them to review the documents and make comments as required at the IWG or IWG subgroup. Even if the documents have not been amended, they are to be sent to stakeholders for comment as required.

14. Depending on the complexity of the Air System, the TAA may consider having separate Strategy Documents for each discipline (ie Structures, Systems and Propulsion). The discipline-specific contribution to AISD is shown in Table 2.

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[24] ►Refer to RA 5012 – Type Airworthiness Safety Assessment.◄

[25] Refer to RA 1225 – Air Safety Documentation Audit Trail.

15. The IMP, aligned with the AISD articulating how the Strategy will be implemented, indicates the timeline for routine / scheduled activities. The IMP is owned by the TAA and is made available to all Stakeholders, and like the AISD, standalone IMPs for each discipline may be better suited to some Air Systems depending on the complexity of the Air System. The IMP will identify all IM activities within the ESVRE framework required to achieve Airworthiness until the funded OSD. It will contain routine meeting dates, one off or recurring activities along with document reviews. In addition to addressing the requirements in RA 5726, the plan considers any major Type Design change and capability upgrade programmes, integration of new stores, changes in fleet disposition, fleet draw-down and OSD.

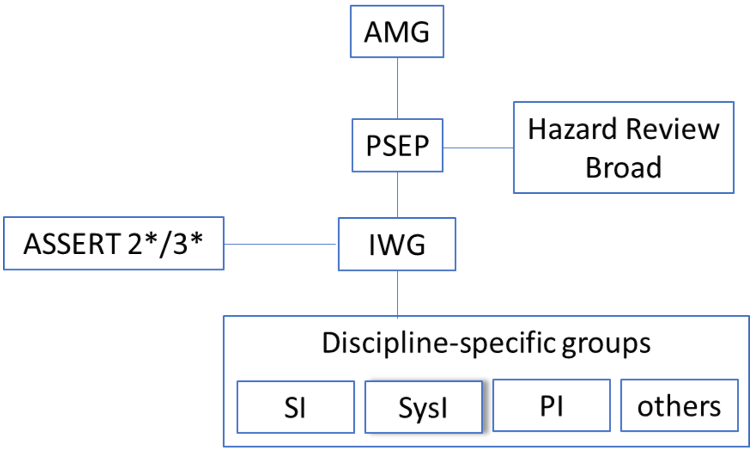
16. An IWG will be initiated by the TAA prior to ISD and sufficiently ahead of higher-level meetings to allow Integrity risks to be raised at these fora. The IWG discusses Integrity issues and formally endorses IM processes, decisions and documentation, considering projected usage and known risks. Supplementary specialist working groups may support the IWG as required. In multi-national projects, although multi-national fora may be established to progress Integrity issues common to the partner nations, it is likely that a UK-only meeting will also be necessary to progress national issues associated with UK configuration, usage, operating practices, Integrity standards and regulatory framework. A meeting will be held every 6 months focusing on Airworthiness and not the management of logistics and supportability issues, unless these issues are manifesting as a threat to Air System Integrity which in turn may have an impact on Airworthiness. IM activities conducted at the IWG will focus on the Integrity Baseline to pro-actively manage the IM Systems in mitigating the threats to Integrity, through monitoring and reviewing the Integrity Evidence and assuring that Integrity Assertions remain valid.

Table 2 - Discipline-Specific Contribution to AISD

<table>
<tr><th>Structures</th><th>Systems</th><th>Propulsion</th></tr>
<tr><td colspan="3">At discipline level:
- Define the design criteria used in the Design / Certification phase, including the design philosophy such as Safe Life, Fail Safe or Damage Tolerant; the associate environment in which the Air System will operate; and the life requirement appropriate to the design philosophy and defined environment.
- State design evidence such as testing of materials, components, subsystems and assemblies, the analysis of the design, full scale test, ground / flight tests and qualification and / or verification tests.
- Identification and management of critical or significant items.
- Follow-up control through processes and procedures that will be used to manage In-Service Air Systems, such as Maintenance, inspections and usage monitoring.</td></tr>
<tr><td>Additional SI[7] contribution:
a. Critical or significant items are the Structural Significant Items (SSIs) for FW and Critical Parts (CPs) for RW.</td><td>Additional Systems Integrity (SysI)[7] contribution:
a. **MECHANICAL SYSTEMS**
- Damage tolerance criteria include leak before burst and proof testing on each production component.
- Additional design criteria include inherent improbable occurrence of failure for items such as fuel lines, fuel line couplings and wire harnesses.
- Critical or significant items are Functional Significant Items (FSIs)
b. **AVIONICS AND ELECTRONICS**
- Impact on Integrity of implementing requirements such as lead-free electronics and anti-temper.
- Critical or significant items are Flight / Safety Critical Functions.
c. **EWIS**
- Document overall EWIS and identify critical circuit paths and functions.
- Identification and management of EWIS failure, critical problem areas through the conduct of Air System physical electrical inspection.
- Management of materials / ageing of wiring.
- Overall risk and life assessment of the Air System electrical system.
- Follow-up control include partial or total replacement or implement new technologies.</td><td>Additional PI[7] contribution:
a. Define performance and functional requirements.
b. State environments internal to specific equipment such as pressures and temperatures inside an engine, module or fuel / oil component; and external environments applying to equipment through airframe interface connections.
c. Expand on operational usage to include steady-state and cyclic mission usage detailed at engine and component levels.
d. Life capability can be life limited, on condition or damage tolerant; and corresponding reliability, safety and hazard assessments.
e. Critical or significant items are Critical Parts (safety and mission critical).
f. Engine life management covering operating limits and plans for quality control, integrated logistics and component life management throughout the operational lifetime of the engine.</td></tr>
</table>

17. The IWG sits in a hierarchy of Airworthiness, Safety and other meetings as shown in Figure 3, with information flow in both directions. Note that this is not a complete hierarchy as it will depend on the DT and other stakeholders' meetings. On a more complex Air System it may be beneficial to conduct discipline-specific reviews for in-depth technical discussions relevant only to the specific discipline. A summary of discipline-specific issues and respective status can be reported to the Air System IWG. Note that the IWG construct will need to be tailored to the complexity and needs of the Air System .

Figure 3 - IWG



18. The IWG will be chaired by the TAA or the holder of a delegated Letter of Airworthiness Authority (LoAA) (at least OF4 or L4), who is empowered to cover all systems discussed at the meeting and to make Airworthiness decisions at the meeting.

19. The IWG is a stakeholder group with key and additional stakeholders as shown in Table 3. However, the TAA will consider including anyone who supports IM on their Air System or equipment on an "as required" basis, to ensure that:

a. Threats that cross organizational and process boundaries can be fully explored.

b. The elements of Risk that reside in the organization or process boundaries and handovers can be identified and managed at the IWG.

c. A breadth of Suitably Qualified and Experienced Person (SQEP) individuals is available to support decision making which might have an impact on Airworthiness.

d. Solutions and potential solutions which enable recovery action to be implemented, restoring Airworthiness, can be discussed by the relevant stakeholders at the IWG.

e. All Integrity stakeholders have an opportunity to bring to the DT concerns over the threats that are identifiable from their AoR.

Table 3 - IWG Stakeholders

Key Members Role	Responsibilities
TAA	To chair the Air System IWG and has the overall IM responsibilities iaw RA 5726[7].
LoAA holders and DT members responsible for IM	If applicable, LoAA to chair discipline specific IWGs or Air System IWG on behalf of the TAA. DT members to maintain the Integrity Baseline / Evidence that are within the TAA authorities such as Service Modifications (SMs), SI(T)s etc.
Mil CAM	To report tail specific elements of integrity and IM to the TAA. To trend and to interpret In-Service data as required by any 2N/A/R(1) Leaflet obligations To provide feedback on any inconsistencies between current Maintenance Programme and the Maintenance Schedule to the TAA. To make recommendations from the trending and interpretation of In-Service Data to the TAA. To report inadequacies of, or inability to follow the ADS (through MOD Form 765 or equivalent).
Service provider / Support contractor (if applicable)	To report tail specific elements of Integrity and IM to the TAA. To trend and to interpret In-Service data. To provide feedback on any inconsistencies between current Maintenance Programme and the Maintenance Schedule to the TAA. To make recommendations from the trending and interpretation of In-Service Data to the TAA. To report inadequacies of, or inability to follow the ADS.
DO / Co-ordinating DO	To maintain appropriate access to Integrity Evidence including approved data. To maintain Integrity Baseline / Evidence, on behalf of the TAA, that are within the TAA authorities such as SMs, SI(T) etc. To analyze and / or interpret results of In-Service data analysis. To provide options and recommendations based on In-Service Data analysis.
DT Safety Manager	To act as focal points for Safety, Airworthiness and environmental issues; to provide assurance that all equipment safety hazards are being communicated to stakeholders.
Civil Aviation Authority for military registered Air Systems subject to civil oversight.	To provide regulatory Subject Matter Expert (SME) advice.
Independent Airworthiness Advisor	To provide specialist domain knowledge to support the TAA or appointed representative at specialist working groups or IWG. An Independent Structural Airworthiness Advisor (ISAA) will attend IWGs discussing SI matters; however, the use of other IAAs for other disciplines will need to considered where the TAA requires that SQEP (ie propulsion, systems, software etc).[26]
Release To Service Authority (RTSA)	To confirm that the Integrity Evidence underpins the RTS.
MAA (not part of IWG Quorum, but will be invited)	Certification division to provide SME advice. Oversight and Approvals division to provide third part assurance on behalf of the regulator.

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[26] Refer to RA 5726 – Integrity Management. An experienced ISAA is regarded as SQEP in pan-discipline IM matters from a regulatory compliance perspective, but an IAA in the required field will be required to address specific issues in disciplines other than structures.

Additional Members (as necessary) Role	
1710NAS	To provide RW damage assessment and repair design schemes, Material Integrity Group for materials, develop and undertake Non-Destructive Testing (NDT) specifications and Prognostic Health Monitoring issues.
71(IR) Sqn	To provide FW damage assessment and repair design schemes, develop and undertake NDT specifications.
Station / Ship / Unit Aircrew / Engineering	To confirm that the usage is as described, and that the technical evidence is valid.
Requirements Manager	To assess changes in the requirement settings when there is a change in the intended use of an Air System.
Original Equipment Manufacturer (OEM)	To provide design information

20. At the higher level, the IWG will ensure the Air System will safely achieve OSD at the current and forecast usage rates and that processes are in place to ensure the RtL arising from threats to Integrity are managed; and deemed as ALARP and Tolerable by the ADH[8]. Current Risks to Airworthiness are to be discussed by all Stakeholders in sufficient detail to allow the LoAA holder to understand the current level of Risk. Risks are to be formally recorded, to provide an audit trail for IM decisions, and to inform the Duty Holder (DH) of any increase in equipment contribution to RtL. Any Airworthiness risk identified that is potentially generic in nature or broad-based will be raised by the TAA at the appropriate Airworthiness Management Group.

IM Systems

21. IM Systems[7] refers to the IM Programmes, tools and processes, established by the TAA, necessary to assure the Integrity of the Air System through-life.

22. The Integrity Governance sets out the requirements for various IM Systems to monitor and track the health and usage, configuration control[27, 28], repairs[29] and modifications[30], exceedances, AD and ED findings, or component failures. These activities are captured in Table 4[31] in the form of tasks; and further expanded on the task objectives and corresponding IM Systems necessary to fulfil these tasks.

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[27] Refer to Defence Standard 05-57 Configuration Management of Defence Materiel.
[28] Refer to RA 5301 – Air System Configuration Management.
[29] Refer to RA 5865 – Repairs (MRP Part 21 Subpart M).
[30] Refer to RA 5305 – In-Service Design Changes.
[31] Table lists the minimum requirements to satisfy RA 5726 hence it is not an exhaustive list.

Table 4 - IM Systems Objectives

Tasks to assure Integrity	Task Objective	IM System(s) to fulfil the Task
MOD Form 724 / 725 data	Validate usage rates and assumptions of selected condition / metrics	**Statement of Operating Intent Usage (SOIU) reviews**: - Annual - Triennial
Health and Usage monitoring: - Capture usage data - Capture health data	Validate design assumptions: - Usage assumptions - Operating intent - Design parameters - Failure rates	**AUVP:** **Air System with high-level Individual Air System Tracking (IAT) capability:** - Structural Health Monitoring System (SHMS), Health and Usage Monitoring System (HUMS). **Air System with low-level IAT capability:** - Operational Loads Measurement (OLM) / Operational Data Recording (ODR) in conjunction with limited SHMS, HUMS, Fatigue Data Recorder (FDR), Air System Data Recorder (ADR) and Manual Data Recording Exercise (MDRE). **Air System with no IAT capability:** - OLM / ODR
Condition monitoring: - Examine critical or significant items	Validate design assumptions: - Environmental conditions - Loading - Material allowables	EDPC programme Examination Programme (EP) / Sampling Programme (SP) / Teardown / Zonal AAA[32]
Configuration tracking: - Collect data for AD - Track mass and Centre of Gravity (C of G)[33] - Track repair / modification	Validate Air System against: - Type Configuration Baseline	CC programme AAA
Exceedance monitoring: - Capture overloads - Capture conditions exceeding operational limits	Validate design assumptions: - Operations envelop - Flight limitations - Design limitations	Exceedance monitoring system
Faults monitoring: - Track Faults reported - Identify Fault trends	Validate design assumptions: - Failure rate - Failure mode	Failure Reporting Analysis and Corrective Action System (FRACAS) / Data Reporting Analysis and Corrective Action System (DRACAS)
SSI / FSI / CP monitoring: - Track inspections	Validate design assumptions: - Maintenance schedule - Component replacement time	Maintenance Schedule Review (MSR)[20] EP / SP / Teardown / Zonal AAA
Service data monitoring: - Track service data from Forward / Depth domains	Validate design assumptions: - Maintenance schedule - Maintenance actions	Maintenance data reporting EP AAA

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[32] Refer to RA 5723 – Ageing Air System Audit.
[33] Refer to RA 5212 – Weight and Moment Determination.

ESVRE Framework

23. The 5 phases within the ESVRE framework present a system engineering approach to IM for the variety of Air System Types on the Military Air System Register.

24. The artefacts within the IM cycle in Figure 1 evolve through the ESVRE framework as illustrated in Figure 4. A breakdown of the tasks associated with each artefact through the ESVRE framework is presented in Table 5.

Figure 4 - IM within the ESVRE framework

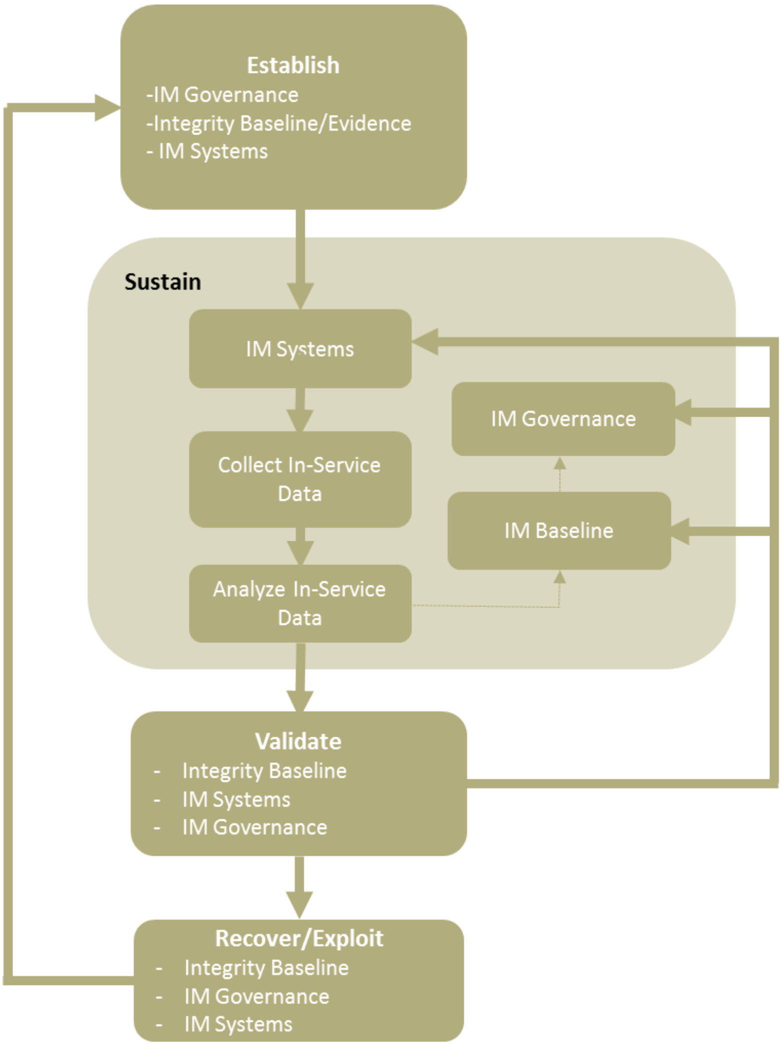

Table 5 - IM artefacts evolving through ESVRE framework

ESVRE Phase	Integrity Governance	Integrity Evidence / Baseline	IM Systems
ESTABLISHING - This phase typically spans across Design, Certification and early In-Service stages for most of the establishing activities. - Considerations are to be given to all IM Systems listed in Table 4 to fulfil the IM objectives. - This phase will be revisited subsequent to Recovering or Exploiting activities.	Establish an IM Strategy and document the Strategy in AISD.	Identify Integrity Baseline and corresponding Integrity Evidence.	Establish HUMS / SHMS.
	Establish an IM Plan and document the plan in IMP.	Identify all critical or significant items for Structure, system and Propulsion System disciplines.	Establish system to capture sortie occurrences and a means to quantify unmonitored sorties
	Establish an IWG and identify appropriate stakeholders.	Ensure all critical or significant items have appropriate Maintenance activities.	Establish system to validate usage data.
		Review critical and non-critical component lives and where applicable exchange rates.	Establish exceedance monitoring system.
		Ensure Commodity DTs establish lifing details of components with evidence.	Establish FRACAS / DRACAS Establish CC system Establish Maintenance Data Reporting (MDR) Establish EDPC programme Establish Inspection Programme (EP / SP / Teardown / Zonal) Establish MSR Establish AAA programme Establish Obsolescence plan
SUSTAINING - This phase typically starts when an Air System Type enters service. - Integrity Governance and all IM Systems are implemented and are reviewed periodically. - In-Service data and associated findings are reported to IWG, Platform Safety and Environment Panel (PSEP) and Platform Safety Working Group as required.	Implement Integrity Strategy per AISD and review AISD at IWG.	Monitor changes to Integrity Evidence / Baseline	Implement the established IM Systems and ensure accurate recording where applicable.
	Implement IM per IMP and review IMP at IWG.	Report any significant failure, trends or issues to IWG.	Report any significant findings, including data loss, unmonitored sorties and CC issues to IWG.
	Review In-Service data and report key issues at IWG meetings; ensure unmitigated or unqualified	Report any significant changes in usage or operation, or any changes to lives, inspection thresholds or	Convert SOI to SOIU and review whether current or projected usage will achieve OSD. Consider fatigue

ESVRE Phase	Integrity Governance	Integrity Evidence / Baseline	IM Systems
- IM Systems are maintained to maximize capture, use and monitoring of usage data by Continuing Airworthiness Management Organization (CAMO), DT and IWG.	Airworthiness risks are reported to PSEP and / or Air System Safety Working Group (ASSWG).	intervals to IWG.	conservation measures.
		Carry out Risk Assessment and update TASA arguments prior to updating records.	Implement first Usage Data Validation to enable validation downstream.
VALIDATING - This phase starts at different stages in life for different IM Systems. - IM Systems set up for validating purposes are those that check for deviation in usage (severity and frequency), condition (degradation), configuration baseline (repairs and Type Design changes) or Maintenance (deferred Maintenance actions).	Revisit the Strategy and Plan as In-Service evidence becomes available.	Review and update Integrity Baseline / Evidence with support of DO.	Review and validate Maintenance Schedule and associated Maintenance processes; consider failure rates data from MDR
	IWG to validate the In-Service data against the Integrity Baseline.	Review cleared life in response to changes to fleet planning assumptions	Conduct AUVP / SOIU reviews
		Review component lifing, recording processes and metrics.	Conduct SP / Teardown as required.
		Review all critical and significant items in terms of lifing and inspection regime; attention will be paid to assumptions regarding items having the same life as the Air System, eg ‘sealed for life’ bearings.	Verify systems or components are functioning within defined limits.
			Ensure safety-critical system dependencies are checked, verified or calibrated.
			Initiate AAA as required.
			Validate configuration, mass and centre of gravity.
RECOVERING - Recovering activities to re-establish Integrity Baseline are required upon adverse findings from the Validation phase. Activities may include repairs, Type Design changes, decrease inspection intervals or impose operating restrictions or an ADH decision to accept the resultant RtL.	Treat any loss or potential compromise of Integrity as an Airworthiness issue.	Ensure processes are in place for when Integrity Evidence no longer supports the Integrity Baseline.	Rectify any issues associated with IM Systems such as data loss.
	IWG to identify and assess unmitigated or unquantified Airworthiness risks and to recommend recovery action.	Ensure measures to conserve life to achieve OSD are considered.	Exploit data from IM Systems and existing complementary processes for Issues Management, Configuration Management and managing equipment RtL, to aid

ESVRE Phase	Integrity Governance	Integrity Evidence / Baseline	IM Systems
- Significant arisings are reported to IWG and all relevant stakeholders, as Recovering actions may involve more than one organization or may cross process boundaries. - Recovering actions are also required for any Airworthiness related issues such as loss of usage data, to ensure conservative assumptions are made.			recovery activities to aid recovery activities.
	Unmitigated or un-quantified Airworthiness risks identified in IWG are raised to PSEP and / or ASSWG.	Consider Type Design change, refurbishment, component replacement or change inspection / Maintenance regime to mitigate threats, to achieve fleet planning objectives.	Assess the adequacy of the IM Systems and consider measures to amend shortfalls in the IM systems.
	Any recommendation at an IWG to amend inspection threshold / interval are to be ratified by the LoAA holder prior to incorporation in the Maintenance Schedule.	Ensure repairs are assessed against the appropriate design standard.	
		Action to be taken in the case where configuration, mass and C of G have deviated.	
EXPLOITING - Different facets to exploiting include making use of failure / Accident rates, Maintenance databases, usage data and worldwide fleet data. - Information may be used as part of revised hazard analysis carried out in support of Airworthiness related decisions. - Where there is an opportunity to relax requirements within the Integrity Baseline, Exploiting activities can be taken without introducing new threats.	IWG to review, assess and subsequently recommend if applicable, any exploiting activities including relaxing the requirements, temporary extension beyond lifing or inspection requirements.	Identify opportunities to make better use of the capabilities of the Air System, such as to increase component life or consider a LEP[34], or to extend OSD[35], reduce inspection requirements or relax operational limits.	Identify outputs from IM Systems that could be used in exploiting activities.

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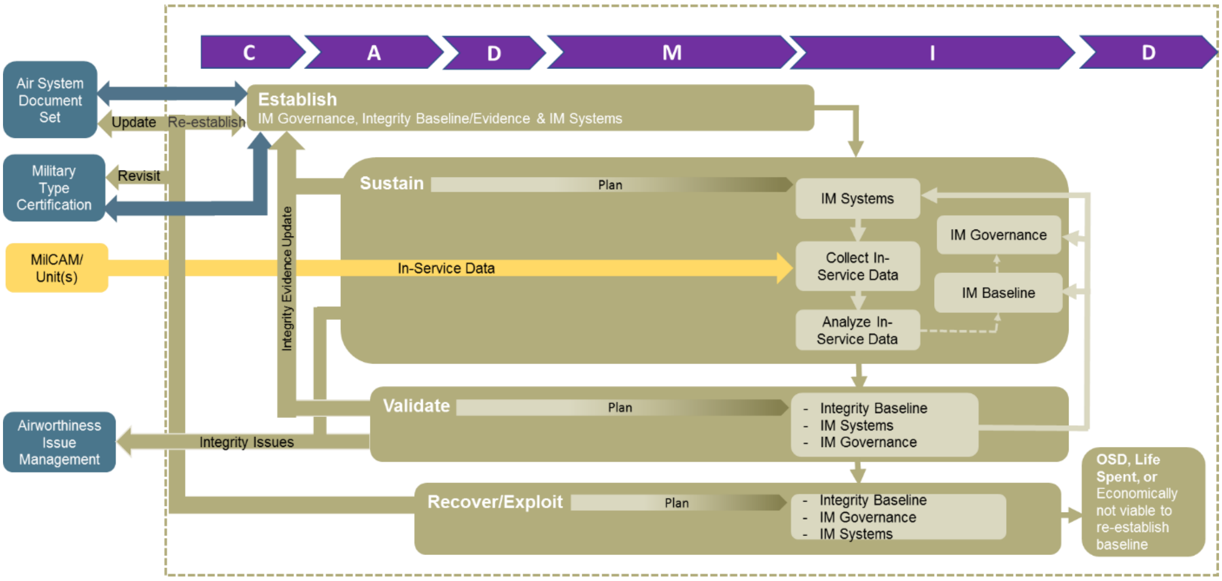
[34] Refer to RA 5724 – Life Extension Programme.

[35] Refer to RA 5725 – Out of Service Date Extension Programme.

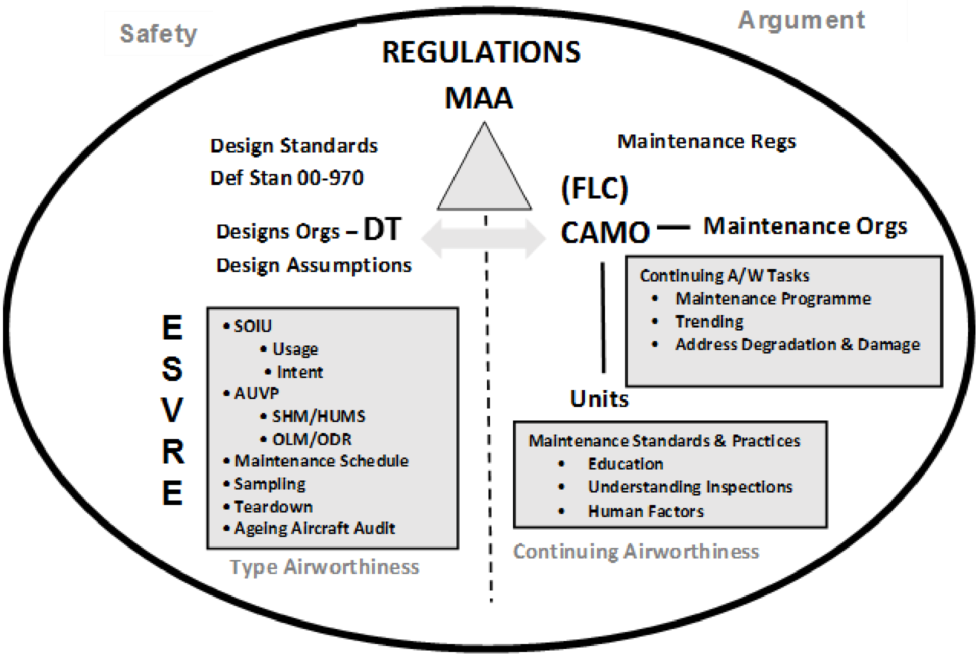
25. The set up and implementation of the IM Systems are aligned to the ESVRE framework as illustrated in Figure 4. Note that the framework is not chronological, and aspects of each phase may occur at various stages of an Air System's CADMID life cycle as shown in Figure 5.

Figure 5 - ESVRE Through Life Concept



26. The DO's role at each stage of ESVRE is crucial; however, it is not limited to generating, maintaining and updating the evidence record through life. It is essential that contractual arrangements allow for the DO's participation in the exchange of information that is fundamental to In-Service IM, such as attendance at working groups, upkeep of Usage Monitoring systems or reassessment of component lives in response to changes in Air System usage. Figure 6 illustrates the importance of contributions from other stakeholders to achieving Air System Integrity.

Figure 6 - ESVRE in the context of Air Safety



27. Measures to assure Integrity are to be planned in advance and to be included in the Air System TLMP, as well as the whole life cost forecasts as adequate funding is key to supporting the Air System Integrity strategy intent throughout the intended service life of the Air System.

Chapter 3: Integrity Management Systems

Air System usage

1. **SOI.** The operating intent for a new Air System is formally conveyed to the DO in the form of a SOI at the design stage, to be published as Topic 15S within the ADS mandated for all UK military Air System Types no later than the agreement of the initial TCB. The SOI describes and quantifies the intended usage of an Air System Type, by defining flight profiles and associated parameters for each sortie profile, in addition to mission profiles and mission mix, for a given Air System configuration. Based upon this SOI, the DO will derive a Design Usage Spectrum (DUS) considering the mission mix of the agreed set of sortie profiles for various operational roles. Accordingly, the DUS is an estimate of all loading and the corresponding number of occurrences that an Air System Type is expected to experience within its Design Service Life. In collaborative projects, this spectrum may represent an agreed compromise among various stakeholders.

2. **Initial SOI Review.** As an initial estimate of the operating intent, the SOI needs to be reviewed once the Air System Type has accumulated sufficient representative In-Service usage data, no later than 3 years after ISD, through a SOI Review process. The outcome of the process is a SOIU that replaces the SOI and documents the actual usage since ISD. This SOIU formally conveys the actual usage to the DO and allows the DO to assess the impact on the Integrity Baseline.

3. **SOIU Reviews**. Subsequent SOIU Reviews are to document the actual usage since the last review, nominally the 1or 3 year period for the annual or triennial review respectively; but the actual usage within the review period will be compared to the original design and operational intent declared in the SOI. When used in conjunction with a Sortie Profile Codes (SPC) recording system, the usage of the individual Air Systems can be tracked. The accuracy of the recording of the Air System configuration, missions, flights and SPCs by Aircrew is vital to ensuring the tracked information is representative of the fleet. Of equal importance, the SOIU Review will validate the actual usage and the mission mix against the design and operating intent; and that the flight and mission profiles are within the operating envelope. It is therefore crucial that the SOIU is continually updated through the reviews and is representative of the actual mission and flight profiles, operating environment and configuration (including mass properties); thereby assuring the continued validity of the Design Life and Maintenance Schedule of the Air System Type. The assurance is achieved through the annual and triennial SOIU reviews outlined below; more detailed guidance is at Chapter 8 – Air System Usage Validation Programme.

4. **Roles and responsibilities**. As owner of the SOIU, the ►ADH / AM(MF)◄[36] can delegate Technical Information (TI) sponsorship and management of the document to the TAA. As TI sponsor of the SOIU, the TAA will plan and allocate resources for these reviews. The TAA may appoint the DO or a competent organization to perform the usage data analysis and to coordinate inputs from other stakeholders.

5. **Annual review.** The annual review is a qualitative assessment to ensure the SOIU is relevant to the Air Systems usage, and to detect observable deviations from the intended usage baseline. Therefore, the ►ADH / AM(MF)◄ will ensure annual reviews of the SOIU are conducted; covering usage and mission profiles for the Air System, sortie profile description, sortie profile definition in terms of relevant parameters, and specifically for RW, the high and low cycle spectra that could include sortie changes and operational changes. The review will cover any known updates on roles, operational use or deployment; and may include interviews with the Aircrew.

6. **Triennial review.** The triennial review, undertaken instead of the annual review in that year, is a quantitative assessment of the Air System usage to validate against the design intent and will consider the usage for each Air System within the fleet, in terms of SPC occurrences and overall SPC distribution which is indicative of the mission mix and identifying significant or persistent

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[36] Refer to RA 1020(1): Role and Responsibilities of the Aviation Duty Holder.

gradual incremental deviations from the design baseline. The data source and details vary depending on the Air System Types and where available, are to take into account the fatigue damage, loads and usage data (refer AUVP) from Air Systems with IAT[37]; OLM / ODR for Air Systems with basic level of, or without, IAT; Logistic Information Systems, MOD Forms 724 and 725; and Aircrew interviews. The triennial review will result in an up issue of the SOIU that will record that an assessment has been carried out even if there have been no changes. It is advisable that planning is initiated in advance of the triennial review to ensure data can be analyzed and the draft SOIU compiled and reviewed by stakeholders, allowing up-to-date information to be checked and agreed ahead of the review.

7. **Other reviews.** In addition to the annual and triennial reviews, any significant or persistent gradual incremental changes in operation or usage will be brought to the attention of the IWG by the ►ADH / AM(MF)◄. The ►ADH / AM(MF)◄ will confirm the accuracy and validity of the SOIU content, and the RTSA will confirm that the SOIU remains within the RTS.

8. **Revisions.** For any amendments or reissues of the SOIU resulting from significant changes to usage and / or intent, the TAA will task the DO to assess the subsequent impact on the Air System Integrity, and to initiate Recovery activities if deemed necessary. All issues of the SOIU will be retained by the DT to maintain a full historical record of the usage and to understand the implications and significance of recent changes.

Usage Monitoring Systems

9. The Structural design, test, qualification and validation methodology for an Air System requires the DO to make assumptions about the Air System's intended usage, operating environment, associated loading and corresponding frequency during its Service life. Substantiation of loads models form part of the certification activity for an Air System and may be addressed by a flight loads survey and specific flight tests. However, these surveys are conducted by flight test Aircraft that may differ significantly in respect of mass and configuration to that of In-Service Air Systems and the flying conducted will be tailored to specific test points and manoeuvres. As a result, the obtained data, which forms part of the Air System's Integrity Baseline, may not be fully representative of the operational Air System's usage. It is necessary to monitor the actual usage of the Air System in service since the usage is unlikely to mirror that assumed for design in its entirety. Operating role changes during the life of the Air System are also likely to result in usage, mass and configuration changes. Usage monitoring systems are necessary to collect data to assess the impact of such changes on the Air System qualification.

10. In addition to identifying actual In-Service usage, it is necessary to identify the loads associated with this usage at regular periods throughout the Air System's life, for comparison with the design usage assumptions and the fatigue spectra used in test and qualification. The SOIU does not typically provide the level of detail required to validate all design usage and loads assumptions. Similarly, the use of simple parametric usage monitoring systems, such as those that rely on flying hours or 'g' counts coupled with Fatigue Meter Formula (FMF), are unlikely to provide the required level of detail. This is because whilst FMF derive fatigue damage from normal acceleration data, they do not provide an accurate means of loads monitoring because they incorporate various assumptions regarding the mass and configuration of the Air System and also assume nominal flight conditions associated with the normal acceleration data. Furthermore, the loads across an entire airframe cannot be characterised purely by normal acceleration measured at a single point. Therefore, a more detailed operating loads measurement system is required.

11. **Operating loads and usage.** In-Service operating loads need to be captured through an operating loads and usage programme (OLM for FW and ODR for RW). The first OLM / ODR will be carried out once in-Service usage is deemed stable, but at the very latest must be conducted within 3 years of the Air System's ISD. The OLM / ODR aims may include:

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[37] Examples are Manual Data Recording Exercise (MDRE), HUMS, Flight Data Recorder (FDR) or Air System Data Recorder (ADR).

a. Substantiation of the DUS used in design and qualification and a review of fatigue clearances and inspection / Maintenance periodicities.

b. Identification of local stresses in structural features.

c. Substantiation of the monitoring systems, including any lifing, damage or Fatigue Index (FI) algorithms and the identification of further monitoring requirements.

d. Capture of data relevant for future fatigue testing.

e. Identification of particularly damaging activity or manoeuvres.

f. Provision of data to support investigations of structural issues or for life extension programmes.

g. Provision data for use in a review of the SOIU.

12. The operating loads and usage programme solution complexity will be dependent on the programme objectives and demonstrated confidence in the actual usage as well as the relationship between usage and the loads experienced by the Air System. The TAA will normally task the DO to define the usage validation requirements and to propose a corresponding solution. This solution will either be designed in from the outset or retrofitted once the Air System is in Service.

13. **Non-IAT Solution**. For Air Systems not fitted with high-level IAT, the solution could be a system of sensors or a parametric system, activated on every flight continuously or as and when required. The instrumentation is typically installed on a limited number of Air Systems that are representative of the typical fleet role and corresponding usage. Usage data validation for Systems can be accomplished through a combination of on-board monitoring systems. For RW, additional instrumentation to measure the characteristics of rotating components may also be required. The capability to conduct operating loads and usage validation programmes will be present through-life, to enable periodic recording on an as-required basis with minimal recovery work.

14. **IAT Solution**. Newer Air System Types may be equipped with high-level IAT that either capture some, if not all, flight and usage related parameters. As a result, the benefit of considering the operating loads and usage validation requirements during Air System development is that these on-board systems can be included in the design to meet the requirements[38]; omitting the need to retrofit the required instrumentation after the Air System Type has entered service. Examples of these high-level IAT systems are SHMS and HUMS.

15. **SHMS.** For FW fleets, some Air System Types are provided with instrumentation to enable the fatigue life consumption to be tracked. The airborne hardware will use configurable data acquisition systems and can be downloaded to an appropriate Ground Support Station for processing and analysis. The ground station is used to maintain Air System lifing data and will embody appropriate cross-checks and trend analysis to establish the short- and long-term Integrity of the data. Flight-by-flight loading information will be retained for subsequent reappraisal if the need arises. Exceedance monitoring aspects of SHMS are to be identified after each sortie, so that any necessary inspections can be carried out before the next flight; whereas issues relating to life consumption can be addressed in the longer term. Faults within the airborne monitoring system requiring Maintenance activity will be identified automatically at Air System turn-round.

16. **HUMS**. The complexity of RW makes it difficult to identify and monitor life consumption using basic instrumentation. The life consumption rates can be managed using one of 5 approaches: operating hours only; basic usage (operating hours, plus rotor starts, take-off etc); manoeuvre recognition; fatigue load / damage synthesis from flight data parameters; and direct load measurement. While some Air Systems equipped with HUMS can provide comprehensive operating usage data for most fleets, many lacking an adequate HUMS fit are relying on automatic flight data logging (manoeuvre recognition) exercises or MDRE. In addition, Propulsion System HUMS is capable of providing health and condition monitoring (wear debris, vibration, diagnostics

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[38] Refer to MASAAG Paper 109, Chapter 7 and MASAAG Paper 120.

and prognostics) and usage monitoring (cycle / hours counting and operating parameters) that can be exploited for operation and usage validation.

17. **MDRE**. Where the method of IAT cannot adequately characterise the Air System usage, MDRE can be employed to record additional flight condition parameters during a representative sample of sorties. MDRE involves an additional crewmember recording the occurrence and duration of all relevant flight conditions throughout each sortie. MDRE will include sufficient sorties of each kind flown by the fleet to obtain statistically significant results. In lieu of a MDRE; a suitable, automatic, means of recording usage data may be employed. It is important that the MOD Form 724 / 725 or technical log contains all necessary conditions (such as LCF events and SPCs for RW) so that the record of usage In-Service can be validated by the results of MDRE and operating loads and usage validation, and to allow effective analysis of usage data.

18. **Data loss / corruption**. Any period of unmonitored usage will threaten the assumptions underpinning the Integrity Baseline. Where usage data is lost or compromized, either due to unserviceability of systems or failure of data capture or computation, fill-in data will need to be derived. This fill-in data is normally based on the mean usage rate multiplied by a standard scatter factor of 1.5. In most cases this factor will be conservative, resulting in a significant life penalty, but where usage is known to be highly variable, it may not be adequate. However, where more statistical evidence is available and more accurate fill-in data is required, the fatigue consumption rate equivalent to the 90th percentile of usage severity for similar sorties will be used. Since this represents a loss of usable Safe Life, or a reduction in the time to the next inspection, such loss of data will be minimized, and recovery action will be undertaken to prevent recurrence. The rate of, and recovery of, unmetered sorties is monitored by the IWG.

19. It is inevitable that there will be some data loss through the life of the Air System; similarly, there may be occasions where the Integrity of the data is suspect. Consequently, provided the data is not from the same Air System or Station / Ship / Unit, or within a single or the most damaging SPC or sortie / flight type, a loss / corruption of up to 2% is considered acceptable within a trinennial review period. Beyond 2%, further investigation may be required; data loss / corruption above 5% may indicate compromized Airworthiness, requiring immediate detailed investigation.

EDPC

20. An EDPC Programme is a comprehensive and systematic approach to managing the Risk from ED throughout the life of an Air System. The Programme will be established early in the life cycle to ensure that an appropriate Maintenance regime is implemented.

21. An evaluation of the susceptibility of the Air System Structure, system and Propulsion System will be conducted as part of the EDPC, identifying locations where components might be susceptible to corrosion and the expected type of corrosion(s) that could occur at these locations, taking into account of the materials, manufacturing processes, corrosion prevention systems (such as coatings and sealants), Preventive Maintenance approaches (wash cycles, wash fluids), the ability to inspect the location, the component fabrication techniques as well as the expected operating environments to which the Air System or components are subjected.

22. Other factors that may have an impact on the EDPC Programme are environmental law changes (eg REACH), material or product form substitutions during sustainment and process changes. For further details, refer to Chapter 7.

CC programme

23. The configuration of an Air System at the point of delivery[27] can be expected to vary from the design baseline due to differing build standards and build concessions[28]. Furthermore, the configuration of In-Service Air Systems is likely to deviate from the as-built configuration over time due to damage, repairs, Type Design changes and SI(T)s[39]. Adding to the complexity of the issue,

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[39] Refer to RA 5405 – Special Instructions (Technical).

there is the interchangeability of lifed items between Air Systems.

24. The deviations may affect the dimension of a component, mass or C of G of an Air System[33], or the Structural layout or Structural stiffness that may lead to a change in the load distribution. These changes may have an impact on the static strength, fatigue or damage tolerance clearances; affecting repair, Type Design change and life extension downstream.

25. The threat to the Air System Integrity is the lack of CC and the counter to this threat is to have a CC system that tracks the configuration of each Air System (Structures, inter-system, intra-system) in the fleet, thereby allowing an informed decision-making on Integrity and Airworthiness issues. The CC system, with the objective of allowing a fleet-wide assessment of the Air System health, could be in form of a database; covering design and as-built configuration, and In-Service data such as concessions, repairs, Type Design changes, AD / ED damage; and will be updated through-life. For legacy Air Systems, it may be necessary to carry out a CS on the whole fleet to establish a baseline.

26. The key elements of a CC System are:

a. Air System Design configuration, build concessions and as-built configuration, including mass and C of G.

b. Component, configuration and associated extent of damage (such as AD and ED) before repair.

c. Component and configuration post repair (eg dimensions post repair).

d. Repairs, including Topic 6 / Structural Repair Manual.

e. Monitored damage within authorized limits.

f. Type Design changes - DO-produced or Service-produced.

27. For safe and effective operation of Air Systems, the mass and C of G will remain within the limits specified in the RTS. The consequences of operating outside the RTS limits may range from an increase in fatigue life consumption that will have an impact on SI, to loss of control and stability that may result in the loss of the Air System. If mass and C of G are changed as a result of Type Design change or operating roles, then the DO will be engaged to assess the impact. Regulation and guidance on Air System mass and C of G can be found in RA 5212[33].

28. Ensuring that equipment changes are approved correctly, resourced through procurement and reflected in the ADS, are fundamental to retaining Air System CC. This requires processes that are appropriate to the task, robust, auditable and understood by all users. If CC is lost, or it is in doubt, immediate actions are to be established and documented as part of the Configuration Control Plan. This enables the appropriate actions, whether the issuance of a Technical Instruction or other investigative or mitigation action, to be initiated appropriately.

Inspection programme

29. The objective of an Inspection programme is to find and correct any deterioration of items critical to, or of significance to, the Integrity of an Air System; and to collect information on the ageing characteristics of less critical or significant items by inspection of a sample of the fleet. It will be viewed as a through-life integrated programme where the level of effort increases as the Air System ages.

30. Critical or significant items are regions within the Air System that require Preventive Maintenance as part of a Reliability Centred Maintenance (RCM) program or Maintenance Steering Group 3 (MSG-3) logic to guard against the failure of these items. As a result, all critical or significant items are subject to detailed inspections that could range from visual to some form of testing.

31. Implicit in damage tolerant designs are inspection requirements intended to ensure damage never reaches the sizes which cause catastrophic failures, hence all critical or significant items are to be inspectable and will be part of the routine inspection regime, through flight servicing and

schedule Maintenance procedures, that are part of the EP.

32. For safe life designs including lifed items, though there are no direct inspection requirements, critical and significant items will also be inspected to find and correct any deterioration that could prevent attainment of the safe life limit. The initial inspection intervals for safe-life items are generally set at conservative values aligned to the reliability assessment of ED and AD; and could be changed on the basis of In-Service findings once the Air System enters service. As a result, all critical or significant items are subject to detailed inspection[40] within the routine inspection regime, through flight servicing and schedule Maintenance procedures that are part of the EP.

33. For ►component parts and structure◄ where the impact on residual strength or susceptibility to deterioration is small, a sampling inspection is used to determine the age characteristics of the fleet, with full knowledge that individual uninspected Air Systems may require extensive repairs by the time the sample inspections identify a problem area. Bearing in mind that the issue is not Integrity, but the relative cost of repairs, the risk of occasional high repair costs is acceptable if the result is a marked reduction in inspection costs. This exposure to Risk would not be acceptable to ►SSIs / CPs / FSIs◄ where failure would have a marked effect on residual strength. In practice, sample inspections are performed on fleet leaders and when a defect is discovered ►within the fleet◄, its incidence on the lower-age Air System ►is expected to◄ be much less. The identification of these ►SSIs / CPs / FSIs◄ and the sampling inspections are part of the Sampling Programme (SP).

34. A review of the EP will determine the requirement of a SP, which can be considered during; Preventive Maintenance, emergent opportunities, directed out-of-phase inspections, controlled disassembly, forensic investigation and analysis, and Post-crash recovery. The SP may involve repetition of previous tests and strip examination of selected items after a predetermined period of In-Service use. The SP will be agreed with the TAA or Commodity DT CE.

35. Appropriate contractual arrangements will be made compatible with the reason for the SP being carried out. For example, in the case of a SP arranged in connection with materiel which does not meet specification reliability requirements, it may be appropriate for the relevant Contractor to bear the costs of additional work arising from the test procedure, eg rig testing, strip examination and preparation of test reports. Similar considerations will apply to the cost of repair work (where necessary), re-assembly and normal testing of materiel on conclusion of strip examination, reporting etc.

36. In-Service Teardown supports the SP on occasions where items are inaccessible. It is a progressive, detailed, controlled and destructive inspection of a component and involves the teardown of whole or selected parts of an Air System or teardown of removable components or sub-assemblies, carried out on an opportunity basis. For further details on Teardown, refer to the MASAAG Paper 105[41]. For Propulsion Systems, the engine overhaul satisfies the teardown requirement where the engine is disassembled for inspection and component replacement (lifed items and on-condition items).

37. The inspection programme (refer to Figure 7) is planned so that by the time the fleet leader reaches 80% of its original design life, or revised life if less, ►all component parts and structure identified as SSIs / CPs / FSIs◄ have been examined either through Preventive Maintenance or ►SP◄. Where it is not possible to examine all parts of all SSIs / ►FSIs◄, alternative approaches can be explored in conjunction with the DO to assess the condition of the SSIs / ►FSIs◄. For example, if it is physically impossible to access and inspect an SSI / ►FSIs◄, the DO may be tasked to assess the Risk associated with not being able to carry out the inspection and propose alternative analysis or mitigations.

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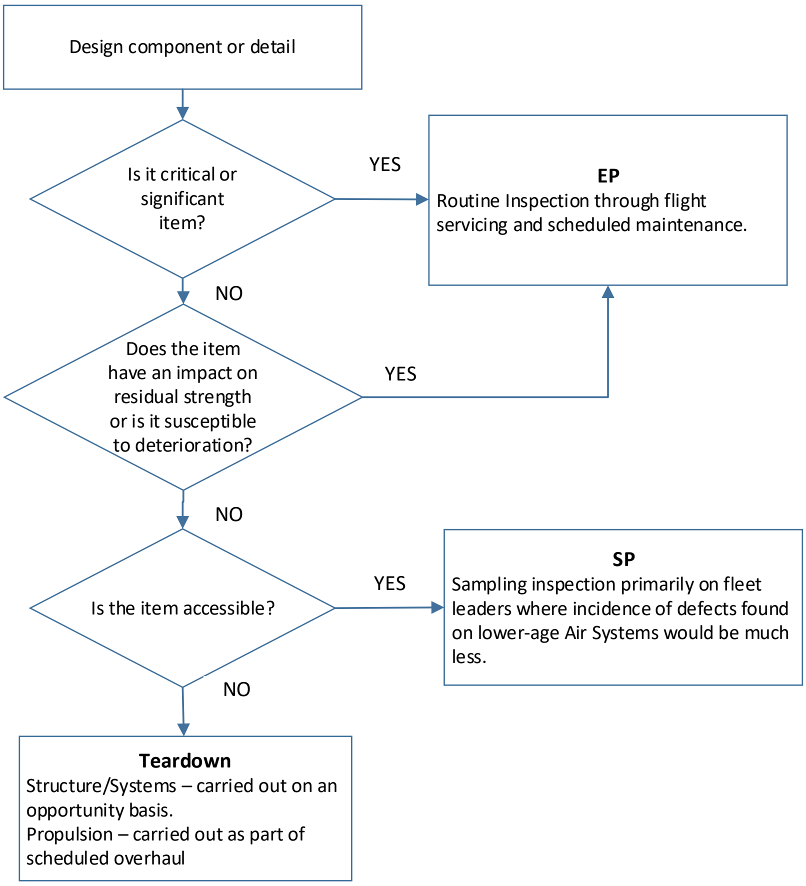
[40] Detailed inspection includes visual and Non-Destructive Testing methods.

[41] Refer to MASAAG Paper 105 Teardown Inspections – Guidance and Best Practice.

Figure 7 - The Inspection Programme



38. A Maintenance Schedule is typically derived using RCM analysis to avoid or reduce the consequence of failure or degradation for an Air System type or mark, covering any associated equipment that requires Preventive Maintenance[20, 42]. The Maintenance Schedule is then maintained and updated through Maintenance Schedule Review (MSR), throughout the life of the Air System / Equipment. It is noteworthy that RCM analysis is not for extension justifications, as the application of RCM analysis through-life may result in a reduced or more extensive Preventive Maintenance requirement.

39. MSR may vary scheduled Maintenance activity and frequency in response to In-Service arisings and any subsequent repairs / modifications; changes in operating intent, fleet disposition, usage and operating environment; results from sampling, teardown and ageing Air System activities; and their subsequent impact on critical or significant items (CPs, SSIs, FSIs) and their inspection regime. The conduct and frequency of the MSR will be detailed in the AISD.

Exceedance Monitoring System

40. An exceedance monitoring system is essential in detecting overload, thereby allowing Recovering actions to take place at the earliest opportunity. Many of the on-board systems for health and usage monitoring can be exploited to provide alerts when an exceedance has taken place. For Air Systems without exceedance monitoring the detection of events which may have resulted in an overload is based upon Aircrew reporting post-flight. Experience has shown that such reporting is not reliable, particularly in cases where the contributing factors are not immediately obvious from the cockpit. For this reason, Air Systems with an onboard health monitoring system will also include an exceedance monitoring capability.

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[42] Refer to JAP(D) 100C-22 Guide to developing and sustaining preventive Maintenance programmes.

FRACAS / DRACAS

41. FRACAS or DRACAS are systems that provide a process for the reporting, classification and analysis of Incidents, Faults or failures; and planning respective corrective actions. The fundamental tasks are outlined below:

 a. Recording and capturing information about failures and problems.

 b. Identifying, selecting and prioritizing failures and problems.

 c. Identifying, implementing and verifying corrective actions to prevent recurrence of failures.

 d. Providing information from failure analysis and corrective actions to support reliability data analysis.

 e. Providing report summaries of incident counts and providing data for reliability and quality metrics.

42. When exploited, data can be used to validate design assumptions. Therefore, the systems are used to capture all Incidents, Faults and failures, including evident and hidden failures.

43. The type of damage or failure can be grouped into evident, suspected or hidden, degradation of performance and / or accuracy or loss of CC.

44. Evident damage or failure to a system can become apparent:

 a. Visually.

 b. Through investigative activities.

 c. Through reduced performance or function.

 d. From Built-in Test Equipment indications.

 e. From other failure indicators.

45. This type of damage or failure can be readily assessed. Although damage may be evident on an individual Air System, it may be necessary to assess whether such occurrences have fleetwide implications.

46. A hidden failure is a failure not evident to the crew or operator during the performance of normal duties. However, most of these failures can be detected during inspections or tests performed by Maintenance personnel. Although hidden failures may be detected on an individual Air System, it may be necessary to assess whether such occurrences have fleet-wide implications. Many systems have more than one function; consequently, there can be one or more hidden failures that could lead to a loss of confidence in SysI. Hidden system failures fall into 2 categories:

 a. Failure of a system that is normally active but gives no indication to the operating crew if it ceases.

 b. Failure of a system that is normally inactive so that the crew cannot know whether it will be available when it is needed.

47. An evaluation of a hidden failure on a single Air System will be undertaken as it may indicate potential for similar failures on, or likely to be sustained by, other Air Systems. The investigation into, and recovery of, a significant hidden failure will be monitored by the IWG. The TAA will ensure that the DO brings to their attention any potential hidden failure information that can be read across from other operators of a similar system or Air System type. Hidden failures will be assessed and recovered using procedures in the ADS or schemes provided by the Air System Repair Organizations or the DO. If a system exhibits persistent, recurring hidden failures, it may be necessary to review Maintenance schedules operating procedures, or consider Type Design change action in order to recover SysI.

48. Over time a system’s operating performance and / or accuracy may degrade and may exceed its specified tolerances and / or operating parameters. Trend analysis may allow prediction

of when any tolerance or parameter will be exceeded.

49. Degradation may be unnoticeable by the operator and only become apparent during Maintenance, testing, or via information provided by a third party. Any discernible trend towards decreasing performance or accuracy will be investigated and recovery action taken.

50. Data degradation may occur, altering potentially key items to incorrect values. The cause of data decay is dependent on the storage equipment: electrical charges may vary where insulation fails, device may suffer wear, or storage may suffer data corruption. Consideration will be given to how the data is managed, review periods, and error correction.

Maintenance data reporting

51. Maintenance data reporting is achieved through the Engineering and Asset Management System where In-Service repair and Maintenance data are logged and are accessible for trending and analysis. Legacy systems include GOLDesp for RW and Logistics Information Technology Strategy (LITS) for FW, as well as manual recording using MOD Form 700s[43].

52. The TAA will establish and maintain a standard for periodic and ad hoc reporting from the Forward and Depth domains, to include the frequency, content and data presentation.

AAA

53. During the life of an Air System, cumulative exposure to the threats to Integrity, and the Risk of them interacting, increase with time and usage. Additionally, calendar-based ageing mechanisms (such as the effects of environmental ageing and degradation) can compromize Integrity. However, these ageing effects are not always comprehensively recognized or addressed by routine Maintenance activities.

54. Additionally, over time there may be loss of corporate knowledge, loss of CC, changes in assumed usage, evolution of regulatory requirements and the accumulated effects of several otherwise minor Integrity problems. Therefore, Ageing Air System aspects are to be considered a continuous through life programme[44] with consideration given to ageing within the IM Strategy. The AAA is an IM Validating activity that can be subdivided into Audits covering Structure, systems and Propulsion System. Further details are covered in Chapter 10.

Hazard Assessment

55. Effective hazard management is key to understanding, and communicating to the ADH, the equipment contribution to RtL[6]. However, the various systems, structure and software within an Air System exhibit various failure mechanisms, some probabilistic (ie can be supported by a likelihood assessment) and some deterministic (ie they will occur unless mitigated). Consequently, understanding how the IM of the Air System interacts with these failure modes is fundamental to understanding the resultant equipment contribution to RtL.

56. **Probabilistic**. Components within an Air System's mechanical and electrical system will generally have a qualified level of reliability, or Mean Time Between Failure (MTBF), based on data gained through thousands of hours of operation of those, or similar, components. As a result, it is relatively straight-forward, through tools such as Fault Tree Analysis, to determine the overall probability that a failure will result in a Hazard and how that Hazard then affects the equipment contribution to RtL. This can then be readily expressed to the ADH in terms of a Hazard Risk Matrix category, thereby allowing the ADH to compare multiple equipment risks in order to prioritise mitigation action. Mitigation can then be **established** at the design stage through either the duplication of essential systems or a scheduled Maintenance policy that replaces key components before failure. Similarly, once in Service, emergent reliability issues can be **recovered** through revised Maintenance intervals or a type design change (modification) to replace the component with a more reliable alternative.

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[43] Refer to RA 1223 – Airworthiness Information Management.

[44] Refer to AAPWG Paper 010 – A Framework for Ageing Aircraft Audits (AAA).

57. **Deterministic**. Unlike mechanical and electrical components that can rely upon a probabilistic approach to safety, aerospace structure relies upon a deterministic approach that is **established** (designed in) from the outset. This is achieved through compliance with Certification requirements that ensure structural safety by combining safety factors with tests of material and structural components. The use of these safety factors, combined with conservative material properties and fatigue and damage tolerance calculations, ensures that a high level of safety is designed into the Aircraft from the outset. Static and fatigue tests are then performed on the full structure to verify that it will not catastrophically fail under ultimate load and will endure for a specified amount of time under repeated or cyclical loading. Thus, the attained level of safety is predicated on the fact that the structure is operated within the design assumptions; therefore, this includes events outside of design assumptions (such as an overload) but also situations where the structure can no longer perform as intended (such as corrosion, cracking etc).

58. When IM **validation** activity has shown that SI has been compromized, it is often difficult to express the resultant equipment contribution to RtL to the ADH for several reasons. Firstly, the threats to SI, such as ED (ie corrosion), are often progressive in nature and therefore do not lend themselves readily to being assigned a risk likelihood figure. Secondly, the outcome of a failure is often difficult to determine for many structural components; this is especially so where it is important to assess outcomes less than the total loss of an Aircraft in order to express the resultant RtL more accurately to the ADH. Thus, the effective use of the DT's independent advisors[45] will be pivotal to the TAA's ability to accurately convey this complex, non-linear Hazard to the ADH to enable them to subsequently understand the resultant RtL.

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[45] Specifically, the ISAA will provide the necessary SQEP to be able to accurately express compromise of SI in terms that the ISA will subsequently be able to assist the TAA express in terms of hazard and likely resultant RtL.

Chapter 4: Structural Integrity Management

Integrity Evidence / Baseline artefacts

1. Air Systems accepted into UK military Service would have been designed to a certification standard, such as Def Stan 00-970, international military or civil standards. Notwithstanding the vast evidence required for Certification and qualification of an Air System Structure, the minimum evidence required to sustain the management of the Air System Structure throughout its service life is to include, but not be limited to, the following:

   a. The Structural design criteria adopted for the Certification basis, as appropriate to the intended operation, including shortfalls in the level of assurance.

   b. The Structural verification and validation programme and the corresponding assumptions.

   c. The Configuration baseline.

   d. Structural Hazards identified in the Equipment Contribution Log and as part of the TASA.

   e. Results of Air System physical inspections (ie CSs).

   f. Existing failure and reliability data.

   g. Obsolescence analysis and reports.

Static and Fatigue Type Records

2. **Static Type Record (STR).** Static qualification evidence is usually found in the form of a STR or an equivalent document. Whether an Air System Type is procured iaw the 5000 series RAs or some alternative acquisition management standard or procurement model, a Type Record or equivalent is the ideal vehicle for the collation and summary of static strength evidence.

3. A STR or equivalent comprises a general arrangement and description of the Air System, a summary of static design assumptions and criteria for a given Air System configuration, a summary of critical loading, shear force, bending moment, torque and mass distributions, and a summary of static reserve factors. The static evidence contains all the relevant supporting stress and test reports, and calculation files. For recent designs, evidence generated using simulation[46] or Global (Air System level) Finite Element Models (FEMs)[47] will need to have the models identified to an Air System configuration, with any discrepancies in configuration at production well documented; and will be maintained through life in the same manner as the static evidence document. Typically, these models are only updated when there is a significant configuration change such that there is an impact at the global level. Evidence generated at component level, such as a local FEM, will be identified to an Air System part number and maintained through life. The scope of the static evidence document, in terms of the Structural components involved, will include all SSI and CP.

4. **Fatigue Type Record (FTR).** Fatigue qualification evidence is usually in the form of a FTR or an equivalent document. Notwithstanding how an Air System Type has been procured, an FTR or equivalent is the ideal vehicle for the collation and summary of fatigue qualification evidence to support the ADH in Safety Assessment for RTS and in sustaining SI.

5. An FTR, or equivalent, will comprise of 4 key parts, as follows:

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[46] Such as Computational Fluid Dynamics (CFD) as a form of aerodynamics analysis.
[47] Such as loads or stress models.

a. **Part 1 - Historical Record**. The historical record will state the principles used to underpin the Air System's design life and to provide tolerance to unforeseen sources of damage. It will be based upon a survey of all existing fatigue and damage tolerance analyzes and tests used in the original design, which will be summarized for each fatigue critical component or detail in the main load paths of the airframe. Any gaps in the analysis or data will be identified. The format and content of the Historical Record part will comprise of the following Sections:

(1) **Introduction.** This will outline the general philosophy of the Structural design and the likely tolerance of the Structure to unforeseen sources of damage, such as those arising from increased loads, AD and hostile environments. The principal fatigue critical Structure will be illustrated by appropriate drawings showing materials used, reference to the relevant part numbers or assemblies and a cross reference to the type record. A summary will cover the basic design life requirements, the development and certification tests conducted, the life factors used and describe the fleet monitoring system proposed. Finally, the document will give appropriate references to stress office records so that the source of data summarized can readily be located.

(2) **Fatigue and damage tolerance summaries.** Each fatigue critical Structurally significant detail which has a safe life less than 1.5 the safe life requirements of the Air System TCB, will be described by an individual summary which contains the following data, as far as is reasonably practical:

(a) A sketch showing the component, its location and points which are fatigue critical;

(b) Material specification(s);

(c) Part number(s) and relevant issue;

(d) Loading data and spectrum references;

(e) Reference stress or strain at each critical point;

(f) S-N curve reference with comment on reasons for selection;

(g) Life and / or stress factor used plus any additional allowance for scatter, where necessary;

(h) Safe life; from calculations, test or operational statistics and whether inspection is detailed in paragraph A.4 below.

(3) **Inspection schedules.** If the safe life of a detail is less than the specified life and the life is being extended by periodic inspections, then the additional data needed will be included in this section, with appropriate references to paragraph A.3 above.

(a) Fracture toughness (K_{Ic} or K_c) value for the critical feature and basis of derivation;

(b) da-dN curve reference, with comments on interpretation;

(c) Stress intensity solution reference and basis of derivation;

(d) Non-Destructive Inspection(NDI) method recommended and means of access;

(e) Post inspection damage assumed and basis of derivation;

(f) Critical damage size when strength of Structure as a whole has fallen to 80% of the Design Ultimate Load (DUL);

(g) Safe inspection interval and basis of derivation;

(h) Related entry in the Air System Maintenance Schedule.

(4) **Fatigue usage monitoring.** Details will be given of any usage monitoring systems intended for the assessment of fatigue life consumption of individual Aircraft (as distinct from a sampling type Operational Load Measurement programme).

(5) **Fatigue test summaries.** A synopsis will be given of major fatigue tests, which have been conducted for both development and qualification purposes. The loading spectra will be given, with reference to their deviation. Reference to final test reports will be given.

(6) **Materials data.** The basic S-N and fracture mechanics data used in the analysis of details quoted in Sections 2 and 3 will be summarized and the data source identified. Any corrections or changes made to standard data will be clearly stated.

(7) **Loading data.** The loading spectra used in the original design and in any subsequent analysis will be clearly defined. This will include those based on fatigue meter data from Service usage, Operational Load Measurement programmes and User Requirements or Statements of Operating Intent. Each spectrum will be uniquely identified.

(8) **References.** This will list all documents and data used in the fatigue analysis.

b. **Part 2 - Reassessment of Fatigue Life**. The reassessment of fatigue life will comprise a complete reanalysis of the fatigue life of all fatigue critical Structurally significant details in the airframe. The analysis will be based upon an agreed Service user spectrum (as defined by the Air System’s SOIU) and / or additional fatigue data to be agreed with the TAA, and it will take account of any test or operational failures up to the date of the reassessment. The report will be updated as necessary to reflect changes in Service usage or design standard and will be presented in a separate volume that parallels and cross refers to the materiel in the FTR Part 1. It will stand alone as the updated situation and the FTR Part 1 will be amended to show where the FTR Part 2 has superseded it.

c. **Part 3 - Reassessment of Inspection Requirements.** This will comprise a reassessment of the NDI methods used, post-inspection flaw assumptions and inspection intervals for those features which are shown to be necessary by the reassessment of the FTR Part 2. This reassessment of NDI methods may show that development of existing or of new methods is necessary and additional fracture toughness and crack growth data or re-analysis may be required; consequently, this is presented as DO recommendations for acceptance by the TAA. The revised inspection requirements generated by this reassessment will be added to the requirements of the FTR Part 1 as amendments. The total updated inspection requirements will be stated in the FTR Part 3, and the FTR Part 1 will be amended to show where it has been superseded by the FTR Part 3.

d. **FTR Part 4 - Operation Beyond the Specified Life**. The FTR Part 4 will be prepared well into the Service life of the Air System, if or when it is agreed that the Service life will be extended[48]. If there is a basic change in the Service role of the Air System or design standard this would be covered in the FTR Part 2. Where it is necessary to extend the Air System life beyond that initially specified, the original calculations will be reviewed iaw the requirements of the Air System’s Type Certification Basis. The results of the review will be contained in an TAA-approved annex to the FTR, containing the following:

(1) An appropriate redefinition of the Air System together with revised mission profiles, utilisation and any other relevant operational data.

(2) A description of each Structurally significant detail showing likely sites and type of damage to be anticipated. Reference may be made back to the FTR Parts 1 to 3.

(3) The new inspection procedure including the method of inspection, the inspectable fault size, the inspection periods, and if appropriate, the inspection threshold[49].

(4) Any Structural rework.

(5) Any detail where Structural Integrity cannot be maintained by inspection and where life now falls within the extension period.

(6) The period for which the extension applies.

6. For multi-national or off-the-shelf designs, for both the static and fatigue evidence, it may be possible to develop a multi-national fatigue evidence document or to adapt existing evidence to fulfil the STR / FTR requirements. However, it may become necessary to develop a UK specific fatigue evidence document to reflect the UK military as-flown usage and configuration, as fatigue evidence develops and diverges from that of other operators.

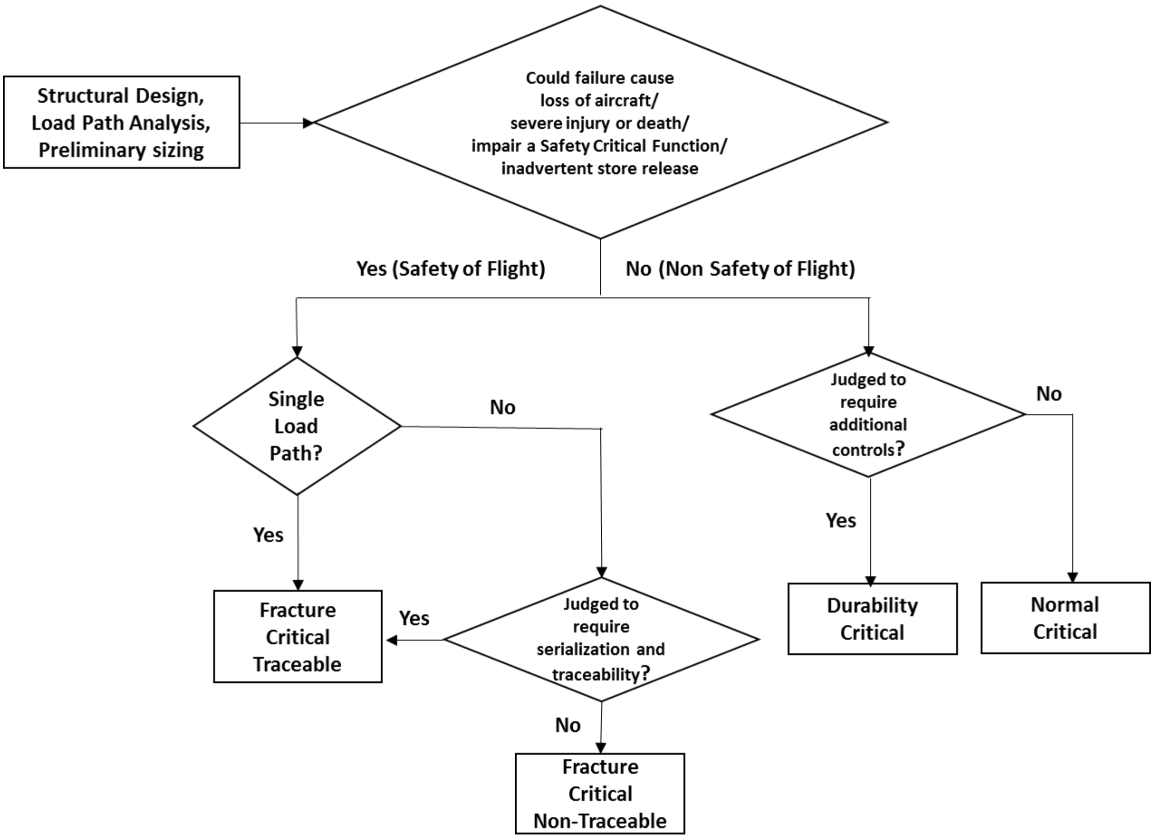
7. The requirement to establish, maintain and update Integrity Evidence through life leads to the need to ensure adequate arrangements are in place with the DO and appropriate organizations, to support and make available the evolving Integrity Evidence for the life of the Air System.

SSI and CP

8. An Air System's Structure comprises assemblies, components and elements that are classified based on their contribution to carry primary loads and the criticality of their function based on their consequence of failure and their impact on flight safety.

9. For Certification standards that mandate damage tolerance requirements (such as DoD and civil certification standards), the selection of SSI / CP follows the flow chart as shown in Figure 8.

Figure 8 - SSI / CP selection logic diagram[50] (with Damage Tolerance Requirements)



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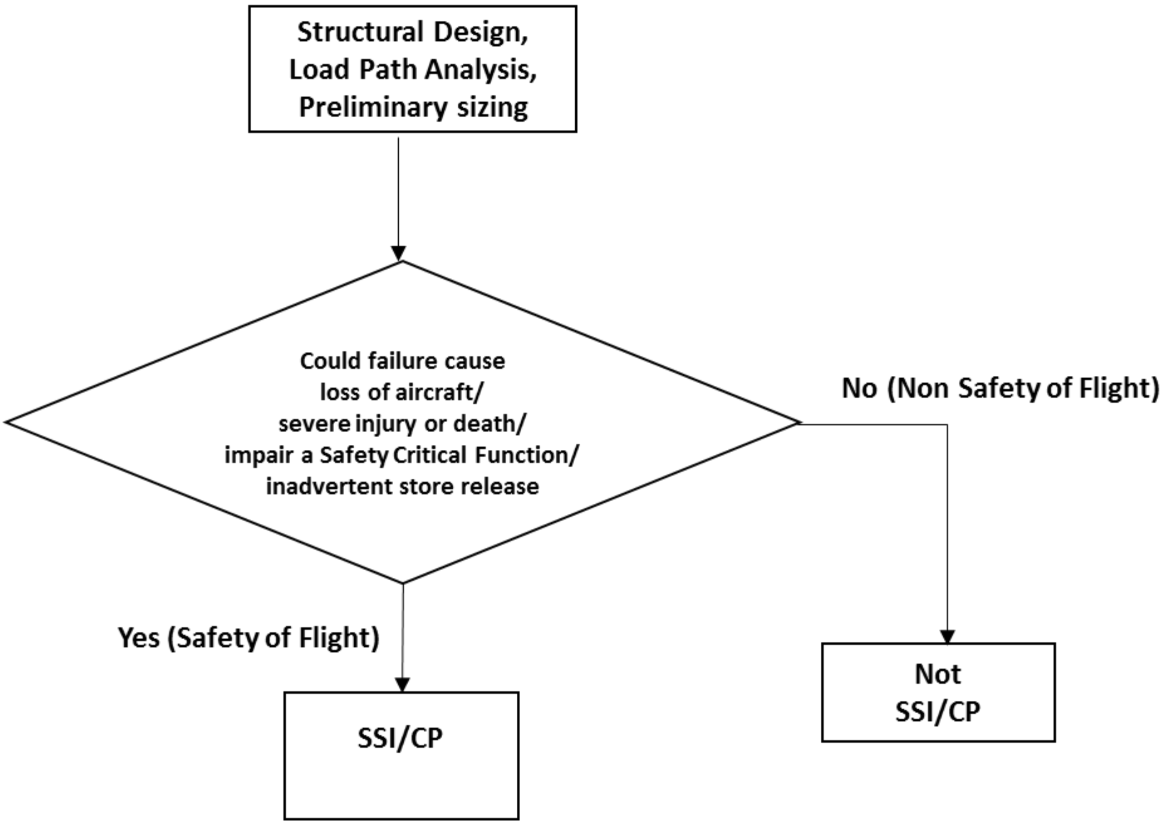
[48] Refer to Chapter 11 and also RA 5724 – Life Extension Programme.
[49] The point at which the usage of a structure is sufficiently high that the probability of a fatigue crack being present has increased to a level where inspection has become necessary.
[50] MIL-STD-1530D Aircraft Structural Integrity Program (ASIP); Department of Defense Standard Practice.

10. For Certification standards that do not mandate damage tolerance requirements (such as Def Stan 00-970), the selection of SSI/CP follows the logic diagram as shown in Figure 9.

Figure 9 - SSI / CP selection logic diagram (no Damage Tolerance Requirements)



11. Most Certification standards mandate the compilation of an SSI list or CP list as one of the TAw requirements. As a result, the SSI or CP selection process is only required after a repair or modification has been carried out. The exception is Air System Types certified to CS22[51] (Sailplanes) where there is no requirement for an SSI list, whereby the inspection programme will have to be established by the DO based on the OEM inspection regime, and to draw on In-Service findings from the civil and worldwide fleet. During the selection of SSIs / CPs, consideration is given to the susceptibility of various parts or assembly to ED and AD.

FW

12. For flight safety critical items that contribute significantly to carrying flight, ground, pressure or control loads on a FW Air System, terminologies such as SSI, Principal Structural Element, Airworthiness Limitation Item, CP, ‘Grade A’ Part or Safety of Flight (SoF) Structure have been used in various publications. Though there are slight differences in the definition of each of these terminologies, broadly they refer to Structures with critical characteristics that will be controlled through a specific inspection regime to ensure the required level of Integrity through life. For legacy and continuity reasons, this manual will refer to such Structural items as SSIs.

13. The selection of SSIs typically starts at the design stage, where Detailed Design Points with high stress concentration; components with high stresses, low fatigue lives or adverse environmental conditions; components with compromised design trade-offs etc are considered as candidates. The selection of SSIs from the candidate list is based on the SoF critical and / or Single Load Path criteria, followed by analysis and tests to establish their critical characteristic to arrive at an appropriate inspection regime. The list is subject to update following findings from Full Scale Fatigue Test and In-Service findings through-life.

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[51] EASA CS-22 Sailplanes and Powered Sailplanes.

RW

14. For RW Air Systems, the flight safety critical items include some dynamic components since the definition of Structure includes rotor blades, rotor heads and associated transmission systems. Therefore, any part, assembly or installation with critical characteristics are termed CPs or Flight Safety Parts. A critical characteristic is any feature, throughout the life cycle of the component, which if non-conforming, missing or degraded, could cause failure or malfunction of the CP; and whose failure, malfunction or absence could cause loss of or serious damage to the Air System, and / or serious injury or death to the occupants. Critical characteristics include dimension, tolerance, finish, material, assembly, manufacturing and inspection processes. This manual will refer to such Structural items as CPs[52].

15. The CPs are identified by means of an appropriate failure assessment due to the dynamic systems (rotors, drive systems and upper controls) that are very sensitive to broad spectrum repeated loads comprising manoeuvring and high vibratory loads. Under this severe loading environment, the dynamic systems may not meet the life of the fleet without replacement. As a result, a CP may be qualified as a lifed item based on Safe Life, to be removed from service before a predicted failure can occur. Given the loads are highly variable, the safe life assigned to the part will have a defined probability of failure. With more than one part in the dynamic system that may not meet the design life, the probability of failure for each component will be low enough to achieve less than one failure in the fleet life.

16. As a result, components on RW first go through a failure analysis by which CPs and all hazardous and catastrophic failure modes are identified, this is followed by summarizing all the identified failures and appropriately substantiate the compensating provisions (such as analysis or adding redundancy as a design feature) used to minimize the likelihood of occurrence.

Assessing SSI / CP characteristics

17. The characteristics of SSIs or CPs are assessed in terms of their sensitivity and vulnerability to threats. Consequently, the characterisation of SSIs is dependent on the use of Safe Life or Damage Tolerant design philosophy and in turn, a Fatigue assessment and / or a Durability and Damage Tolerance (DaDT) assessment. The outcome from a fatigue assessment is primarily the safe life of the component while the outcomes from a DaDT assessment are the inspection threshold and inspection interval for a given inspection method.

18. For CPs, a Fatigue Tolerance assessment is used to develop safe lives and damage tolerant features; as some CPs may be susceptible to inherent flaws, or some dynamic components may have several fatigue failure modes due to the broad spectrum of loading or may be sensitive to high frequency vibratory loads leading to unrealistic inspection requirements such as sophisticated inspection methods at frequent intervals.

19. Safe Life (Stress Life or Strain Life) is a design philosophy that establishes a finite service life within which the probability of fatigue cracks developing and compromising the residual strength is acceptably low. Safe Life SSIs / CPs are Structural items designed to have a fatigue life that can meet the target Design Life of the Air System type, or those that cannot satisfy the Damage Tolerant requirements.

20. Damage Tolerance (Fail Safe[53] / Damage Tolerant) is a design philosophy that allows the Structure to retain the required residual strength for a period of use after the Structure has sustained specific levels of detectable damage caused by fatigue, AD, ED or discrete source damage. Airworthiness of a Damage Tolerant Structure is therefore assured by an inspection regime and as such all SSIs / CPs will be inspectable. Damage Tolerant SSIs / CPs are often subject to fatigue and / or durability assessments to ensure that reasonable economic life and inspection threshold can be achieved.

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[52] iaw Def Stan 00-970 Part 7.

[53] The definition is also applicable to Systems and Propulsion System disciplines, where redundancies are in place to retain the required function and capability in the event of a component failure.

21. Both Safe Life and Damage Tolerance are qualified by test and analysis; with SSIs / CPs subject to an analysis of their vulnerability to AD and ED during development of a Preventive Maintenance programme.

Maintenance Schedule

22. In parallel with the above characterisation, each SSI / CP is also assessed for its vulnerability and susceptibility to AD / ED as part of the Maintenance Schedule development process. However, typical Maintenance Schedule development processes, such as RCM or MSG-3, commonly only deal with AD or ED mechanisms acting independently. It is therefore necessary to consider the vulnerability and susceptibility of each SSI / CP to the interaction of AD and ED (eg the onset of corrosion following a breach of corrosion protecting coating caused by an impact damage) and to the interaction of AD and ED with fatigue or static loading (eg stress-corrosion cracking or corrosion-accelerated fatigue), even though this may not be accounted for by the RCM / MSG-3 process. The result of the assessment of vulnerability and susceptibility to AD / ED will designate each item as either At Risk (AR) or Not at Risk (NAR) of AD / ED. For further details, refer to Chapter 7.

23. All SSIs / CPs, both AR and NAR, are to be included in the Master Maintenance Schedule (MMS) to ensure they are examined at a suitable frequency to detect threats before it becomes a Hazard to SI.

24. The results of the Maintenance Schedule development process, and subsequently any updates from the review process, are promulgated in a Topic 5V (Sampling Requirements and Procedures) or equivalent, which lists all SSIs / CPs (both AR and NAR) and states the inspection method and corresponding process. The list of SSIs / CPs is supported by use of diagrams, drawings or photographs as appropriate. The Topic 5V also specifies the method for recording the results of each inspection; and the information, in form of positive or negative reporting, will feedback to the TAA to ensure SI[7] is maintained.

Annex A – SI Case Studies

A1 Grob Tutor Propeller Fatigue Failure

A1.1 **Background**. On 29 Jun 04, Grob G115E Tutor, G-BYXJ, was completing an aerobatic manoeuvre when one of the propeller blades separated from the hub. Despite severe vibration, the pilot was able to shut down the engine quickly and perform a successful forced landing in a field. On further inspection it was evident that the No 1 propeller blade had detached due to a fracture of the blade socket of the aluminium alloy hub. The fracture originated in the threads inside the blade socked and allowed the outer part of the blade socket and the blade retaining nut to separate from the hub, thus releasing the propeller blade. Figure 10 shows the damage sustained.

Figure 10 - Propeller hub showing fractured No 1 blade socket

A1.2 **Establishing SI:** The manufacturer conducted successful vibration testing on the propeller blade however no Aircraft-level vibration testing was conducted on the propeller, engine, airframe combination as it was deemed unnecessary due to previous testing on the Grob 115D variant. The design of the blade retaining collar (or nut, as the Air Accident Investigation Branch (AAIB) report calls it) had an established torque value of 30-40 Nm to sufficiently preload the threads to avoid relative movement, fretting and wear, and to decrease the effects of high cycle fatigue. The inspection regime for the propeller was established and consisted of a daily inspection during each Check 'A' and a ‘50 Hour' inspection. The Check 'A' inspection requirements include an inspection of the propeller and spinner for damage. This includes a check for blade tip play. The manufacturer's specified overhaul life of the propeller is 1,600 flying hours or 7 years, whichever occurs soonest. During overhaul, the hub is NDT inspected using liquid penetrant dye.

A1.3 **Sustaining SI:** Notably, despite observing and documenting low blade retaining nut torque values at overhaul, some being as low as 8 Nm rather than the 30-40 Nm specified, this issue was not addressed prior to the Accident.

A1.4 **Validating SI:** In February 2004, just months before the Accident, design usage and assumptions for the propeller were reviewed and recommendations were made to reduce the maximum propeller speed. The DO issued Service Letter No SIL115-50 recommending that the engine is to be operated at 2,400 RPM or below whenever possible; the high vibration levels found to be present above 2,400 RPM having a detrimental effect on engine ancillary components.

A1.5 **Recovering SI:** Prior to the Accident, opportunities were missed to recover SI by recognizing the inadequacy of penetrant dye NDT on threaded assemblies (the liquid pools in threads and cracks can easily be missed), leading to potentially cracked hub assemblies leaving overhaul erroneously declared ‘serviceable’. The incident propeller had only 249 hrs since overhaul. Likewise, despite observation of inadequate torque on the blade retaining nut at overhaul, the opportunity to address this was missed, even when combined with above normal removal rates for blade tip movement on inspections. Post G-BYXJ Accident, all propeller hubs were inspected with eddy current and a total of 26 hubs were rejected for cracks. Further the torque specification for the blade retaining nut was increased to 70 Nm to allow for the well documented reduction in torque as components bedded in.

A1.6 **Exploiting SI**: Data from other operators may be exploited to support SI activities, provided usage and configuration are the same or deemed to be more conservative. In the case G115E, Aircraft-level vibration was not surveyed as the manufacturer leveraged the survey previously conducted on the Grob G115D variant, which has the same engine as the G115E and a Hoffmann three-bladed constant speed propeller, which is similar to the propeller of the G115E. Both shared the same hub, but the propeller blades differed in aerofoil design and span. A natural frequency analysis performed on both propeller blades showed the resonant frequencies to be largely the same. The vibration survey on the G115D and the comparable blade natural frequency analysis results were used to demonstrate compliance with the design requirements on the G115E, thus precluding the need for separate tests. One notable difference between the 2 designs was that the G115D has a glass fibre reinforced plastic airframe, whereas the G115E airframe is constructed of carbon fibre. Thus, it was concluded that the exploitation of the G115D variant vibration survey was inappropriate. The AAIB recommended a vibration analysis be conducted on the engine / airframe combination of the Grob G115E, in order to establish the vibration characteristics of the propeller and the resultant stresses in the propeller blades and hub.

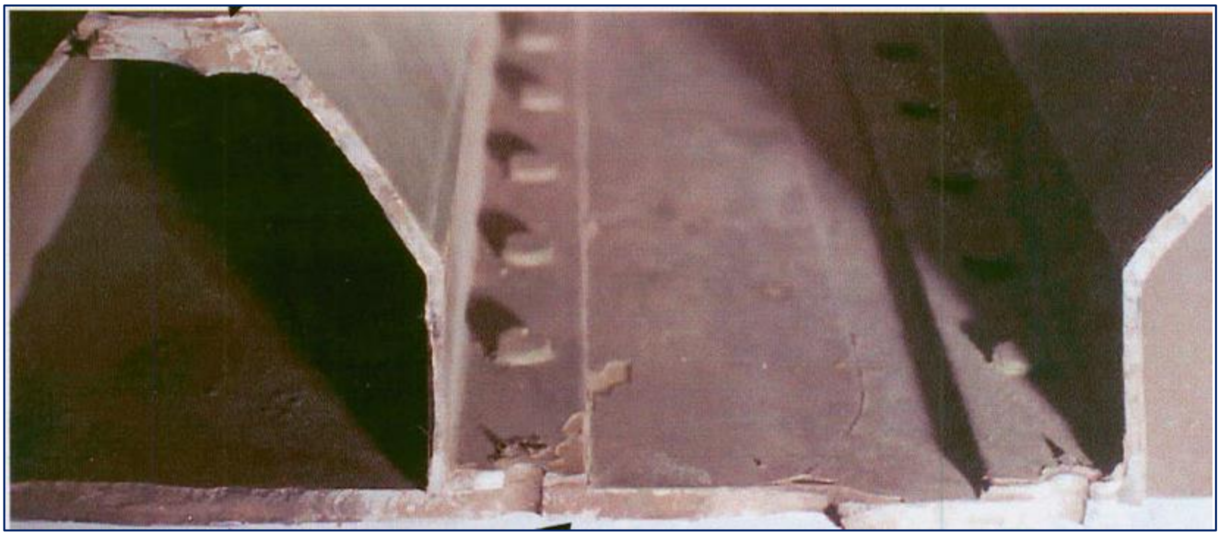
A2 Lockheed C-130A Hercules Centre Wing Failure

A2.1 **Background.** N130HP was a military surplus C-130A, delivered to the United States Air Force (USAF) in Dec 57 as a Lockheed Aircraft Corporation C-130A Hercules, Air Force serial number 56-0538. On 17 Jun 02, when being operated by Hawkins & Powers Aviation, the Aircraft broke apart in flight while executing a fire-retardant delivery near Walker, California; Figure 11 refers. The whole event from initial break up to ground impact took just 4 seconds killing all 3 crew.

Figure 11 - Lockheed C-130A Hercules N130HP Centre Wing Failure

A2.2 Subsequent examination of the wreckage and the right wing disclosed evidence of fatigue cracks in the right wings lower surface skin panel, with origins beneath the forward doubler at Centre Wing Station 53R at the stringers 16 and 17 location. The origin points were determined to be in rivet holes, which joined an external doubler and the internal stringers to the lower skin panel. These cracks, which grew together to about a 12-inch length, were found to have propagated past the area where they would have been covered by the doubler and into the stringers beneath the doubler and across the lap joint between the middle skin panel and the forward skin panel; Figure 12 shows the area of cracking.

Figure 12 - Centre Wing Failure



A2.3 Metallurgical examination of the centre wing box lower skin revealed a 12-inch long fatigue crack on the lower surface of the right wing beneath the forward doubler, with two separate fatigue crack initiation sites at stringer attachment rivet holes (which join the external doubler and the internal stringers to the lower skin panel). The cracks from both initiation sites eventually linked up to create a single crack. The portion of the wing skin containing the fatigue crack was covered by a manufacturer-installed doubler, which would have hidden the crack from view and, therefore, prevented detection of the crack from a visual inspection of the exterior of the airplane.

A2.4 **Probable cause and findings**. The National Transportation Safety Board determined that the probable cause(s) of this Accident to be:

A2.4.1 **Failure.** That an inflight Structural failure occurred at the wing-to-fuselage attach point, with the right wing failing just before the left failure of the right wing due to fatigue cracking in the centre wing lower skin and underlying Structural members.

A2.4.2 **Fatigue.** A factor contributing to the Accident was inadequate maintenance procedures to detect fatigue cracking and WFD.

A2.4.3 **Inspections.** The centre wing inspection programmes that were being performed by the operator were based on inspectionstaken from various USAF C130A Technical Orders produced in the late 1980s.

A2.4.4 **Actual vs Design usage.** Review of these programs revealed that they were based on the original design intent and military mission profile, and that no CAw program had been established to determine if the current inspection and Maintenance programs were appropriate and effective considering the increased age of the Air System and the new low-level firefighting mission.

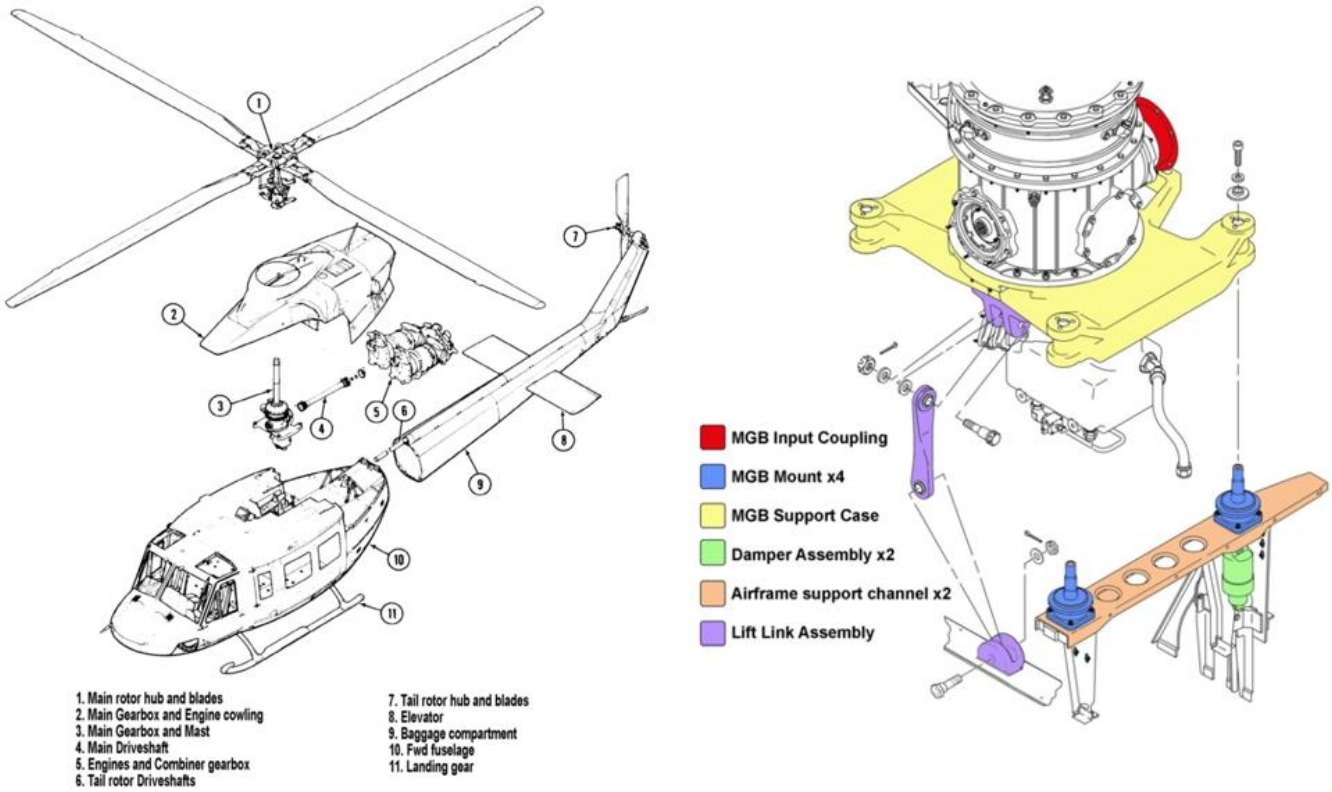
A3 Bell 412 Griffin Main Gearbox Support Bracket Failure

A3.1 **Background.** ZJ241, a Griffin from 202(R) Sqn, departed RAF Valley on 9 Aug 16 for a composite mission involving crew training and collection of a passenger from the peak of a local mountain. Following a sloping ground landing on the hilltop, some abnormal ‘Tapping’ noises and associated severe vertical vibration were experienced. The Crewman Instructor called to abort the landing due to suspect ground resonance, but the helicopter commander deemed that safe flight was no longer possible and elected to land. During the landing a fragment of driveshaft coupling was ejected, landing at the feet of the waiting passenger. The engines were shut down and first signs of a fire identified, at which point all crew successfully abandoned the rotorcraft, from which the fire quickly engulfed the wreckage.

Figure 13 - Griffin ZJ241

A3.2 **Probable cause.** The main cause of the Accident is suspected to have been an excessive sloped landing that lead to misalignment of the gearbox (due to fatigue in the support case - yellow component in Figure 14). This resulted in misalignment of the gearbox / driveshaft coupling and its subsequent ‘locking’ that failed catastrophically ‘in the manner of an explosion’.

Figure 14 - Griffin 412 Main Rotor Gearbox assembly (Ident 3)



A3.3 **IM.** Whilst IM was applied 'in principle' to the MOD's Griffin fleet, significant omissions were identified by the Service Inquiry (SI) as contributory factors. The key IM thread throughout the sequence of events is the TAA's lack of clear understanding, and communication to the DO, of the Air System's usage.

A3.4 **IM activities undertaken:** The Air System's Airworthiness strategy clearly included the ESVRE approach to IM. The TAA / DT relied on civil equivalents for usage comparison. The DO (Bell) requirement for basic usage recording. MDRE in 2005

A3.5 **IM activities NOT undertaken**: No Griffin specific SI Strategy; SOI not correctly aligned to usage, not validated correctly and then not maintained through regular review; no Independent Structural Airworthiness Advisor overview; regular review of fatigue limiting factors; AAA 8 years overdue. Usage management across the fleet not undertaken - specific tails for specific SPCs.

A3.6 **IM factors affecting accident**: TAA assumption (and action) based on civil is good enough; deferral verging on abdication of responsibility to civil organization. No limitations placed on fatigue limiting sloping-ground landings; DT did not monitor usage to ensure remained within DUS and fatigue limits. Assumption that ac were operated within the DO DUS and were not 'old' so comparison with other (mainly civil) fleets was OK. DO engagement with SOIU review was not properly contracted and scope of DO activity did not pick up usage disparity.

A3.7 **Conclusions.** Reliance on civil regulations does not ensure compliance with military regulations. These are there to account for differences in military operation and are more proactively focused on usage than reactive civil CAw requirements. Exploitation of / reliance on other users more extensive usage is not necessarily applicable - DO understanding of specific mil usage is required (Triennial SOIU review is key). You can only Exploit others experience if you know their usage is relevant to yours - it is essential to understand your own usage.

Chapter 5: Systems Integrity Management

Integrity Evidence / Baseline artefacts

1. The minimum evidence required to sustain the management of systems throughout the service life of an Air System will include, but not be limited to, the following:

   a. System design data.

   b. Component criticality analysis.

   c. Zonal safety analysis.

   d. Zonal Hazard Analysis (ZHA).

   e. Functional hazard analysis.

   f. RCM analysis.

   g. FSI analysis.

   h. System safety assessments.

   i. Results of Air System physical and Husbandry inspections.

   j. Functional surveys.

   k. Failure and reliability data from design and verification tests.

   l. Obsolescence analysis and reports.

2. The Integrity Baseline will include, but not be limited to, the following:

   a. Life Declaration for major components.

   b. Failure Modes Effects and Criticality Analysis (FMECA).

3. Systems are designed using failsafe design techniques. FSI are identified during design and where Preventive Maintenance[20] is appropriate, FSIs are included in the Maintenance Schedule using MSG-3 logic. FSIs with a critical failure mode are to be identified to the TAA by the DO as critical components and they will become candidates for lifing.

4. When an Air System or system is designed, reliability predictions for the components of the as-designed system are assumed; collectively the reliability of each part would form a system-level probability of failure. For catastrophic Hazards, this will meet the technical system safety target.

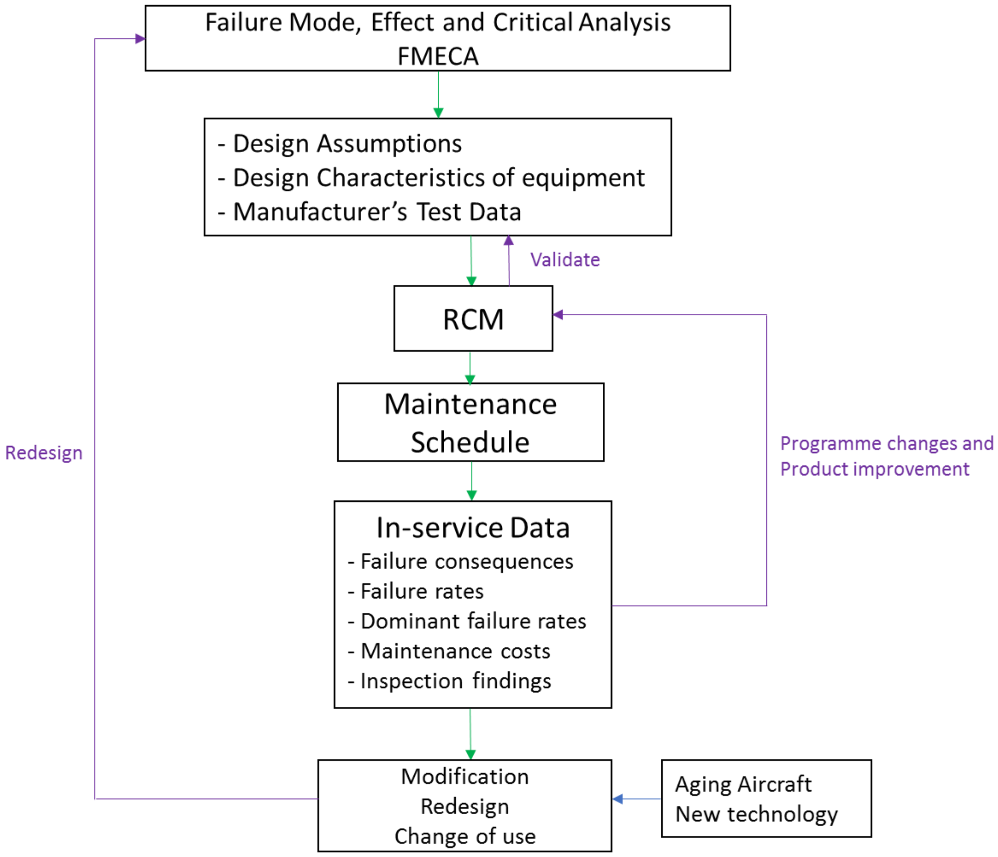
5. These failure probabilities are design assumptions that, depending on their method of calculation, may be inaccurate. Analysis of failure data is required to validate these design assumptions and is dependent on the availability of the original design information. Data exploitation, including fault trending and analysis as part of a wider FRACAS programme, is essential to validate design assumptions against undue frequency of failure.

6. All systems are to be designed such that there is no adverse effect on any other systems even in failure modes. ZHA and consideration of common cause failures will validate the design for potential undesirable system interactions based on system composition within a zone and / or adjacent zone. The ZHA will include a comprehensive Hazard Identification survey of the Aircraft in order to capture zonal hazards that are as a result of system operation over a prolonged period and, for civil-derived Air Systems, the interaction of any military-specific modifications with other Aircraft systems.

7. For systems with multiple redundancies using the same system elements, there may be further complications over the possibility of cascade failure, where the additional loads imposed by failure of one system element on the rest of the system increases the probability of failure for other system elements. It may also be possible to identify adverse trends by analyzing fault data against failure effects, for example considering fault data for fuel leaks may identify an adverse fault trend to indicate a compromise to SysI.

8. Once In-Service, the defined limits for Air Systems, as documented in the ADS, are verified by testing. A system's failure to retain its function within the defined limits might indicate a system Fault to be rectified as part of normal Maintenance. It may also indicate the impact of one of the threats and require deeper investigation. Zonal Inspections, identified during RCM analysis and carried out as part of Preventive Maintenance, may also indicate zonal effects that could compromise SysI. A diagram of the interactions to validate design assumptions is at Figure 15.

Figure 15 - Validating Design Assumptions[54]



9. Ongoing MSRs using RCM analysis will validate design assumptions and change the Preventive Maintenance appropriately. For system elements where Preventive Maintenance is not appropriate; fault trending, FRACAS or DRACAS, and other occurrence reporting will help validate the design assumptions.

10. Procedures are in place within the ADS to recover SysI[7] automatically for routine Faults and occurrences; particularly for systems that are designed using fail-safe design principles with incorporated redundancy and are expected to be replaced through Corrective Maintenance. These Faults are unlikely to require the attention of the IWG and will be recovered by routine Maintenance. However, fault trending may indicate system reliability might be compromising design assumptions and that there is a potential for a loss of SysI. Prevalence of a particular Fault might then require elevation to the IWG.

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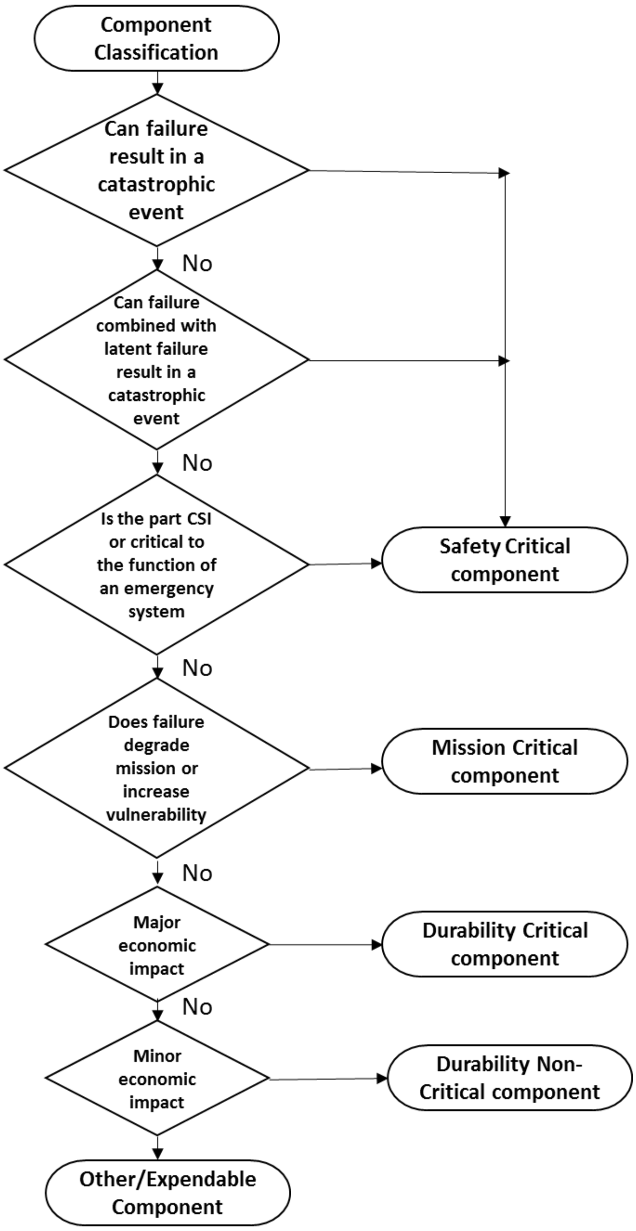
[54] The concept is applicable to all disciplines.

FSI

11. Critical or significant items, whose failure modes have significant economic, safety or mission effects on the system, are termed FSI. The items may be system, sub-systems, components or parts. FSIs are identified during design and those with a critical failure mode are identified as Critical Safety Item (CSI) which are candidates for lifing. Figure 16 shows the logic diagram for FSI selection.

Figure 16 - FSI selection logic diagram[55]



Maintenance Schedule

12. For FSIs that are Maintenance appropriate, they will be included in the Maintenance schedule using MSG-3 logic.

13. Ongoing MSRs using RCM analysis will validate design assumptions and update the Preventive Maintenance appropriately.

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[55] MIL-STD-1798C Mechanical Equipment and Subsystems Integrity Program; Department of Defence Standard Practice.

Annex A – SysI Case Studies

A1 Merlin Nosewheel Fails to Lower

A1.1 **Background**. Following a routine trooping task in Jul 15, ZJ123 carried out a series of approaches to the airfield. Prior to starting the second and final approach the crew conducted pre-landing checks and selected the gear to DOWN. The gear status lights all turned to red to indicate the undercarriage was moving, with the Main Landing Gear (MLG) lights turning green to indicate it locked. The Nose Landing Gear (NLG) light remained red indicating it was not in a locked configuration. The gear was recycled twice more and again the same configuration resulted. A PAN was declared and the DOWN EMERG was selected; however, this did not change the NLG configuration. The helicopter was brought to the hover and 2 squadron engineering personnel inspected the nose undercarriage. A mechanical engineering technician was able to reach the Change Over Valve (COV) lever and manually actuate it. At this point the nose gear rapidly extended and locked down. In the process it injured the supervisor's arm and almost impacted the head of the other. The helicopter landed without further incident.

A1.2 **Merlin Undercarriage System.** A Merlin has a conventional tricycle undercarriage; hydraulic actuators move (retract and extend) the undercarriage. Hydraulic pressure maintains the MLG in the retracted (up) position whereas the NLG is locked in the up and down position by a drag strut. Microswitches throughout the system indicate the position of the system to the pilot as shown in Table 6.

Table 6 - Undercarriage Indications

U/C Condition	Cockpit Indication
DOWN and Locked	**LEFT NOSE RIGHT** (green lights)
Unlocked (and retracting)	**LEFT NOSE RIGHT** (red lights)
UP and Locked	No lights

A1.3 The drag strut is hydraulically unlocked by the flow of pressure through the COV the position of which is controlled by a lever arm. When an UP selection is made hydraulic pressure is directed through the COV via the UP pipe. The pressure moves a piston within the drag strut and unlocks a mechanical claw lock. As the piston moves the microswitch connection is broken and the cockpit indication changes from green to red. Once the claw is unlocked the drag strut is free to compress[56] and the retract actuator raises the NLG. When the NLG is near the end of its travel, a striker plate on the shock strut contacts the lever arm which moves an internal spring-valve in the COV; and the UP pressure is blocked off. The pressure holding the piston and claw bleeds through the (now open) DOWN pipe and the claw retracts and is locked by the piston. The cockpit lights extinguish when the microswitch connection is made.

A1.4 When a DOWN selection is made the pressure flows through the DOWN pipe to unlock the claw and bleeds off through the UP pipe which is opened as a result of the striker plate moving away from the lever arm. The claw locks automatically when the drag strut reaches the end of its travel. When a DOWN EMERG selection is made emergency accumulator pressure flows into the COV and connects with the same channel as the DOWN pipe. Because hydraulic pressure is limited, a sequence valve on the emergency pipe ensures that the drag strut is unlocked before the NLG actuator tries to lower the leg.

A1.5 **Investigation**. During the subsequent investigation, it was found that the striker plate on the

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[56] The drag strut is fully extended in both the UP and DOWN position and is fully compressed about halfway through the retraction or deployment of the NLG.

nose wheel that manipulates the COV lever had twisted, see Figure 17, following the failure of 5 of the 6 spot welds. This twisting resulted in the lever arm of the COV being in an intermediate position such that both the UP and DOWN hydraulic pathways in the valve were blocked preventing the claw lock from being hydraulically released allowing the gear to lower.

Figure 17 - Deformed Merlin NLG Changeover Valve Striker Plate

A1.6 ZJ123's NLG required significant Maintenance in the run up to the Incident, the singular effect of each Incident being a Maintenance burden but when taken cumulatively they present a picture of a more serious underlying problem. The Maintenance history of the NLG Drag Strut and lever arm fitted to ZJ123 during the Incident was examined and is shown in Table 7.

Table 7 - ZJ123 NLG Drag Strut / Lever Arm Service History

SNOW	Date	Comment
At 28 Squadron, RAF Benson		
3354	27 Jan 15	Nose undercarriage cockpit indications incorrect. Not rectified and Tx'd to pt 2
3368	28 Jan 15	Change over lever replaced and assessed serviceable.
3406	3 Feb 15	Nose undercarriage cockpit indications incorrect. Change over lever found sheared. Tx'd to pt 2
3597	9 Mar 15	Nose undercarriage drag strut replaced, unable to carry out drag strut op test due to change over lever AGS. Tx'd to pt 3
Transferred to 846 NAS, RNAS Yeovilton		
3698	16 Jul 15	Nose undercarriage drag strut functional test carried out assessed unserviceable. Change over lever AGS found to be unserviceable during op test. Pt 2.
3988	20 Jul 15	Nose undercarriage change over lever replaced and functionally tested assessed serviceable. Pt 2 cleared.
	27 Jul 15	**Incident** – NLG fails to lower

A1.7 **Conclusion.** Although difficult, the ability to spot trends either in failures or escalating Maintenance / Aircrew observations can be an incredibly useful diagnostic tool to prevent a system degrading to a potentially catastrophic condition. The highlighting of FSIs to maintainers and developing suitable reporting mechanisms to allow DT tracking of issues can also ensure system Integrity is managed and maintained.

A2 Loss of USAF B-2B Spirit

A2.1 **Incident.** On 25 Feb 08, the B-2B “Spirit of Kansas” lifted off the runway at Andersen Air Force Base (AFB) in Guam. Seventeen seconds later, the crew lost control and the left wing struck the ground.

A2.2 **Flight Control System.** The B-2 is a fly-by-wire Air System which uses a Flight Control System (FCS) to respond to a pilot’s commands. Essential flight data enters the system through 24 Port Transducer Units (PTUs). Using the PTU air pressure measurements four flight computers independently calculate airspeed, angle of attack, sideslip and altitude. Three of the 4 computers must agree before the FCS uses these calculations to move the various flight surfaces.

Figure 18 - Destroyed B2-B ‘Spirit of Kansas’ at Andersen AFB Guam

A2.3 **Investigation.** The subsequent investigation identified that, prior to take-off, the B-2B’s computers had called for an internal Air Data System calibration. However, due to Guam’s humidity, there was moisture in the air data sensors during calibration and, during the subsequent taxi for take-off, the moisture evaporated. Now, the mis-calibrated Air Data System sent skewed data to the FCS, which pitched the bomber nose up 30^o upon take-off. Unable to regain control, the bomber’s 2-member crew ejected safely before the plane crashed and burst into flames. The $1.4 billion bomber was destroyed, see Figure 18. The investigation identified several underlying issues surrounding this Accident:

A2.3.1 **Undocumented workarounds**. Normally based out of Whitman AFB in Missouri the B-2 force had been deploying to Andersen AFB in Guam since 2004. When flight line technicians first noticed increased air data calibration requirements during the B-2’s 2006 deployment in Guam, written procedures did not address the humid climate; as a result, Maintenance technicians followed established practice and sought advice from manufacturer’s support personnel who recommended the use of the pitot heat to remove moisture from the Air Data System. This Air Data System calibration issue typically occurred as a time-critical pre-flight discovery by the flight crew, rather than during a Preventive Maintenance check. Such Corrective Maintenance was not documented in the same detail as scheduled work. Thus, the issue was never documented in a formal technical order change or a “Lessons Learned” report. Because the pitot heat workaround technique was not documented, some flight control technicians and all but one supervisor were unaware of the moisture issue and technique to overcome it.

A2.3.2 **Incomplete understanding**. The Air Data System calibration was viewed the same as an altimeter readout calibration; the critical importance of PTU inputs to the Flight Control System was not understood. During the investigation, the review board contacted manufacturer design engineers who had not been involved with the B-2 program for over 10 years, to obtain complete understanding of FCS interactions. Skewed PTU sensor data effectively bias FCS decisions, but a discrete PTU problem was only discoverable in the ground Maintenance mode of the FCS. Once the crew switched from Maintenance mode to begin take-off, their warnings and indicators would not specify a problem from the PTUs.

A2.3.3 **A Low-Profile Problem**. Supervisors were generally not aware of the increased air data calibration requirement during deployment. The increased requirements only surfaced during brief deployments in Guam, and never registered as a concern at the B-2’s home base in Missouri. Maintenance supervisors were focused on issues that grounded jets, and air data calibrations had never been recorded as preventing a take-off.

A2.4 **Conclusion**. A complex Air System was lost as a result of operating in an unfamiliar environment to a known problem about for which a fix existed; one of the post-accident recommendations saw the pitot-heat being added to the PTU calibration procedure.

A2.5 **Summary.** As Air System get ever more complicated, how well do you as a maintainer / engineer on the squadron or a desk officer in the DT understand the systems and their many interactions; what is ‘essential’ rather than ‘a nice to have’? Are all the low-profile problems seen on the front line and associated workarounds adequately reported to the DT and DO such that the underlying issues can be evaluated and SysI maintained or enhanced?

A3 Loss of Watchkeeper WK006

A3.1 **Background**. On 2 Nov 15, Watchkeeper (WK) 006, a RPAS, had completed its assigned sortie and was recovering back to base. However, the RPAS' Automated Take Off and Landing System (ATOLS) was unusable and, as a result, the crew elected to conduct the landing sequence using the backup GPS / inertial navigation take-off and landing system. However, despite 2 attempts, the RPAS aborted the approach and a third approach in was made with the RPAS self-abort prevented by a MASTER OVERRIDE (MO); following a normal approach WK006 abruptly pitched nose-down and impacted the runway, see Figure 19.

Figure 19 - WK006 wreckage

A3.2 **WK RPAS.** Procured by the British Army to provide an aerial platform to allow the targeting of weapons at day or night the Watchkeeper was a modified Hermes 450 drone providing intelligence, surveillance, target acquisition and reconnaissance thanks to its suite of onboard sensors. Watchkeeper does not have a traditional stick and throttle for control but instead relies on push button commands within the ground control station) that are translated into the desired flight control inputs occurs by the onboard Vehicle Management System (VMS) and Flight Control Software that is hosted within the VMS Computer (VMSC).

A3.3 The RPAS is ATOLS-capable and, as a result, the sensing of a landing required a Weight on Wheels (WoW) switch to sense touch-down and air jump through acceleration and rotation rates. However, a pseudo WoW switch, utilizing a laser altimeter, was required as the trails of a physical sensor, measuring undercarriage 'squat', had proven unreliable during design. Once the pseudo WoW switch sensed the RPAS on the ground, the control surfaces would pitch the vehicle's nose down to improve steering authority whilst taxying.

A3.4 Several software logic aborts were built into the ATOLS system to abort the landing and initiate a go-around; however, user-selectable overrides were available to the crew to prevent the landing being aborted in sub-optimal conditions. Additionally, MO was also available that prevented any of the aborts prohibiting the landing and initiating a go-around in situations where this may result in a RtL.

A3.5 **Investigation**. The subsequent Service Inquiry[57] identified several issues pertinent to this Accident.

A3.5.1 **Weather**. The weather conditions were far from favourable; surface visibility was 150 meters, with the sky obscured ("RED conditions" where the lowest cloud base was below 200 feet and visibility was less than 800 meters). The conditions did not improve throughout the day. Crewed military Aircraft do not usually launch in RED conditions in the UK, but records of previous Watchkeeper flights using MASTER OVERRIDE showed eight aborted flights in RED (or nearly RED) conditions. This indicates that crews expected the RPAS to take off and land in very low cloud cover and low visibility, which was not specified as a design requirement.

A3.5.2 **Crew actions**. When the crew discovered that ATOLS was unusable in its normal mode, ATOL "Alt Dev" override was selected, as per their Flight Reference Card, for the first attempted approach. However, WK006 aborted this approach, displaying the LAND STATUS TIMEOUT caution alert, and navigated toward the beginning of its recovery profile despite the crew retransmitting the LAND command. A second approach was made but yielded the same results. After the crew discussed the problem with the authorizing officer, they selected MASTER OVERRIDE to preclude a RPAS abort. The RPAS flew a normal approach profile until over the runway at 23 feet altitude, at which point WK006 abruptly pitched nose-down and impacted the runway at a 35 degree angle, just like WK031 had done in 2014.

A3.5.3 **RPAS actions.** Analysis of the VMSC identified that it has commanded postlanding actions while the RPAS was airborne. Furthermore, there was evidence that the VMSC was susceptible to sensing and latching a false Ground Touch. In the case of WK006, reflection from the low cloud in the circuit had resulted in the laser altimeter returning a height of less than 1m; this resulted in the VMSC now looking for roll rates and accelerations indicative of ground touch, a subsequent air jump and then being on the ground. Each of these sensing phases had an associated time limit to prevent false indications leading to an unsafe condition and would generate an abort causing the RPAS to go around. However, for WK006, the selected MO overrode these protections and resulted in the VMSC commanding post-landing actions to the still-airborne RPAS.

A3.6 **Contributory Factors.** The Service Inquiry also identified several contributing factors associated with the mishap, those listed below have been selected for their relevance to SysI:

A3.6.1 **Scarcity of information on the landing phase within the ADS**. The Interactive Electronic Technical Publication (IETP) 7.1 contained limited information about the landing regime and did not provide operators with sufficient information to deal with the landing of WK006. This contributed to the crew's limited understanding of the landing logic and messages displayed to the crew during the WK006 recovery.

A3.6.2 **The TAA was not informed of the weather restriction in place at West Wales Airport (WWA).** The DO had been aware of the system limitations regarding cloud at / beneath the Connect Point[58] and had limited the operating envelope of Watchkeeper when operating from WWA under the Military Flight Test Permit. However, the DO did not communicate this increased limitation to the TAA. Also, "the opportunity to introduce similar weather limits" at Boscombe Down "was missed." The Watchkeeper was not an all-weather RPAS, and its operating envelope will have been limited accordingly.

A3.6.3 **Normalization of the use of the Low Cloud Recovery Procedure.** The IETP stated that due to changing weather, occasionally the RPAS may need to be recovered with cloud at or

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[57] Service Inquiry, Watchkeeper 006, 2 Nov 15, Defence Accident Investigation Branch.

[58] The Connect Point is the beginning of the landing phase, at this point the UA will lower flaps, reduce speed and test its laser altimeters. Height is determined through GPS and the UA adjusts its height as required to achieve the glide slope and enter the approach phase.

below the Connect Point and directs crews to perform the procedure for recovery in low cloud conditions. The wording and lack of formal limitations led the crew to think they could routinely conduct flights when clouds were expected at or below the Connect Point.

A3.6.4 **The decision-making process that led to the premature selection of MO.** The MO, an emergency function, “had inhibited the protection measures that would otherwise have resulted in the final landing attempt being aborted by the system.” Although the decision to use MASTER OVERRIDE was within FRC guidance, the use of MO “was predicated on the decision to continue to attempt to land with cloud at the Connect Point.”

A3.7 **Previous Incident.** A previous WK (031) was lost when it also began post landing actions whilst still in the air as a result of a gust that generated sufficient loads to allow the system to sense a ground touch. The VMSC logic was flawed in that it falsely allowed a ground touch to be sensed and latched whilst the RPAS was still flying, leading to the crashes seen in both cases.

A3.8 **Conclusions**. In both Accidents the RPAS was being operated in conditions beyond those the manufacturer would fly the RPAS in; additionally, previous ‘success’ with MO had generated a false normal as to what would be expected without adequate understanding of the levels of safety that were being removed through the use of MO. The ‘simple’ interface the operators had with the RPAS did not allow operators to easily determine the impact their decisions, particularly in operation of override / emergency modes.

A3.9 **Summary**. In each of these mishaps the software performed as designed but not as intended, comprehensive hazard analysis may have highlighted potential situations where this could occur leading to these conditions being designed out of the system. In heavily automated systems the Integrity of the design of the system is essential with DTs requiring a full understanding of the working of the system and any Hazards. The operators of an automated system require training too, to ensure in the event of Faults / unusual situations they do not take unnecessarily risky decisions.

Chapter 6: Propulsion System Integrity Management

Integrity Evidence / Baseline artefacts

1. The minimum Integrity evidence required to sustain the management of Propulsion Systems throughout the service life will include, but not be limited to:

    a. Engine reference stresses, temperatures and time-points in cycle.

    b. Reference cycle documentation.

    c. Temperature normalization parameter used.

    d. Predicted Safe Cyclic Life (PSCL).

    e. Exchange Rates.

    f. ZHA.

    g. Results of Aircraft physical inspections and functional surveys.

    h. Existing failure and reliability data.

    i. Obsolescence analysis and reports.

2. The Integrity Baseline will include but not be limited to:

    a. Life Declaration for Major Rotating Parts.

    b. FMECA.

3. The Integrity Evidence / Baseline artefacts can be categorised as either Structures or systems.

    a. The Structures discipline deals with the mechanical design of all the engine rotating and static components. The focus is on the durability and robustness of the Propulsion System under various loads and mission usage; including aero, thermal, pressure, centrifugal, gyroscopic, manoeuvre and acoustic inputs. The design will also consider failure conditions such as overspeed and overtemperature, containment and blade-out, unbalanced loads, surge / stall events, and manufacturing or handling-induced defects.

    b. The systems discipline covers controls-level and subsystem-level components and systems, covering main control loops such as air management, fuel management, nozzle position, speed and flight control inputs; and subsystems such as fuel, ignition, electrical, variable geometry, thermal management, hydraulics / fuel, lubrication, mechanical, sensing, anti-ice / de-ice, tubing / brackets and health monitoring.

4. The Integrity of a component is determined such that the probability of individual failure of any critical part in service is at an acceptably low level. This is achieved by establishing the service usage of the part, determining its capability to meet that usage and ensuring consistent product quality by manufacturing control. Periodic reviews of the service environment and investigation of service arisings are carried out to confirm the predictions concerning usage and capability.

5. There is a mandatory requirement to establish and monitor component lives for both rotating and non-rotating critical parts identified in the FMECA; this is achieved by implementing a lifing policy[59]. This lifing policy will be agreed with the TAA and referenced in the Engine Model Specification. Note that there are several ways in which the life of a critical part may be determined with some approaches being more conservative than others, and they are Safe Life[60], Databank method[61], Damage Tolerance approach.

6. It is the responsibility of the DO to make the Life Declaration figures available to the DT. An

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[59] Refer to RA 5602 – Propulsion System Part Lifing, Critical and Common Pool Parts.

[60] Def Stan 00-970 Part 11/6 Annex A, also refers to CS-E 515.

[61] This method, proposed by QinetiQ and Rolls-Royce, involves the flight cycle critical area stresses and temperatures being entered into a material databank to calculate safe lives directly. Refer DTIC ADP014140.

example format which the Life Declaration may take is detailed below:

a. Version control of document.
b. Previous life statement number if applicable.
c. Reason for change if applicable.
d. Engine and mark number.
e. Engine operating limitations reference.
f. Assembly and / or component.
g. Part numbers.
h. Diagram of potential critical areas.
i. Material (common name and specification code).
j. Stress / Strain-Life (SN) curve ref.
k. Engine reference stresses, temperatures and time-points in cycle.
l. Reference cycle documentation reference.
m. Exponent used.
n. Temperature normalisation parameter used.
o. Test references and whether results were cracked or not.
p. Failure Investigation References.
q. Over-stresses.
r. List of critical areas and calculated critical area safe lives.
s. Predicted Safe Cyclic Life (PSCL).
t. Approval signatures.
u. A sketch indicating the position of the critical areas.

Critical Parts (CP)

7. Critical or significant items are termed CP and can be rotating or non-rotating. The definition of CP is stated in EASA CS-E AMC E 515 (European Aviation Safety Agency Certification Specifications for Engines) (Safety Analysis). RA 5602[59] also provides further Guidance Material.

Maintenance Schedule

8. As part of the certification process for Propulsion Systems, safety analysis is conducted to identify critical parts whose failure has the potential to cause hazardous Propulsion System effects, or where failure would have unacceptable consequences. Non-critical parts whose failure or reduced reliability would erode safety margins may also be considered. These parts are subject to monitoring and review through an inspection programme that is part of the Maintenance Schedule.

Unsafe Conditions

9. Certification of a Propulsion System is a demonstration of compliance with requirements which are intended to ensure an acceptable level of safety. This demonstration includes certain accepted assumptions; in time, evidence may emerge to show that these assumptions are not correct and that a Propulsion System is being operated in an unsafe condition, due to an adverse usage change, resulting in components in service being flown beyond the declared safe cyclic life.

10. Amendments to critical component lives may be made by a DO following a technical life review, as a result of for example, a historic change in usage not accounted for or improved fatigue analysis methods becoming available. The TAA (or a delegated individual) will be aware of the potential for this to occur and implement recovery procedures in a timely manner to restore PI

consistent with the applicable certification requirements.

11. The TAA will ensure that an assessment for operating in an unsafe condition is carried out. This may be undertaken by the DO who provided the revised critical component lives, but the DT responsible for the Propulsion System will be able to verify the outcome in order to make recommendations to the Air System TAA. Both the European Defence Agency (EDA)[62] and the Federal Aviation Administration (FAA)[63] produce guidance on addressing unsafe conditions.

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[62] European Military Airworthiness Requirements 21 (EMAR 21 - derived from EASA Part 21).

[63] FAA Advisory Circular 39-8 Continued Airworthiness Assessments of Powerplant and Auxiliary Power Unit Installations of Transport Category Airplanes.

Annex A – PI Case Studies

A1 Tucano T1 Engine Failure Leading to Wheels Up Landing (Jan 13)

A1.1 **Background.** Tucano ZF349 was on a Partial Test Flight from RAF Linton-on-Ouse, following Maintenance to investigate an Exhaust Gas Temperature (EGT) over-temp. During the DTF, the pilot is required to carry out Engine Electronic Control (EEC) checks in both Normal and Manual operation. In Normal operation, the EEC maintains Turbine EGT and Engine Torque, whilst in Manual, the pilot is required to monitor the engine instruments to ensure that the engine limits are not exceeded. There is also a propeller governor that, in Normal operation, provides a constant engine RPM to the propeller drive shaft. In Manual operation it is mechanically set to provide 100.5% RPM.

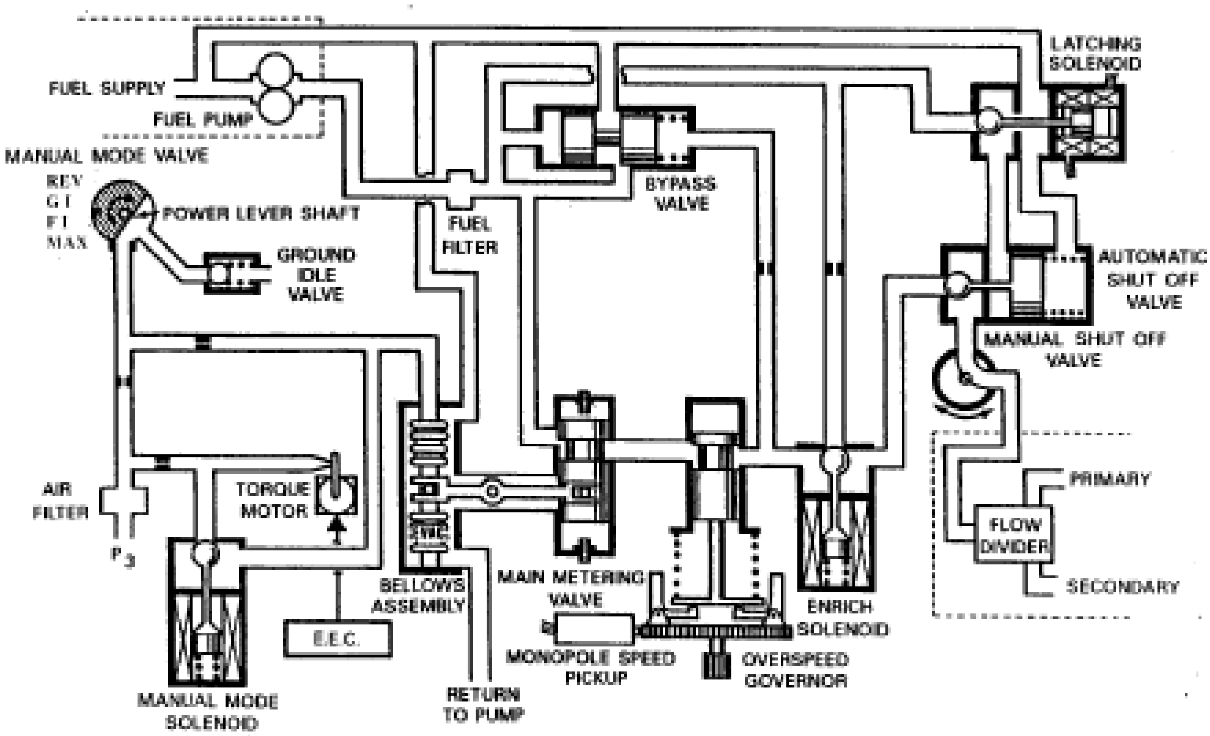
A1.2 During the EEC Manual checks, the pilot noticed abnormal torque indications and decided to end the sortie and return to Linton-on-Ouse. On reselecting the EEC to Normal, the Air System experienced a loss of thrust and a large increase in drag. The pilot suspected an engine failure, shut down the engine, and then attempted an emergency landing. The undercarriage was lowered, but due to the undercarriage requiring hydraulic pressure to positively lock it down, and with the engine driven hydraulic pump now no longer being able to provide sufficient pressure due to lack of engine drive, the Tucano landed wheels up, then travelled 3700 ft along the runway and onto the grass. Fortunately, both pilots exited unharmed.

Figure 20 - Tucano ZF349

A1.3 **Investigation.** A Service Inquiry Panel (SIP) was convened to establish the cause of the Accident and it was soon apparent that the Tucano had suffered an engine failure and it was on this area that the SIP concentrated. Initial investigation centred on the Engine, EEC and propeller governor. No leaks or damage were evident on the engine, and both the EEC and propeller governor passed test that were assessed as serviceable. The investigation then moved to the Fuel Control Unit (FCU) which controls fuel flow to the engine in both Normal and Manual operation, thus controlling engine torque and EGT.

A1.4 Within the FCU is a Torque Motor (TM) which, using P3 engine air acting on a sealed bellows unit, controls the fuel flow to the engine via a flapper valve. The FCU failed test and was stripped for further investigation and testing. This testing found that the TM was unserviceable and an X-ray examination was carried out on it. This X-ray examination showed that the bellows were deformed and not seated correctly within the housing. Further strip and inspection showed that the epoxy resin sealing the bellows to the housing had failed. This meant that the bellows had become unseated and therefore blocked the flapper valve. This severely reduced the flow of fuel to the engine and subsequently resulted in a total loss of engine RPM.

Figure 21 - Fuel Control Unit Schematic



A1.5 **SIP findings.** The SIP determined that the cause of the Accident was due to the failure of the epoxy resin in the TM. The de-bonding of the epoxy resin on the TM bellows within the FCU resulted in the bellows becoming lodged against the flapper valve, thereby reducing engine fuel flow and a corresponding decay in engine RPM. The Panel also concluded that age and environmental degradation was the most likely reason that the de-bonding had occurred. The SIP found that a lack of a rigorous lifing policy was considered to be an “Other” factor in the Accident. An “Other” factor was described by the SIP as; `Factors that were noteworthy in that they may cause, contribute to, or aggravate future accidents`. Differences were also found between the overhaul life stated by Honeywell (the engine DO) and the published ‘Engine and Ancillaries Lifing Policy’. Furthermore, engine critical components were not clearly identified. There was also a poor paperwork trail detailing the control of critical components and the SIP were unable to fully identify which components from build were still fitted to the engine.

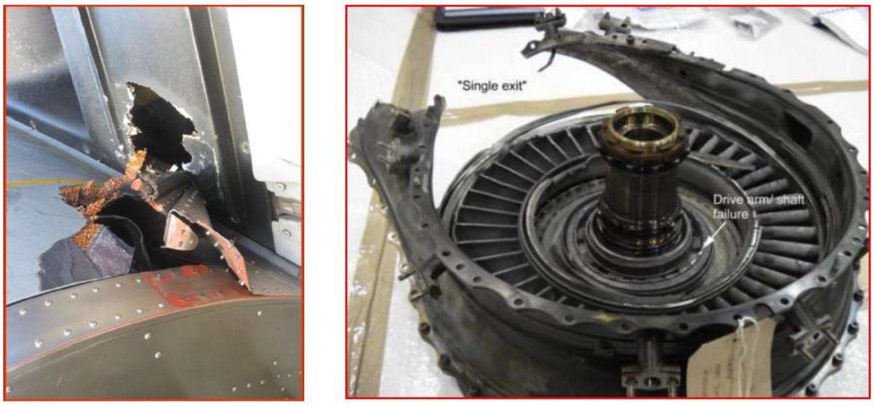
A1.6 The inability for the OEM to identify a failed TM through the FCU Standard Serviceability Test was also cited by the panel as an additional “Other” factor. The TM was not routinely tested as a separate component and this had resulted in several FCUs being returned to service as `No Fault Found`

A1.7 The SIP observed that the MTBF of the TM had reduced significantly from 12696 flying hours in 2009, to 1449 flying hours in 2012. This is indicative of an ageing component and this reduction in MTBF should have resulted in an increased monitoring of the TM. This Incident was caused by a compromise to PI due to ageing components.

A2 Merlin Mk1 Turbine Disc Failure (Jan 10)

A2.1 **Background.** On 13 Jan 2010, a Merlin Mk1 was undergoing a rotors turning ground run at RNAS Culdrose to investigate a reported Fault on the No.3 engine. After approximately 10 minutes, the No.1 engine suffered a major failure and the No.2 engine also shut down. Initial investigation showed that there had been an uncontained release of all the blades on the 1st Stage Power Turbine (PT1) as shown in Figure 22.

Figure 22 - RTM322 Power Turbine Disc Failure

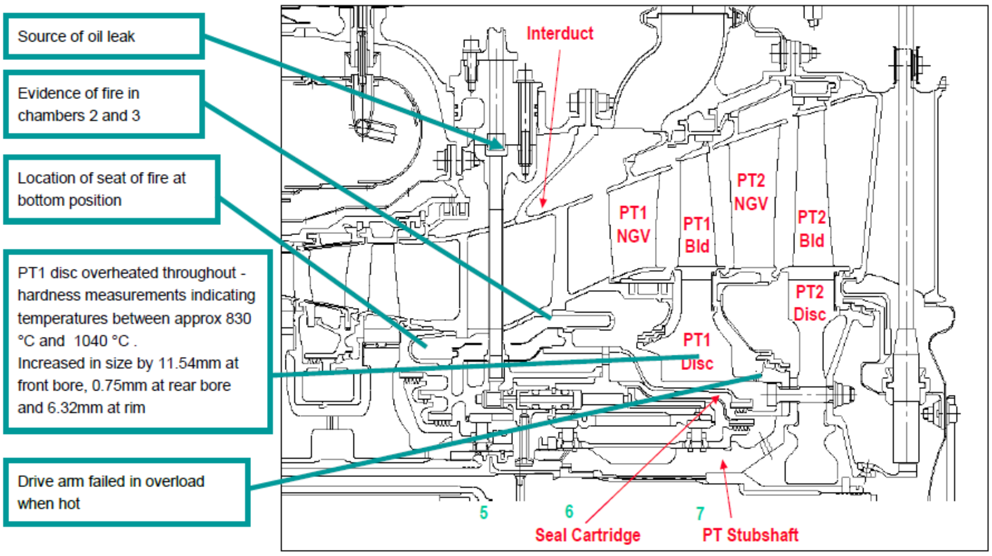


A2.2 **RTM322.** The RTM322 Engine Change Unit (ECU) is fitted to all marks of Merlin (3 off ECUs) and to the Apache (2 off ECUs) so this failure was to have a large impact on flying operations. Immediately following the Incident, One Engine Inoperative (OEI) flying was restricted with OEI training prohibited. The Merlin Air System was also prohibited from carrying out twin Engine Cruise.

A2.3 The ECU in this Incident had been built by Rolls-Royce (RR) in Nov 98 and initially fitted in Apr 99. It completed ≈ 333 Flying Hours (FH) and was then removed to storage in Sep 00. In Jun 2006 the ECU was transferred and subsequently moved to the subject helicopter in Nov 2008 when it had completed ≈ 830 FH. At the time of the Incident, the ECU had completed ≈ 1150 FH and ≈ 840 starts.

A2.4 **Investigation findings.** Investigation by the Materials Integrity Group revealed that the failure of the turbine disc had been caused by an oil leak from the Interduct Feed Tube joint as shown in **Figure 23**. This then started a fire, which subsequently caused the PT1 disc to overheat and then fail with catastrophic consequences.

Figure 23 - Cross Section of RTM322 indicating failure mode



Source of oil leak

Evidence of fire in chambers 2 and 3

Location of seat of fire at bottom position

PT1 disc overheated throughout - hardness measurements indicating temperatures between approx 830 °C and 1040 °C .
Increased in size by 11.54mm at front bore, 0.75mm at rear bore and 6.32mm at rim

Drive arm failed in overload when hot

A2.5 This leak was caused by the torque loading on the joint not being sufficient to create a seal with the gasket that was fitted. A modification was developed to change the gasket and to increase the torque loading of the clamp from 4.8 Nm to 7.8 Nm. Routine borescope inspections of the oil feed / drain / vent adaptors were introduced, and the allowable oil consumption rate was lowered to 0.2 litre / hour to act as a warning for any possible failure. This example shows how PI was compromised by a procedural design error due to incorrect calculations for the torque loading of the clamp.

A3 Airbus A380-842 VH-OQA Uncontained Engine Failure (Nov 10)

A3.1 **Background.** On 4 Nov 10, a QANTAS Airbus A380-842 (Registration Number VH-OQA) departed Changi Airport, Singapore for Sydney. On board were 5 flight crew, 24 cabin crew and 440 passengers. Following a normal take-off, the crew reported that, while maintaining 250 knots in the climb and passing through 7000 feet above Mean Sea Level they heard two co-incidental 'loud bangs', followed shortly after by indications of a failure of the No.2 engine. After competently managing the resulting multitude of system failures, the crew made a successful and safe emergency landing back at Changi Airport.

Figure 24 - Trent 900 Uncontained Turbine Disc Damage

A3.2 **Trent 900.** This Airbus A380-842 was fitted with four RR Trent 900 series engines. The Trent 900 engine had been developed from the earlier RR RB211 series of engines and was first test flown on 17 May 04, gaining European Aviation Safety Agency (EASA) Certification on 29 Oct 04. The United States FAA Certification was awarded on 4th December 2006.

A3.3 **Investigation.** The subsequent Australian Transport Safety Bureau (ATSB) Investigation indicated that fatigue cracking had taken place in an engine high pressure / intermediate pressure bearing Structure oil feed stub pipe within the No.2 engine. This resulted in oil leakage followed by an oil fire in the No.2 engine. This then subsequently led to an uncontained failure of the Intermediate Pressure Turbine (IPT) disc assembly. Sections of the liberated disc penetrated the left wing and the left wing-to-fuselage fairing resulting in Structural and systems damage. Figure 24 shows the resulting physical damage to the engine and nacelle assembly.

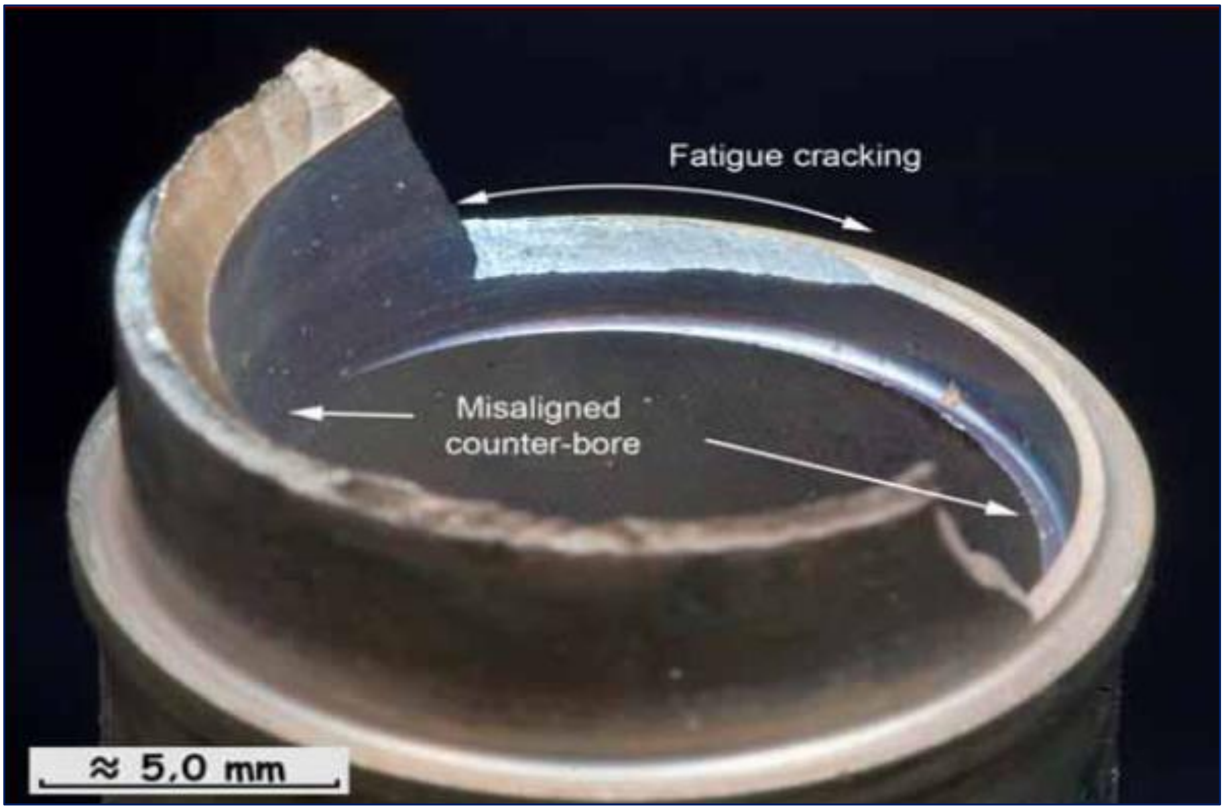
A3.4 The ATSB investigation report also indicated that segregated wiring routes were cut by two of the three individual pieces of disc debris, and as a result led to difficulties in the shutting down of the No.1 engine after landing. The findings of the report were determined to be a "critical safety issue” and the ATSB recommended immediate inspections of all In-Service Trent 900 engines. On 8 Dec 10, the ATSB reported that 45 Trent 900 engines had been inspected. Three of these engines had failed inspection and had been removed from service.

A3.5 **Safety actions.** As a result of this occurrence, several safety actions were immediately undertaken by EASA, QANTAS, Airbus and Rolls-Royce. On 1 Dec 10, the ATSB issued a safety recommendation to RR in respect of the Trent 900 series. In addition, the Civil Aviation Authority

(CAA) issued a Regulation 38 Maintenance directive that addressed the immediate safety of flight concerns in respect of QANTAS A380 operations with the Trent 900 series engine.

A3.6 Investigations into the uncontained engine failure identified the root cause of the failure was a manufacturing defect in an oil feed pipe (see Figure 25), which in turn caused fatigue cracking due to the pipe wall being too thin. This crack led to an oil leak and internal oil fire that weakened the No.2 engine's IPT disc assembly. This consequently separated from the turbine shaft and then punctured the engine casing and wing Structure.

Figure 25 - Stub pipe showing misaligned counter-bore



A3.7 On the 18 May 11, the ATSB released an interim factual report which stated that 53 Trent 900 engines had been removed from service, 11 of which, were due to out-of-tolerance oil-feed stub pipes with a misaligned counter-bore, leading to an incorrect pipe wall thickness. The other 42 were due to a lack of measurement records relating to the oil-feed stub pipe. Therefore, PI had been compromised from the outset due to a manufacturing error. It is important to recognize PI can be compromised in many ways.

Chapter 7: Environmental Damage Prevention and Control

Introduction

1. ED is the term used to describe the physical degradation of material properties as a direct result of interaction with the climate or the environment. ED includes corrosion, erosion and the degradation of surface finish and composite material properties. The methods of minimizing the effects of ED on metallic and composite materials have commonality in that prevention relies heavily on the effective Maintenance of protective systems such as coatings, tapes and corrosion-preventive compounds (CPCs).

2. Corrosion is the most significant form of ED to the metallic Structure or systems, including component parts, of an Air System. It can reduce static strength, initiate stress corrosion cracking, shorten fatigue lives and detrimentally affect avionic and mechanical equipment. Through either extreme environments or adjacent systems, the strength of composite Structural or system components can be adversely affected by excess heat and moisture uptake and can also suffer degradation by fuels, oils, lubricants and ultra-violet (UV) light if left unprotected.

3. The severity and effects of ED increase with time and if it remains undetected and unchecked it will impair the Structural and SysI of the Air System. The costs of inspecting for ED, and the subsequent costs associated with ED recovery and repair, are significant drivers in terms of overall Maintenance cost, Structural and system Airworthiness, capability and availability of the Air System. Careful consideration during the design stage can reduce susceptibility to ED by avoiding design features that can precipitate its onset and by selecting corrosion resistant materials with appropriate surface treatments. Furthermore, susceptibility to ED can also be reduced when the is In-Service by applying appropriate Maintenance procedures and carefully selecting appropriate Husbandry materials, dependent on the operating environment. However, ED will not be eliminated by such measures and efforts to manage these Risks will continue throughout the life of the Air System. Therefore, the EDPC Programme will manage the risk to Airworthiness, capability, availability and costs arising from ED.

EDPC Programme

4. An EDPC Programme is a comprehensive and systematic approach to managing the Risk from ED throughout the life of an Air System. The TAA will establish an EDPC Programme that defines the requirements for preventing, controlling and managing ED within the fleet. It is not the intent of an EDPC Programme to establish rigid requirements for eliminating all ED problems, but to control the Risks arising from ED at or below levels that do not jeopardize TAw of an Air System type by using ED Control Plans and the management activities detailed in this chapter, plus those detailed within Structural Examination Programmes in ►RA 5726(2)[64]◄. TAAs will ensure that inspections of the Structure, systems and components are incorporated within the MMS at intervals appropriate to the susceptibility of individual components to ED and the risk to Airworthiness. TAAs will also ensure that component Maintenance requirements are addressed by equipment / commodity DT programmes.

5. **Timing**. An EDPC Programme is a through-life approach and therefore will be established early in the life cycle to ensure that an appropriate Maintenance regime is implemented. For new Air Systems this will be no later than the introduction to Service; for In-Service Air Systems, TAAs will introduce EDPC programmes at the earliest opportunity in order to manage and minimize the risks from ED.

Management activities

6. **Prevention and control activities.** TAAs, in conjunction with Designers / DOs, will develop and implement appropriate EDPC activities relevant to the ED threat to the Air System. TAAs, in consultation with the CAMO, will periodically review the effectiveness of these activities and any

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[64] ►Refer to RA 5726(2): Establishing Integrity Management.◄

associated procedures within the ADS. Such activities are described below.

a. **Corrosion prevention and control**. Corrosion prevention and control can be promoted by:

(1) **Use of good anti-corrosion design practices.** These can include appropriate material selection, surface treatment and protection, wet assembly and drainage routes when procuring Air Systems and subsequently when commissioning modifications and repairs iaw the appropriate design requirements.

(2) **Use of CPCs, otherwise known as Temporary Protectives.** These are the collective name for a range of oils, greases, waxes and pastes that are designed for easy application and are used to enhance the corrosion resistance of bare and painted metal whilst being relatively easy to remove to allow further work or inspection. The use of CPCs on assemblies and mechanical moving components will be carefully considered since they may reduce friction of joints, resulting in loosening, or attract dust / dirt, which can subsequently restrict movement of these systems. Additionally, the properties (flow / stickiness) of some CPCs are temperature-dependent and thus the appropriateness / effectiveness of a CPC solution varies with operating environment. TAAs will consider and approve the selection and use of CPCs for specific applications.

(3) **Removal and neutralization of corrosive agents.** This is a critical Maintenance activity, as severe corrosion of metal and Structurally significant damage to non-metallic materials and damage to protective coatings can be caused by environmental fluids such as sea water, waste water (toilet or galley systems) or the careless use or inadvertent spillage of corrosive fluids such as acids, alkalis, mercury and certain Maintenance materials, eg paint stripper or hydraulic fluid. In such an event, recovery action will be taken iaw instructions contained within the appropriate ADS or AP 119A-0200- 1/0202-1. In all cases of corrosive agent spillage, the TAA will ensure that Structural and SysI is recovered. In addition, where body fluids have been spilled, recovery action will accord with RA 4103[65].

(4) **Husbandry.** The following Husbandry procedures, appropriate to the operating environment, will be employed:

(a) Whenever practicable, Air System are to be stored in hangars or other suitable shelters to reduce environmental effects.

(b) Washing removes corrosive contaminants and facilitate inspection of the Structure. As a minimum, TAAs will mandate an Aircraft wash prior to each appropriate Preventive Maintenance activity undertaken by a Depth organization, or when environmental or operational considerations dictate. Washing is a vital Maintenance activity, which will only be deferred in response to urgent operational requirements. For littoral and low-level over-the-sea operations, where salt accretion can occur, TAAs and CAMOs are to consider introducing post-sortie or even daily fresh-water washing. TAAs will approve the use of washing materials and equipment.

(c) Keeping drain holes / paths / traps clear and open to prevent blockages, pooling of liquids and collection of solids (eg sand).

(d) Zonal surveys to confirm the Integrity of temporary and permanent protective systems and the efficacy of Husbandry procedures.

(e) Use of sealants and filleting compounds to prevent moisture and liquids penetrating the Structure and system components.

(f) Air System wiring Husbandry, refer to Chapter 9.

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[65] Refer to RA 4103 - Removal of Body Fluid Contamination from Aircraft.

(5) TAAs will ensure that promulgated procedures, techniques, materials and equipment, such as for surface finish removal, do not undermine or deplete corrosion protection systems, thereby increasing the risk of the onset of corrosion.

b. **Erosion prevention and control**. Erosion is the loss of material from Aircraft components (eg leading edges, helicopter rotor blades) by the action of small particles such as grit, sand, stones, ice and water. This form of ED destroys component corrosion protection, introduces wear to mechanical and avionics systems, degrades optical quality and strength of transparencies, affects intake and airframe aerodynamics, may be a source of fatigue crack initiation and is a mechanism that has a significant impact on operating availability. The relative significance of ED varies with respect to the natural environment and operating procedures. The impact of erosion may be significantly reduced by the effective use of tapes, abrasion-resistant or anti-erosion paints and suitable operating procedures to reduce the risk of erosion. Specific processes and materials used to protect and control against erosion will be approved by TAAs and detailed within the ADS.

c. **Surface Finish (SF)**. SF systems, such as paints, protect the underlying substrate of Structure and components from ED, as well as from AD, in 3 ways:

(1) By providing a barrier, preventing mechanical damage of the substrate from the environment.

(2) By separating water, oxygen and other corrosive contaminants from the substrate, thus preventing chemical damage.

(3) Where the physical barrier fails to separate the environment and metal substrates (eg microscopic pre-existing flaws, damage, and permeability of the SF system), corrosion inhibitors contained within the paint limit corrosion of the substrate. SF on military equipment also has additional functions such as adjusting the conspicuity and decontamination characteristics. However, SF materials are also subject to ED and have a finite useful life. The correct selection, application, Maintenance and replacement of the SF are essential to preserve materials from environmental attack. When approved by the TAA, in-theatre repairs of SF systems may be achieved using ‘Touch-up’ kits iaw AP 119A-0601-OA.

d. **Composite material Maintenance**. Composite materials are degraded by heat, moisture ingress and contact with fuels, oils and lubricants, plus exposure to UV light. The operational life of composite Structure is directly related to the amount of ED and AD sustained in service. However, ED and AD of composites may not always be visible or detectable (see MAM-P Chapter 5.3). ED of composites may be limited by application of effective Maintenance policies and by appropriate SF Maintenance (see paragraph 6c(3)).

e. **Dehumidification**. Dehumidification, or Controlled Humidity Environment (CHE) is the process of reducing the Relative Humidity (RH) of the local environment surrounding Structure or equipment to below 50% RH to minimize the rate of corrosion. At or below this level, materials are kept free from corrosion and mildew. If the RH is taken below 40% certain materials (eg sealants and seals) will dry out. It therefore follows that the ideal RH for In-Service use is between 40% and 50%. Within the context of this chapter, dehumidification or CHE may be exploited to reduce degradation of two significant groups of assets:

(1) Components, systems, equipment and assets that can be containerized or packaged. These items are containerized in controlled humidity packages, which can be transported via the stores system either from manufacturer / supplier or re-work to Forward or return from Forward to Depth. Packaging, silica gel and effective storage / warehousing are standard means of minimizing the effect of the prevailing environment.

(2) Large multi-system assemblies that cannot be containerized; dehumidification or CHE are to be employed:

(a) During storage of attrition / reserve assets (immediate, short, medium and long term).

(b) Where practicable during Maintenance periods and during transport to / from theatre of operations by sea.

(c) Where practicable on unit and in theatre. In such circumstances, CHE may be applied intermittently and / or to selective parts of the Structure / system.

f. **Storage.** Generic procedures for the preparation, Maintenance and recovery of Air Systems placed in short, medium and long-term storage are contained in JAP 100V-21. TAAs are responsible for promulgating type-specific procedures, including EDPC activities, within the appropriate Topic 5L, 5N, 5P and 5Q.

7. **Management techniques**.

a. **Capture of ED data.** TAAs will establish a means of detecting and tracking trends in corrosion and other ED mechanism arisings across fleets by capturing and retaining relevant data that can support decision-making both for Structures and SysI and through-life management. Consideration will be given to recording the life of products used for EDPC on an Air System in an accessible location such as the ADS. Additionally, to meet the requirements of an electronic CC database, TAAs will capture fleet-wide ED data to track the condition of individual Aircraft where it is expected that the information will be of value in repair, Structural and SysI, AAAs and life extension assessments. The means of data capture and retention may be by one, or a combination, of the following:

(1) Enhanced reporting (using ED keywords, such as corrosion and erosion, in engineering documentation fields).

(2) MOD Form 704 Series documentation (typically MOD Form 704C supported by corrosion and other ED maps).

(3) Unit or fleet databases.

b. **ED Control Plans.** TAAs will produce and maintain ED Control Plans and may decide it appropriate to have a separate plan to counter each ED mechanism. The ED Control Plan is a living document used by the TAA to highlight and manage current ED issues, proposed solutions and details of prevention and control initiatives, which will be retained for the life of the Air System. It will also be used as a briefing document for all agencies involved in operating, maintaining and supporting the fleet and when planning for life extension and future procurement. The plan will be reviewed by the TAA, with input from the CAMO where required, at an appropriate Working Group and updated to reflect any changes in managing ED issues.

c. **ED management and reporting**. TAAs are to proactively manage EDPC Programme issues and to establish auditable management processes to ensure that Structural and system Integrity is maintained throughout the service life of the Aircraft. TAAs will:

(1) Collect, manage and interpret ED arising data.

(2) Consider ED data reports in order to direct prevention and remedial programmes through:

(a) Identifying new ED arisings.

(b) Considering the significance and effect of ED arisings.

(3) Control and direct progress on Structural and systems ED issues through:

(a) Review and update of ED Control Plans.

(b) Implementation of controlled humidity procedures.

(c) Review of SF systems and techniques.

(d) Use of CPCs.

(e) Review of Preventive and Corrective Maintenance procedures.

(f) Review of composite material Maintenance issues.

(g) Review selection and authorization of ‘exposure incident’ recovery Husbandry materials.

(h) Co-ordination of Forward and Depth ED reporting.

(4) Monitor and adjust the effort expended at Forward and Depth to ensure ED prevention and remedial programmes are optimized to provide best value for money and operational capability and availability.

(5) Review the collection, management and suitability of ED data to ensure suitability for:

(a) Structure and systems lifing reviews.

(b) Reporting requirements to higher-level management forums.

(c) Type Structural and systems Airworthiness.

(d) Establish and review the need for special-to-type EDPC training and the EDPC content of Phase 2 and 3 training.

d. **EDPC forum**. TAAs will establish a forum to manage the EDPC activities. The forum may be a dedicated EDPC Working Group, or a secondary element of another Working Group as deemed appropriate by the TAA. The TAA will appoint a chair and decide the level of membership of the forum, which will be appropriate to the level of meeting within the DT Airworthiness management Structure. Membership will include representatives from the DO, Front Line Commands (FLCs), Forward and Depth EDPC focal points, CAMO, other key personnel from the Depth organization and ►1710 NAS SMEs.◄ Additional advice, including representation and / or appropriate expertise from independent specialists ►and Military Aviation Authority Certification Division are also to be considered.◄ Issues addressed by the EDPC forum that are deemed significant will be raised to the next appropriate meeting (such as Structural issues raised to the Structural Integrity Working Group (SIWG)) within the TAA management Structure.

Resourcing EDPC

8. EDPC is an integral part of routine maintenance and in normal circumstances there is no requirement for ►a tradesperson◄ to be established exclusively for these duties. However, ED, in particular corrosion, is a threat to Structural Airworthiness and DTs will adequately resource EDPC activities.

9. **Forward organizations**. DTs are responsible for putting arrangements in place with FLCs, who will identify EDPC posts for a Senior Rate / Senior NCO or civilian equivalent within the Forward organization for each Stn / Ship / Unit. These posts will act as focal points for all EDPC matters. Exceptionally, if a TAA considers a particular Type to be seriously at Risk from ED, full-time teams may be established by FLCs within Forward organizations to mitigate the ED threat.

10. **Depth organizations.** TAAs are responsible for managing the ED threat and are to consider the need for a focal point to act on all EDPC matters. DTs will ensure that EDPC is adequately resourced within their Depth support arrangements.

Training of personnel

11. **Requirement for EDPC training.** A ►tradesperson◄ who ►is required◄ to carry out EDPC maintenance will be trained to do so iaw JSP 822[66].

12. **EDPC specialist training**. TAAs are to define the requirement for any EDPC Maintenance

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[66] Refer to JSP 822 – Defence Direction and Guidance for Training and Education.

activities based upon the perceived threat to Airworthiness from ED. EDPC specialist training at Depth, to meet the TAA's Maintenance activity requirements, will be determined by the provider organization. Similar EDPC specialist training for personnel within the Forward organization will be determined by the respective FLC in consultation with the appropriate TAA.

13. Specific specialist training in EDPC is currently limited to those Senior Rate / Senior NCO or civilian equivalent, of the appropriate trade, appointed as a Stn / Ship / Unit EDPC focal point. Course CN3720 (EDPC Coordinator) is available for nominated Service, MOD civilian and Industry personnel at DSAE Cosford.

Responsibilities

14. **Forward organizations**. FLCs will ensure that:

a. The requisite level of EDPC training, in subjects such as corrosion prevention and control, Maintenance of composite Structures (where appropriate to type) and Husbandry, is provided to engineering personnel prior to employment on Aircraft work.

b. Where necessary, and in consultation with TAAs, Senior Rate / Senior NCO or civilian equivalent posts act as a focal point for all EDPC matters within Forward organizations at each Stn / Ship / Unit.

c. The EDPC capabilities of Stns / Ships / Units will be assessed through the appropriate Audit process.

15. **TAA.** TAAs are responsible for:

a. Ensuring that Master Maintenance Schedules contain inspections and procedures defined at intervals that are appropriate to the operating environment and that meet the threat of ED to Structures and components.

b. Ensuring that any component requirements within the EDPC Programme are addressed by the appropriate equipment / commodity DTs.

c. Ensuring that appropriate ED data capture systems are employed by Forward and Depth organizations.

d. Ensuring that EDPC is addressed by an appropriate WG.

e. Producing and maintaining ED Control Plans, as required, and ensuring their review at an appropriate WG.

f. Approving Husbandry procedures, materials and equipment.

g. Defining the requirement for EDPC specialist training at Forward and Depth.

h. Determining the requirement for and, where appropriate, resourcing EDPC focal points.

i. Maintaining the level of awareness of ED issues across Forward and Depth organizations where collocated.

j. Ensuring that Depth support arrangements address the need to:

(1) Carry out appropriate EDPC management techniques as specified by the TAA.

(2) Maintain a single ED data capture system (see paragraph 15c) as defined by the TAA.

(3) Appoint an EDPC focal point within the Depth Organization.

(4) Adequately train personnel in EDPC techniques.

(5) Provide support to TAAs on EDPC at appropriate WGs.

16. **DE&S Air Commodities Delivery Team (ACDT)**. The ACDT are responsible for the introduction, provision, efficiency and through-life support of equipment associated with washing, dehumidification, surface finish and supplementary protection systems. The ACDT are also

responsible for the supply of Air System paints.

17. **MAA Certification (Cert) Division**. S&ADS is responsible for:

a. Defining EDPC policy where ED has a direct effect on SI.

b. Providing advice and guidance to DE&S on EDPC design requirements in Def Stan 00-970.

c. Co-ordinating the identification and definition of In-Service pan-Air System EDPC capability deficiencies and providing air vehicle engineering advice into MOD research programmes, ensuring the relevance and effective delivery of research work packages for implementation by the relevant TAAs.

18. **1710 NAS**. 1710 NAS is responsible for:

a. Providing specialist scientific and engineering advice and guidance on EDPC, assessment, investigations and analysis services to FLCs, Unit focal points and TAAs.

b. Supporting DE&S DTs on EDPC at appropriate WGs.

c. Sponsoring AP 119A-0202-1.

d. Identifying, evaluating and developing new EDPC technologies, methods, equipment and materials and making recommendations to TAAs and FLCs.

e. Assisting in identifying and defining In-Service pan-Air System EDPC capability deficiencies and providing scientific advice into MOD research programmes, ensuring the relevance and effective delivery of research work packages for implementation by the relevant TAAs.

Chapter 8: Air System Usage and Validation Programme

Introduction

1. During the fatigue safe life substantiation and / or determination of damage tolerance inspection regimes of any Air System, the DO will make assumptions on how the Air System will be used in service; the DUS. As fatigue lives and crack propagation rates can be significantly altered by relatively small changes in usage, such as number or severity of manoeuvres, or increased mass, it is important that the DO is advised of the actual, recorded In-Service usage to enable the validation of the DUS assumptions and to underwrite the continued Integrity, and therefore Airworthiness, of the Air System – this is the purpose of the AUVP. For Air Systems In-Service this includes periodic reviews of the usage, together with identification of likely future changes. For Air Systems not yet In-Service, this activity is likely to be limited until a enough data is collected to support the DUS; however, read across from current Air Systems may be used where applicable to the role.

SOI / SOIU

2. **SOI.** The SOI is owned by the ►ADH / AM(MF)◄ and is a descriptive, rather than prescriptive, document containing anticipated usage data extracted from MOD requirements and, where applicable, existing legacy Air Systems. The SOI provides essential information for the DO to determine the DUS, and thus produce the FTR or equivalent fatigue evidence document. For off-the-shelf or multinational projects where the DUS is not based on a UK-specific SOI, the DO may use a UK-specific SOI to identify any deviation between design assumptions and expected future MOD usage in order to assess the effect on Airworthiness, ie component lives, inspection periodicities etc.

3. **SOIU.** Once the Air System Type has accumulated sufficient representative In-Service usage data, the SOI review will produce an SOIU that replaces the SOI and documents the actual usage since ISD. This SOIU formally conveys the actual usage to the DO and allows the DO to assess the impact on the Integrity Baseline through analysis in comparison with usage assumptions; the implications are fed into revised fatigue and damage-tolerance inspection thresholds. The SOIU is the sole authoritative source of descriptions of the SPCs that will be recorded by pilots in their post-sortie feedback declaration.

4. **FW.** For FW Air System and some RW, the SOI contains a breakdown of the typical SPCs for the Type in each of its roles and at each typical operating location. SPCs are typically expressed in terms of height, time, speed, mass and configuration data that is derived from predicted sortie information, Aircrew knowledge and the Concept of Operations for the Type.

5. **RW.** For RW, usage may also be expressed in terms of low and high-cycle loading usage spectra for each typical role and environment. For Air Systems that are subject to surface (land / sea) transportation methods, additional surface movement profile codes may be required. The initial issue of the SOI will be produced as early as possible in the project life cycle. The SOI will be reviewed annually by the Requirements Manager and any change will be reviewed by the DO. Once In-Service usage data becomes available the SOI is converted into an SOIU.

SOIU review cycle

6. Since usage inevitably changes over the life of a Type, it is necessary to ensure that the SOIU continues to represent actual usage by means of a programme of review and update. Thus, the SOIU will be reviewed annually to check its continued validity and triennially to carry out a quantitative update, including fleet fatigue and usage data derived from IAT (incl. MDRE, HUMS, FDR, ADR etc).

7. **Roles and responsibilities.** As owner of the SOIU, the ►ADH / AM(MF)◄ can delegate technical information sponsorship and management of the document to the DT. As Technical Information (TI) sponsor of the SOIU, the DT will plan and allocate resources for these reviews and initiate them through the IWG or equivalent. The DT will appoint a Publication Organization to coordinate the results of these reviews and issue amendments as required.

8. The appropriate ►ADH / AM(MF)◄ conducts the annual review of sortie profiles and / or (for RW) high and low cycle spectra which could include sortie changes and operating changes, plus the descriptive content of the SOIU, normally in conjunction with the operating Stns / Ships / Units. This may include interviews with Aircrew, reviewing the usage and mission profiles for the Air System. For the triennial review, undertaken instead of the annual review in that year, the DT may appoint another competent organization, in addition to the PO, to perform the usage data analysis and to coordinate inputs from other stakeholders. MAA Certification Division, may provide regulation, advice, technical clarification and assurance to the DT for SOIUs.

9. The SOIU annual review is a 'table-top' staff review of the fleet usage carried out in association with the appropriate ►ADH / AM(MF)◄ staff. The objective of this review is to ensure the continuing relevance of the information presented and detect any significant changes since the SOIU was last updated. The review will consider the continued accuracy of usage profiles and any known update on roles, operational use or deployment.

10. The SOIU quantitative review, carried out at regular 3-yearly intervals, is the responsibility of the appropriate ►ADH / AM(MF)◄ who can delegate the Technical Information sponsorship and management to the DT, with the DT appointing a Publisher to co-ordinate the results of the review. The review is carried out with support from other stakeholders including operators and the DO.

11. The objective of the quantitative review is to provide an accurate presentation of the data for the actual usage since the previous quantitative review and aims to confirm that the SPCs are current, including the percentage of time spent in each of them. The source of data and the level of details within the data will vary between Types. Data sources may include, but not be limited to: OLM / ODR, LITS, GOLDesp, HUMS, MOD Forms 724 and 725, and Aircrew interviews

12. If at any time the operating usage is thought to differ from the SOIU, the person or organization perceiving the change in usage will report their concern to the RTSA, DT and ►ADH / AM(MF)◄. When such a report is made, the RTSA, in conjunction with the DT and DO, will consider the effect on the Safety Case and the associated releases and amend them as necessary. Fatigue life can be estimated using a range of metrics such as FI, Ground-Air-Ground cycles, flying hours, pressurisation cycles, etc.

13. It is advisable that planning is initiated in advance of the quantitative review to ensure that the data can be compiled and analyzed and the SOIU draft then reviewed by stakeholders to ensure that all current information has been checked and agreed in advance of the SIOU endorsement and publication.

SOIU update

14. The triennial review will normally result in publication of a new version of the SOIU. In addition to the annual and triennial reviews, any significant changes in operation will be brought to the attention of the IWG by the appropriate ►ADH / AM(MF)◄ as and when they arise. The appropriate ►ADH / AM(MF)◄ will confirm to the DT the accuracy and validity of the content and the RTSA will confirm that the statistics and descriptions of operations confirm that the usage is within the RTS limits, this doesn't mean that if the statistics prove the Air System is operated within the RTS limits that the usage isn't more severe than the usage assumed in the DUS. Severe usage could exceed the DUS, this could be as a result of operating changes that require more time spent at high mass, including but not restricted to, the clearance to fit external fuel tanks or weapons systems and all discrepancies will be investigated. In all cases, the appropriate ►ADH / AM(MF)◄ will approve amendments and reissues of the SOIU. If amendments or reissues of the SOIU arise from significant changes to usage and / or intent, the DT will task the DO to assess the fatigue and damage tolerance and SI implications introduced by changes such as increased undercarriage functional checks that require more frequent jacking operations than originally assumed. Previous issues of the SOIU will be retained by the DO iaw RA 5726(4)►[67]◄ to maintain the full historical record of usage and to understand the implications and significance of recent changes. Other SI

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[67] ►Refer to RA 5726(4): Validating Integrity.◄

stakeholders may also keep previous issues of the SOIU as required.

Stakeholders

15. **Roles and Responsibilities**. AUVP stakeholders have specific roles and responsibilities; the details given below are generic in nature and may vary in detail between Types:

a. **►ADH / AM(MF)◄.** As the owner of the SOIU and SME for operations, the ►ADH / AM(MF)◄ is responsible for:

(1) Reviewing its descriptive content during annual and triennial reviews, and propose amendments when necessary;

(2) Alerting the IWG to significant operating changes that are to be reflected in the SOIU at other times;

(3) Ensure the applicability and accuracy of SPCs and / or Mission Codes, any changes may result in the reissue of the DUS.

(4) Confirming to the DT that the content of the SOIU, as regards operations, is valid and accurate, following revision or amendment;

(5) Through the CAMO, provide assurance that the type-specific SOIU fulfils its essential SI functions;

(6) Ensure that Aircrew are familiar with the SOIU so that any deviations can be brought to the attention of the DT; and

(7) Authorize amendments or new issues of the SOIU for release and publication.

b. **RTSA.** The RTSA are to review the SOIU and its amendments, including usage data to confirm that Air Systems are being operated within the limitations of the RTS; suspected conflicts are to be investigated in cooperation with the TAA.

c. **DT.** As TI sponsor and manager of the SOIU, the DT is responsible for the following:

(1) Initiate annual and triennial reviews through the IWG or equivalent.

(2) Appoint a Publication Organization.

(3) Ensure that processes are in place to provide IAT data for triennial reviews.

(4) Task a competent organization to carry out the SOIU review, including an audit trail to the source of all changes.

(5) Task the DO to compare the usage to the DUS and subsequently provide to the MOD a statement of acceptance or advice on sustaining SI.

d. **DO.** The DO is responsible for:

(1) Specifying what data could be included in the SOIU review, the format in which it is presented and may be tasked with compiling the usage data for triennial reviews;

(2) Comparing actual usage as presented within the SOIU with the usage assumed in the DUS and providing the TAA a statement of acceptance or advice on sustaining SI.

(3) Analyzing the implications of SOIU changes upon component / airframe lives, fatigue test spectra, individual Air System tracking, Maintenance schedules and Airworthiness.

e. **Operating Units.** Operators (flying Aircrew, squadron, standards and HQ staff) are stakeholders within the AUVP and are responsible for:

(1) Accurate data recording (post sortie feedback etc);

(2) Correct recording of SPCs and mixes of SPCs; and

(3) Ensuring that all profiles flown are included in the SOIU and accurately described.

(4) Standards staff may also make other Aircrew aware of the SOIU and its intended use. The SOIU is the single source of all SPC breakdown percentages.

f. **Data Source / Data Management Agency (DMA).** The DMA is the organization who, for a specific Type or SOIU review, is responsible for the collection and analysis of usage data. The DMA could be any of the following, the designer / DO, a contractor or the Independent Structural Airworthiness Advisor (ISAA). During the Annual Review a DMA would not normally be required. During the Quantitative (3 year) Review a DMA will be appointed by the DT who is responsible for:

(1) Collating the data necessary to undertake the analysis of current usage

(2) Performing a validation exercise to provide confidence that the data is free from errors / inaccuracies

(3) Process the data to produce relevant statistics in a suitable format for presentation in the SOIU. These statistics may include tables based on SPCs. Maintain an Audit trail of the data source.

g. **ISAA.** An ISAA will be involved in the stakeholder meeting to assist in the scoping of the content of the SOIU*.* During both the Annual and Quantitative Review, the Independent Advisor is responsible for providing independent comment and a review of any changes to the SOIU.

h. **Publisher**. The Publisher is the organization responsible for the incorporation of the approved SOIU into the ADS, and promulgation of respective ADS changes, to the user community. Thus, the Publisher will coordinate the SOIU review by acquiring all relevant up to date information to print and distribute the SOI / SOIU, whilst maintaining an audit trail of content source.

AUVP activities

16. The following is a detailed breakdown of the AUVP activities; a representation of this process is shown in Figure 26 below.

17. SOIU Annual Review:

a. Initiate the annual review. The annual review is normally initiated at the IWG and will include the identification of the stakeholders. This may include holding subsequent meeting(s) to define the roles and responsibilities of the stakeholders that will plan and / or complete the review.

b. **Stakeholder Roles and Responsibilities:**

(1) Stakeholders (normally the DT and ►ADH / AM(MF)◄ staff) to consider any known or anticipated changes to operations. Factors to be considered include, but are not limited to:

(a) Operational Deployments;

(b) New roles or equipment (weapon) fits;

(c) Significant changes in percentages of profiles / SPCs being flown or to be flown; and

(d) Significant changes to Maintenance practices or procedures.

(2) The information obtained will be considered to determine if a revision (amendment) to the SOIU content is required.

18. SOIU Triennial Review:

a. **Initiate the triennial review:**

(1) The initiation of a triennial (quantitative) review, which is undertaken instead of the annual review in that year, needs to be well ahead of when the SOIU revision would need to be issued.

(2) The requirement for a quantitative review will normally be the approaching of the 3-year anniversary of the issue of the current version of the SOIU.

(3) The requirement for a quantitative review will normally be the approach of the 3-year anniversary of the issue of the current version of the SOIU. A view will be taken as to how long the SOIU review process is likely to take and therefore how far in advance the quantitative review needs to be initiated. It would not be unreasonable to initiate the quantitative review at the completion of the annual review a year ahead of the 3-year anniversary of SOIU issue.

(4) The initiation would normally be discussed and be formally agreed at the relevant DT SI meeting, which will be held every 6 months.

(5) Consideration may be given by the TAA to allow some quantitative reviews to be extended beyond the 3 year point. The likely considerations for extending the review could be the maturity of the Air System, the stability of use and usage profile and any associated Risks.

b. **Stakeholder Roles and Responsibilities:**

(1) The DT, appropriate ►ADH / AM(MF)◄, DO and ISAA are normally actively involved with the triennial review of the SOIU.

(2) The stakeholders are to identify who is going to act as the Reviewing Officer on behalf of the appropriate ►ADH / AM(MF)◄. This could be the appropriate ►ADH / AM(MF)◄ or RTSA staff, Group or Headquarters staff, Standards staff and squadron Aircrew.

(3) Data Management Agency. The selection of the 'Data Management Agency' who will actually undertake most of the data manipulation will depend upon a number of factors such as, but not limited to:

(a) Availability of data, in what form (electronic or hard copy);

(b) Source of data (MDS, LITS, GOLDesp, Designer, other IT system);

(c) Extent and complication of analysis task;

(d) Capacity of Stakeholders to undertake the data analysis task;

(e) Stability of use and usage profile; and

(f) Assessment of Risk.

(4) To be clear as to their responsibilities during the quantitative review, each stakeholder will be briefed on their responsibilities and the details of the triennial review for the specific Air System type and Mark. The responsibilities are outlined in Chapter 2 of this document. If necessary, hold a Stakeholders meeting to ensure all stakeholders are clear as to their respective commitments.

c. **Data acquisition, validation and analysis**. The data to be used for the Quantitative Review could come from a number of sources. The handling of the data will often depend upon its source.

(1) **LITS.** Several Air System’s usage data is collected via the LITS system.

(2) **MDS.** Many older Types have usage data recorded on the MDS, comprising of a transcription of the data from MOD Form 725 forms.

(3) **DO.** Newer Air Systems may have usage data collected by the DO; therefore,

they will need to be tasked with extracting the SOIU data.

(4) **Operator Interview.** ►ADH / AM(MF)◄ and / or Aircrew review and interviews are to be carried out.

(5) **Other Data.** Where other data sources are used, the TAA will need to ensure that the correct data can be extracted for use by the data management agency.

(6) **Data Validation.** No matter where the data is sourced, it is important that the data has an assurance level commensurate with the importance to which it will be put. Therefore, it is essential that some form of data validation be carried out.

(7) **Data Analysis.** The plan for the data analysis will consider whether any stage reviews of the analysis are required. ie when initial analysis has been completed, but is in the 'raw' state, it is advisable to have key stakeholders review the outcome to determine if there are any unexpected results.

(8) **Presentation.** It is often useful to provide a presentation of data, which shows the current SOIU usage, plus the minimum, average and maximum value from the analysis. This can be used to highlight any anomalous data, or unexpected results (incl. usage trends), which can be investigated further if required.

d. **SOIU Changes.** The stakeholders are to be given the opportunity to review the draft SOIU. The proposed changes are to be clearly identified ie it ought to be easy to compare the content and data of the current SOIU with the content and data of the new (draft) SOIU. The stakeholders are to have the opportunity to comment on the proposed changes to ensure they reflect reality. There will be a clear documentation audit trail of all comments and amendments that are applicable to the revised SOIU. If the stakeholders' review / comments results in significant changes, the Publisher will re-issue the draft SOIU for a second review.

e. **Issue and distribution of the SOIU:**

(1) Obtain signed appropriate ►ADH / AM(MF)◄ endorsement.

(2) LoAA holder to sign-off SOIU iaw the DT procedures.

(3) The signed documents are to be returned to the Publisher.

(4) The appropriate ►ADH / AM(MF)◄ and DT are to confirm the distribution list. This list will vary for each Type and Mark but would typically include all squadrons operating the Type, the user Command(s), the DT, the Designer / DO Structures team, the ISAA and the MAA relevant SI desk officer.

(5) Publisher to distribute the revised SOIU to the stakeholders.

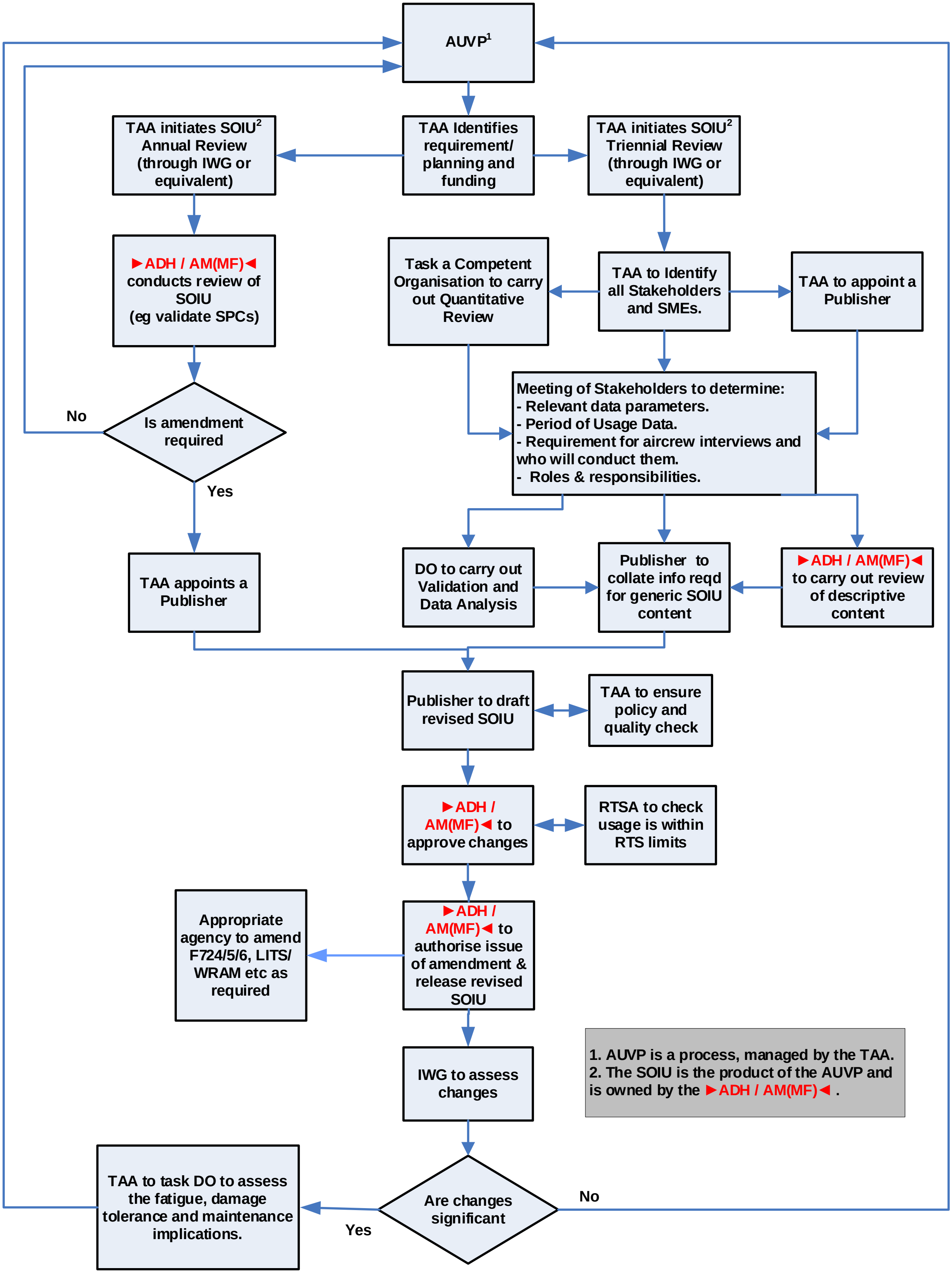
f. **DO Review.** The TAA will task the DO to review the new issue of SOIU. This review will include, but not be limited to, the following aspects:

(1) Comparing the usage presented in SOIU with the DUS and associated assumptions; and

(2) Reviewing all information within the SOIU to identify any aspect that may affect continued SI or Airworthiness.

(3) Upon completion of its review the DO will issue a formal statement on the continued SI, including Airworthiness, of the Type to the TAA. Any issues identified by the DO will be considered at the appropriate SI forum.

Figure 26 - Air System Usage Validation Programme Flowchart



1. AUVP is a process, managed by the TAA.
2. The SOIU is the product of the AUVP and is owned by the ►ADH / AM(MF)◄ .

g. **Quantitative Review Stakeholder Meeting.** The aim of the meeting will ensure that all stakeholders are clear as to what is expected of them in support of the Quantitative Review. In addition, this meeting provides an opportunity to plan and agree tasks, timescales, and review meetings. A stakeholder meeting may not be required if the aims can be adequately covered; however, consideration will be given to the fact that many of the stakeholders may not have undertaken a Quantitative Review before. Possible Agenda Items could include:

(1) **Background:**

(a) Introduction.

(b) Overview of ESVRE and AUVP.

(c) Why a Quantitative Review is required?

(d) Who are the Stakeholders?

(e) Any known issues: ie changes in usage to be analyzed, input or specific need from DO.

(f) Planning.

(g) What are the overall timescales?

(h) What are the constraints?

(i) Detailed plan for who will do what, by when.

(2) **Data Management:**

(a) What is the requirement for data?

(b) Where is the data stored?

(c) Is there more than one data source.

(d) What timescale is data available for.

(e) Aim would be 3 years since last Quantitative Review.

(f) Validation of data - Who is going to analyze the data.

(g) Is there going to be review / validation of output of the analysis, and if so, by whom.

(h) When were the MDS / LITS data validation rules last reviewed? (It is recommended that validation rules are to be reviewed during the Quantitative Review).

(3) **SOIU Review and Issue:**

(a) Brief review of the adequacy of current SOIU to identify possible areas for improvement in both content and presentation.

(b) Identify who will review Draft SOIU for the ►ADH / AM(MF)◄ and for the TAA.

(c) Ensure there is a plan for LoAA sign-off.

(d) AOB.

(e) Discuss requirement for further progress meetings.

h. **Data Collection.** It will be likely that there will be a significant amount of useful data available; however, extracting it in a form suitable for populating the SOIU data tables can often be complex. Accordingly, considerations during planning are to include:

(1) Scope of data. There will be a need to be very clear as to what data elements are needed in order to derive the SOIU tables.

(2) Need to be clear as to what dates the data is to be extracted for.

(3) The output format of the data.

(4) The data file itself can be very large. This can cause issues with simply moving it about (email or CD). Moreover, there may be row / column limits that could be breached for large data files; therefore, consideration will be given to producing

separate files for each Type or Mark for each year.

(5) The usage data gathered from the MOD Form 724 / 725 can result in data taking a long time to be available electronically, as delays can occur in processing completed forms.

i. **Data Validation.** Checks need to be undertaken to ensuring that the presented data is correct. Consideration will be given to undertaking some or all of the following:

(1) Check all sortie data is in the required range.

(2) Are there any unexpected, missing or corrupt data rows or cells?

(3) Are the minimum and maximum values of all data elements within expected ranges. If any data is outside the values or range further investigation will be carried out to try and ascertain the reason, ie is it corrupt or did the Air System fly outside the range.

(4) What validation was carried out on data input (electronic or manual).

(5) Additional validation checks can be carried out specific to the Type and Mark. This could include checks such as:

(a) Are sorties over a certain duration also listed as Air-to-Air Refuelling (AAR) sorties.

(b) Is take off mass consistent with sortie type / duration.

(6) Check to ensure that all the correct Sortie Profiles have been recorded and investigate any missing data.

j. **Other issues.** In collecting the data for analysis, it is important to make sure that all the data necessary for the SOIU is output from the data source. At the time of requesting data it is worth constructing a matrix of data required (SOIU table entry) versus data available (data element from source database or MOD Form 725). Furthermore, there may be a requirement for other data, in addition to 'basic' sortie-derived data, to permit the necessary SOIU calculations . This could include

(1) Mass data for basic Air System.

(2) Mass data for stores / weapons.

(3) Definition of sortie time (from engine start, taxi, or take off).

k. ►ADH / AM(MF)◄ **/ Aircrew Review of SOIU.** The purpose of the ►ADH / AM(MF)◄ / Aircrew review of the SOIU will ensure that it accurately reflects the operating use of the Type and Mark and future intent. The review will consider the following:

(1) Determine the need to carry out Aircrew interviews to explain the need for the SOIU and an overview of ESVRE and AUVP required.

(2) The operating profiles are an accurate reflection of current operations.

(3) The SPC graphs (if any) are reasonable averages for the sortie type.

(4) The heights and speeds detailed are valid.

(5) The mass data (where given) is a reasonable average for current flying.

(6) The detailed operating techniques (such as take-off, climb, cruise, in-flight manoeuvres, etc) are a fair and accurate reflection of current operating use.

(7) Do all other operating aspects within the SOIU seem reasonable.

(8) Aircrew to consider all future, or potential, changes in operating use; to include; new / amended operating methods, changes to operating locations, etc.

(9) Review and update as necessary to determine the continued accuracy and

relevance of the descriptive content and operating data of the SOIU including:

(a) Operating locations and conditions.

(b) Speeds, ‘g’ levels, altitudes and other parameters quoted in manoeuvre descriptions.

(c) Frequency of occurrence or percentage breakdown of events.

(d) Stores carriage reflects only those in current / planned usage.

(10) Update the table of planned SPC usage by sqn type.

(11) Identify any future plans to change roles, sortie profiles, deployments, or major equipment modifications and stores configurations. Include all known developments that will affect usage over the next 5 years. Any stated developments that have become current activities are to be moved into the preceding chapters.

l. **Appointed Publisher.** Once the various stakeholder reviews have been completed, the appointed Publisher is to conduct an in-depth review of the SOIU to ensure that it is iaw the latest SOIU template. Where necessary, additional information will be sought from stakeholders to ensure that the SOIU accurately reflects:

(1) New or changed Maintenance or engineering schedules or practices.

(2) New locations or agencies for undertaking Maintenance.

(3) Knowledge of any likely future changes in Maintenance activities.

(4) Add or amend Usage / SPC information to reflect current or authorized usage profiles.

(5) Using data from analysis phase, present new figures within annexes to reflect actual usage.

Chapter 9: Electrical Wiring Interconnect System Integrity Management

Definitions

1. **EWIS.** MAA02 gives the definition of EWIS as:

> *"The Electrical Wiring Interconnect System (EWIS) includes any wire, wiring device or combination of these including terminations installed in any area of the Air System for the purpose of transmitting electrical energy or data between two or more termination points."*

EWIS will be considered in conjunction with the definition for SysI as it forms an integral part of SysI. These definitions have been significantly enhanced within the transformed Def Stan 00-970 where the EASA CS Clauses, and supporting Acceptable Means of Compliance, define the certification specification requirements for EWIS. Accordingly, these clauses are to be included by the TAA when developing the Type electrical installation, a fundamental element of the IM Establish phase.

2. **Optical Fibre Interconnection System (OFIS).** AP101A-0006-1 defines an OFIS as:

> *"Any optical fibre or cable, including termination devices, installed in any area of the platform for the purpose of transmitting optical signals between two or more intended terminations points."*

OFIS covers those components within shelves, panels, racks, junction boxes, distribution panels and back-planes of equipment racks but excludes components within the Line Replacement Unit (LRU) / Line Replacement Items and associated fixed connectors on those LRUs. As for EWIS, OFIS will be considered in conjunction with the definition for SysI. Note, that throughout this document, the term EWIS is used to encompass both EWIS and OFIS. Where issues specific to OFIS are encountered, these will be highlighted.

EWIS

3. **The History of Air System Wiring.** Early Air Systems had very little electrical wiring, and with minimal interaction with system operation, it was shown little respect. It was often considered to be a fit and forget item, with no further monitoring. As Air Systems evolved and became more advanced, so did the volume and complexity of their electrical wiring. However, the fit and forget attitude persisted with practically no Husbandry being undertaken. Little or no thought was given to the effect that age, temperature, humidity, contamination and vibration might have upon wiring.

4. However, on 17 Jul 96 a Boeing 747 registered to Trans World Airlines operating as flight TWA 800, exploded in mid-air killing all 230 people on board. Two years later, on 2 Sep 98, Swissair flight SR111 crashed into the Atlantic Ocean with the loss of 229 people. These tragedies caused an immediate and intense public scrutiny of wiring Integrity, which generated significant pressure to acknowledge the importance of wiring installations. The US Congress initiated the Ageing Transport Systems Rulemaking Advisory Committee which, as part of its remit, was to establish a review of wiring Integrity. The output from this committee has changed how EWIS is perceived and generated the legislation and practices that are seen today and are reflected in the transformed Def Stan 00-970 and the MAA's approach to managing System Integrity.

5. A key element in the longevity of an EWIS installation is the design and the quality of the installation standard. These provide the basis for the TAA instructions for continued Airworthiness and future Maintenance requirements. Less stringent design / installation standards and build quality have the consequence of a greater Maintenance burden as the airframe / installation ages.

6. The intent of EWIS design is to build a system with the same service life as the airframe Structure. However, there are a few additional factors that are to be considered by the TAA and the DO during the design (Establish Integrity) phase to minimize the Risk of premature ageing and deterioration. These are:

a. Environmental Conditions.

b. Fluid contamination.

c. Potential for Mishandling.

d. Potential for poor Husbandry.

7. **Through-Life Threats to System Integrity.** The threats to System Integrity and thus EWIS Integrity that will be countered throughout the life of the Air System are:

a. Ageing components.

b. Change of usage.

c. Fatigue.

d. Overload.

e. Lack of configuration control.

f. AD and / or ED.

g. Procedural (design and manufacturing, Maintenance or supply) error.

h. Obsolescence.

i. Legislation changes.

j. A combination of two or more of the threats.

8. **Impact of Loss of EWIS Integrity**. There is an obvious cost in terms of lives and equipment lost in Accidents. However, the cost of recovery, even when there hasn't been an Accident, is also very high. A number of high profile civil and military Accidents have highlighted the potential impact of EWIS failure.

9. The breakdown of insulation over time is well documented. This breakdown is another compelling reason to improve wiring inspection programmes. The civil regulators, namely the FAA, conducted a study which concluded in a statement that:

> *"The continued safe operation of aircraft beyond their expected service life depends on the safe and effective transfer of power and electrical signals between aircraft electrical components. This in turn requires that the physical Integrity of electrical wire and its insulation be maintained. As aircraft increase in age and cycle time, the wire insulation may be degraded to the point that it is no longer capable of ensuring the safe transfer of electrical current."* (FAA, 2008).

10. The above statement is never truer today with the prevalence of more digital Air Systems and "fly by wire" being the norm.

EWIS IM

11. EWIS is a major system that requires frequent monitoring to ensure it will perform effectively for the life of the Air System. Poorly managed EWIS will have detrimental effect on Airworthiness and hence increase RtL. EWIS will be maintained to an acceptable level that has been derived from the analysis of the following data; 'as designed', 'as built', 'as maintained' standards and the various operating environments including the 'as required' standard. Therefore, the TAA ensures that:

a. The Air System complies with the approved EWIS standard.

b. The Air Systems are subject to Air System Wiring Husbandry (AWH).

c. The use of an environmentally sealed, in-line, crimped splice in the Air System's EWIS are defined.

d. Air System Electrical Wire (AEW) meets the design standard and that it is afforded the same importance as that of the Air System Structure.

e. The Integrity of Data Buses on the Air Systems is maintained.

f. The Maintenance policy for any Fibre Optic (FO) systems installed on their Air System is defined and promulgated.

12. **Roles and responsibilities.** MAA Certification Electronic Systems (Cert ES) branch is responsible for defining and promulgating the requirements for EWIS.

a. However, the Air Commodities Delivery Team (ACDT) has the responsibility of assisting MAA Cert ES in:

(1) Defining and promulgating requirements on the support of EWIS and associated components for both future and In-Service Air Systems.

(2) Advising on the relevant aspects of the formulation of Air System requirements and commenting on specifications produced by Defence Equipment and Support.

(3) Providing advice on methods that may be employed during Air System design, manufacture, support and modification to promote high Integrity and low cost of EWIS support.

(4) Advising Air System DTs on the specifications and subsequent modification and Maintenance of their EWIS installations.

b. Similarly, TAAs are responsible for:

(1) Ensuring that the EWIS meets the requirements and associated processes, via agreed and defined standards. The standards will be applicable to new build Types and to Type Design changes to existing Types.

(2) Ensuring that suitable procedures and facilities exist for training all ►tradespersons◄ involved in the support and Husbandry of the EWIS.

13. **Training.** Air System Wiring Husbandry training aims to ensure that an education campaign on AWH is maintained, which is applicable to all personnel involved in maintaining and handling Air System wiring, including non-technical personnel. Introduction to EWIS begins during Phase 2 training and is then reinforced at Unit level with initial and refresher training. Consideration is also to be given to other disciplines that may have access to EWIS. All ►engineering trades◄ employed on the Maintenance of Air System wiring undergo formal familiarisation training in AWH appropriate to their level of responsibility. This also requires that all relevant non-technical personnel are given suitable awareness training in the need for good wiring Husbandry. In particular, personnel within the logistic organizations are to be briefed on the correct method of transportation and delivery of Air System wire between the point of issue and the end user.

14. As a teaching aid, the MOD has produced a DVD AF4056/07 Aircraft Wiring Husbandry Parts 1 and 2 available via British Defence Film Library.

a. **Part 1** is for all Air System engineering trades and support staff, providing an appreciation of good wiring Husbandry and its implications to flight safety. It provides a history of wiring Husbandry, giving examples of wiring installations, both good and bad.

b. **Part 2** is specifically for Avionic Trades and takes an in depth look at specific techniques and trade practices within wiring Husbandry and reiterates those learnt during trade training.

15. Sources of EWIS education external to the MOD are primarily EASA accredited EWIS training providers. These provide the mandated training on EWIS as decreed by the EASA and FAA for operations under FAR/CS 25 Large Aircraft approval. The FAA has produced a presentation with associated notes to assist with EWIS training designed to meet the regulatory requirements[68].

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[68] EWIS Best Practices Job Aid Revision: 2.0.

16. **Precision Termination Tools (PTT).** MAM-P Chapter 6.2 details the training pertaining to PTT which is an essential element to system Integrity with regards to EWIS. AP101A-0005-1, Aircraft Wiring Standards and Practices (Wiring Husbandry) provides Terms of Reference for unit PTT and Wiring Husbandry Coordinators. These then detail the higher-level training objectives for both PTT and Wiring Husbandry subjects to be delivered by these coordinators. Similar information for fibre optic installations can be found in Air Publication AP101A-0006-1, Aircraft Fibre Optics Standards and Practices.

17. With regards to the engineering element of wiring Husbandry, ►engineering trades◄ are to, when completing Maintenance tasks:

a. Carry out an unaided visual examination, as far as possible, of any adjacent exposed cables or looms in the area of work. The examination is for insulation damage, contamination, insecurity of attachment or poor routeing.

b. Report any insulation damage, contamination, insecurity or poor cable routeing found, ensuring that a cable examination is carried out by a SQEP individual.

18. Note that no Air System is returned from a depth Maintenance organization into service with any outstanding MOD Form 704 wiring Husbandry entries, unless prior authorization from the TAA and / or CAMO has been granted.

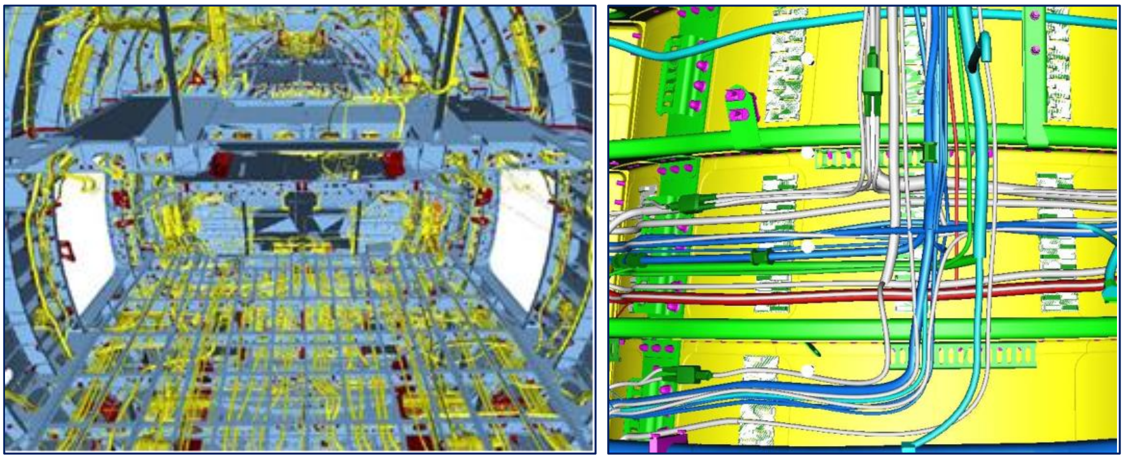
ESVRE Framework and EWIS

19. As with other IM disciplines (such as Structures, propulsion and systems), the EWIS ESVRE approach does not introduce anything fundamentally different from the traditional processes and practices already being adhered to. However, ESVRE introduces a formalized IM process in which issues can be identified and managed accordingly; therefore, ensuring EWIS is considered a system in its own right (including its management) is fundamental to good EWIS IM.

Establish

20. Establishing EWIS Integrity starts with the boundaries of the EWIS being properly defined. The design standard for the EWIS installation needs to be agreed at the earliest opportunity during the design stage. This will ensure integration with airframe and system interconnectivity. The images below show the typical detail regarding the EWIS interaction with Structure during the design stage. The definition of the EWIS requirement will underpin the way that EWIS is managed whilst in service. **Figure 27** shows, in 3D computer aided design (3D CAD), the complexity of an EWIS installation and the relationship with the environment including proximity to Structure and pipework.

Figure 27 - EWIS 3D CAD Representation



21. In order to fully realise the objectives of EWIS Integrity operators, TAAs and Maintenance providers, will need to rethink their current approach to maintaining and modifying EWIS and systems. This may require more than simply updating Maintenance manuals and work cards and

enhancing training. Maintenance personnel need to be aware that EWIS are to be maintained with the same level of intensity as any other system. They also need to recognize that visual inspection of wiring has inherent limitations. Small defects such as breached or cracked insulations, especially in small gauge wire may not always be apparent. Therefore, effective wiring Maintenance combines visual inspection techniques with improved wiring Maintenance practices and training.

22. Good wiring Maintenance practices are to contain a '*protect, clean as you go'* Husbandry philosophy. In other words, care will be taken to protect wire bundles and connectors during work, and to ensure that all shavings, debris and contamination are cleaned up after work is completed. This philosophy is a proactive approach to wiring system health. Wiring needs to be given special attention when Maintenance is being performed upon it, or close proximity to it. This is especially true when performing Structural repairs or other modifications.

23. Supporting publications provide methodology to maintain Integrity. The ability to capture and process the available data required is paramount when establishing an effective EWIS Integrity Program. This Program will be tailored to Air System specific circumstances (ie Maintenance data, financial constraints, OSD, age, statement of intended use, etc).

24. Execution of an EWIS program will assist in the identification and justification of resources required to maintain EWIS Integrity and ultimately Airworthiness. Strategies to develop an EWIS Integrity action plan will vary from Air System to Air System, considering specific circumstances and may include full rewiring, targeted rewiring, training initiatives, automated wiring test, scheduled inspections, periodic data monitoring, foot-printing, improved chafe protection, etc. These processes may also be modified as required to provide metrics on the effectiveness of the implemented EWIS Integrity Strategy (eg RCM analysis, ZHA, etc). A properly applied EWIS Integrity Program will promote a reliable and airworthy EWIS which will ultimately reduce Air System through life costs and improved mission availability.

Standards

25. Standards play a fundamental part in both the procurement and engineering aspects of installation. They provide a common reference for all, from the procurement of EWIS components through to the standard of installation expected from a sub-contractor. Having defined standards ensures all parties are familiar with the requirements and their responsibilities. The primary requirement for EWIS installations in Air Systems is Def Stan 00-970; this is the Primary Certification Code, iaw RA 5810(4)►[69]◄, for all new UK military Air Systems requiring registration by the MAA, and Major Changes to the Type Designs already on the Military Register.

26. **Engineering standards**. The installation of an EWIS, iaw established and proven standards, is a key element to its longevity. Comprehensive commercial EWIS standards can be used to complement Def Stan 00-970 or may even form the basic installation requirement are:

a. **SAE AS 50881**: Wiring Aerospace Vehicle. This standard covers all aspects in EWIS from the selection through installation of wiring and wiring devices and optical cabling and termination devices used in aerospace vehicles. Aerospace vehicles include ►crewed◄ Fixed and Rotary Wing Air Systems, RPAS, lighter-than-air vehicles, missiles and external pods. This is a US national standard that is a conversion of Mil-W-5088.

b. **ASD EN 3197:** This standard provides instructions on the methods to be used when designing, selecting, manufacturing, installing, repairing or modifying the electrical and optical interconnection networks, EWIS, and OFIS. This is an EU standard that emulates AS50881; furthermore, EN 3197 is adopted as an international standard through ISO 15699: Aerospace Vehicle Interconnection Installation Practices.

c. **BS G 244**: Code of practice for installation / repair of EWIS. This legacy code of practice gives the preferred choice of electrical cables, splices, terminations, connectors and

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[69] ►Refer to RA 5810(4): Type Certification Basis (MRP Part 21.A.15).◄

accessories and the methods of installing these elements in wiring system form. The guidance given in this document is intended for general applications where design standards are not provided by a recognized Authority.

27. These standards, where not called out directly as a requirement, often form the basis for OEM installation standards. The OEM standard will detail their interpretation of the installation requirement or where the OEM requirement is more stringent than that specified in the national standard.

28. **Procurement standards.** Both EN 3197 and AS 50881 detail comprehensively a list of the standards to which EWIS components are to be procured. ASD Stan is responsible for EN 3197 and operate a database of approved parts and their qualified sources. The US DoD operates a similar but somewhat more comprehensive Qualified Parts Database which also identifies qualified sources for components. The procurement of these items will only come from these sources or provided with a Certificate of Conformity proving the validity of the item. Furthermore, the OEM standards (BAES, Boeing, Leonardo, etc) will identify the approved sources for their EWIS components which maintains control over their source of supply. Beyond this, procurement is via commercially available off the shelf components which may or may not comply with a standard other than that of the manufacturer’s requirement. This is likely to be a cause for obsolescence during the later life of a Air System, certainly one going beyond 25 years in service. This is brought about through product evolution and the retirement of tooling, in some instances the source of supply no longer exists.

Maintenance Documentation

29. Adherence to standards is fundamental in the design and installation of EWIS; accordingly, the key to maintaining EWIS to those standards lies within a comprehensive Air System Maintenance Manual (AMM); the EWIS content to be considered for inclusion within the AMM is shown in **Table 8** below.

Table 8 - AMM Suggested Content

GROUP	MAJOR TOPIC	DESCRIPTION
GENERAL DATA	SAFETY PRACTICES	Safety regulations and general safety precautions to prevent injury to personnel and damage to the airplane.
	AIRCRAFT ENVIRONMENTAL AREAS	Definition of types of areas upon which wiring configuration and wiring component selection is constrained.
	CONSUMABLE MATERIALS	Wiring Maintenance processing materials (solvents, aqueous cleaners, lubricants, etc).
	WIRING MATERIALS	Materials that become an integral part of the wiring configuration excluding wire and cable, eg sleeves, shield material, tie material, sealants, etc.
	COMMON TOOLS	Description and operation of common tools.
EWIS MAINTENANCE	EWIS PROTECTION DURING MAINTENANCE	Procedures to protect EWIS during airplane Maintenance and modification.
	EWIS CLEANING	In support of inspection as well as prevention of degradation and preparation for repair; recommended cleaning materials and procedures based on type of contamination.
	EWIS INSPECTION	Criteria for correct installation, correct wiring assembly configuration; damage conditions and limits for wiring components (wire and cable, termination types, electrical devices); factors that warrant disassembly for inspection; determination of cause of damage.
	EWIS TESTING	Wiring Integrity testing and fault finding.

GROUP	MAJOR TOPIC	DESCRIPTION
	EWIS DISASSEMBLY	Data and procedures in support of inspection, cleaning when applicable; also supports new wiring installation.
	EWIS REPAIR AND REPLACEMENT	Repair of wiring installation, wiring assembly configuration, wiring components (wire and cable, wiring terminations, electrical devices); wire and cable replacement; wiring functional identification.
WIRING INSTALLATION	WIRE SEPARATION / SEGREGATION	Explanation of separation / segregation categories, separation / segregation identification, and necessary conditions for maintaining separation / segregation.
	ELECTRICAL BONDS AND GROUNDS	Bond surface preparation, ground hardware configurations, bond (earth) Integrity testing.
	WIRE HARNESS INSTALLATION	Routing, supports; wiring protection, factors affecting wiring assembly configuration; connection to equipment, new wiring, removal from service.
WIRING ASSEMBLY	WIRE AND CABLE TYPES	The principal material component of airplane wiring; includes type identification and basic description; alternative wire types (replacements, substitutions).
	WIRE MARKING	Marking; applicable conditions.
	WIRE HARNESS ASSEMBLY	Wiring assembly configuration: Assembly materials, layout, overall protection; factors affecting wiring installation.
	WIRE INSULATION AND CABLE JACKET REMOVAL	Wire and cable: Insulation removal, jacket removal; associated damage limits, tool description and operation.
	<<TERMINATION TYPE>> eg 38999 SERIES CONNECTORS	Wiring terminations and accessories (connectors, terminal lugs, splices, backshells, etc) grouped by termination type from simple to complex: a. Common data or procedures by group (if any) giving general information on the series and accessories, with simple handling techniques including; disconnection, reconnection, checks for correct assembly and locking, cleaning, damage limits and tooling. b. By individual type part numbers and description, with specific procedures detailing assembly methods, stripping and crimping tools and inspection criteria. Also, the operation and inspection of specialist tooling eg crimp tools.
ELECTRICAL DEVICES	<<DEVICE TYPE>> eg KLIXON 7274 SERIES CIRCUIT BREAKER	Electrical devices (circuit breakers, relays, switches, filters, lamps, etc) grouped by device type: a. Common data or procedures by group (if any), eg tool description and operation, definition of internal damage and limits, internal cleaning, accessories. b. By individual type - part numbers and description, definition of internal damage and limits (if not specified by common data), disassembly, assembly, installation.
SPECIFIC SYSTEM WIRING	SPECIFIC WIRING ASSEMBLY	For wiring that has a necessarily specific configuration (eg Primary Flight Control, Fuel Quantity Indicator System, etc): - Applicable conditions for repair and replacement. - Disassembly, assembly, installation, assembly Integrity testing.

EWIS AMM Content

30. Through RCM the requirement and frequency of general and directed inspections are determined and promulgated within the Topic 5A1 MMS or equivalent. A definition and description

of Electrical Standards Wiring and Practices Manual minimum content is necessary to ensure that operators and Maintenance organizations have the information necessary to properly manage EWIS Integrity. Although the OEM electrical installation design philosophy concerning components, installation procedures, segregation rules, etc need not be included within the AMM, sufficient minimum information will be provided to enable the end-user to maintain the Air System in a condition that conforms to the electrical installation design philosophy of the OEM. Thus, the content of any AMM will include, as a minimum, the following:

a. **Front Matter.** Provide information regarding the content and use. Ensure the document contains a table of contents or index to allow the user to readily retrieve necessary information.

b. **Safety Practices.** Provide general instruction, cautions and warnings which describe safe practices implemented prior to the start of any or all of the specific standard electrical practices contained within the core of the ADS. Safety precautions, warnings or notes specific to the procedure are to be placed within the body of the procedure.

c. **Cleaning Requirements and Methods**. “Protect, clean as you go” philosophy.

(1) Non-destructive methods for cleaning dust, dirt, Foreign Object Debris (FOD), lavatory fluid and other environmental contaminants from wiring systems.

(2) Wire replacement guidelines when an accumulation of contaminants, either on the surface and / or imbedded in the wire bundle, cannot be safely removed.

d. **Wire and Cable Identification.**

(1) Specify requirements for wire and cable identification and marking to provide safety of operation, safety to Maintenance personnel, and ease of Maintenance.

(2) Specify methods of direct wire marking. Also, identify specific requirements and cautions associated with certain types of wire marking.

e. **Wire and Cable Damage Limits.** Specify limits to positively identify the thresholds where damaged wire / cable replacement may be necessary and where repairs can be safely accomplished. Establish limits for each applicable wire / cable type, if necessary.

(1) Include damage limits for terminals, studs, connectors, and other wiring system components, as necessary.

f. **Installation Clamping and Routing Requirements.**

(1) Specify the requirements for the installation of wiring systems with respect to physical attachment to the Air System Structure.

(2) Specify applicable methods of clamping, support, termination, and routing to facilitate installation, repair, and Maintenance of wires, wire bundles, and cabling.

(3) Specify minimum bend radii for different types of wire and cable.

(4) Specify minimum clearance between wiring and other systems and Structure.

(5) Include the requirements for the installation of wiring conduit with respect to physical attachment, routing, bend radii, drain holes, and conduit end coverings. Fibre optic cables have different physical properties to conventional AEW. This will be taken into consideration when routing elements of an OFIS.

(6) Emphasise special wiring protective features, such as spatial separation, segregation, heat shielding, and moisture protection that are required to be maintained throughout the life of the Air System.

(7) Ensure necessary information for the Maintenance of bonding, grounding and lightning / high-intensity radio frequency provisions is included.

(8) Include information on the use and Maintenance of wire protective devices,

conduits, shields, sleeving, etc.

g. **Repair and Replacement Procedures**. Describe methods to safely repair and / or replace wiring and wiring system components.

(1) Include types and maximum numbers of splice repairs for wiring and any limitations on the use of splices. When splicing wire, environmental splices are highly recommended over non-environmental splices. Guidance will be provided on how long a temporary splice may be installed.

(2) Specify procedures for the safe handling, repair, replacement, disposal and general Maintenance of connectors, terminals, modular terminal blocks, and other wiring components. Taking into consideration the potential for cadmium and glass shards to be present.

h. **Inspection Methods.** In wiring inspection methods, include a general visual inspection, or a detailed inspection, as determined by MSG-3[70], RCM or Enhanced Zonal Analysis Procedure. Typical damage includes heat damage, chafing, cracked insulation, arcing, insulation delaminating, corrosion, broken wire or terminal, loose terminals, incorrect bend radii, contamination, and deteriorated repairs.

(1) Identify detailed inspections and, where applicable, established and emerging new technologies and non-destructive test methods to complement the visual inspection process.

(2) Whenever possible, ensure that inspection methods can detect wiring problems without compromising the Integrity of the installation.

i. **EWIS Support Policy Statement (SPS).** The SPS, within the Topic 2(N/A/R)1, provides direction as to how the TAA implements EWIS requirements. The SPS also provides the opportunity for Air System-specific policy regarding the management of the wiring system encompassing repair, damage limits and training requirements. Damage limits are not only influenced by wire types but may also be system dependant. This document also formalizes the relationship between Forward, Depth, DT and the Station Wiring Husbandry co-ordinator.

Sustain

31. EASA research identified some specific Maintenance and servicing activities for which more robust practices are recommended to be adopted by operators, and / or Maintenance providers. These activities are discussed in the following paragraphs. The recommendations apply to all activities, including those performed on an unscheduled basis without an accompanying routine work instruction. Performance of these Maintenance practices will help prevent contamination of EWIS that result from contact with harmful solids (such as metal shavings) or fluids during Maintenance, modifications, and repairs of Structure, and components. It has been identified that mitigation is gained with having SQEP to address the potential consequences of their actions in the proximity of EWIS.

32. **Installation, repair or modification**. Wiring and its associated components (protective coverings, connectors, clamping provisions, conduits, etc) often comprise the most delicate and Maintenance-sensitive portions of an installation or system. Extreme care will be exercised, and proper procedures used during installation, repair, or modification of wiring to ensure safe and reliable performance of the function supplied by the wiring.

33. The correct wire selection, routing / separation, clamping configurations, use of splices,

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[70] MSG-3 (Maintenance Steering Group) 'Operator / Manufacturer Scheduled Maintenance Development' is a document developed by the Airlines For America (A4A) (formerly ATA). It aims to present a methodology to be used for developing scheduled Maintenance tasks and intervals, which will be acceptable to the regulatory authorities, the operators and the manufacturers. The main idea behind this concept is to recognize the inherent reliability of systems and components, avoid unnecessary Maintenance tasks and achieve increased efficiency.

repair or replacement of protective coverings, pinning / de-pinning of connections, etc, will be performed iaw the applicable sections of the AMM, Wiring Practices Manual, or other documents authorized for Maintenance use. In addition, special care will be taken to minimize disturbance of existing adjacent wiring during all Maintenance activities. When wiring is displaced during a Maintenance activity, special attention will be given to returning it to its normal configuration iaw the applicable Maintenance instructions.

34. **Structural repairs and modifications.** Structural repair or modification activity inherently introduces tooling and residual debris that is harmful to EWIS. Structural repairs and modifications often require the displacement (or removal) of wiring to provide access to the work area. Even minor displacement of wiring, especially whilst clamped, can damage wire insulation and consequently resulting in degraded performance, arcing, or circuit failure.

35. Extreme care will be exercised to protect wiring from mechanical damage by tools or other equipment used during Structural repairs and modifications. Drilling blindly into the Structure must be avoided. Damage to wire installation could cause wire arcing, fire and smoke. Wiring located adjacent to drilling, riveting or other machining operations must be carefully displaced or covered to reduce the possibility of mechanical damage.

36. Debris such as drill shavings, liberated fastener pieces, broken drill bits, etc is not to be allowed to contaminate or penetrate wiring or electrical components. This can cause severe damage to insulation and potential arcing by providing a conductive path to ground or between two or more wires of different loads. Once contaminated, removal of this type of debris from wire bundles is extremely difficult. Therefore, precautions are to be taken to prevent contamination of any kind from entering the wire bundle.

37. Before initiating Structural repair or modification activity, the work area must be carefully assessed to identify all wiring and electrical components that may be subject to contamination. All wiring and electrical components in the debris field must be covered or removed to prevent contamination or damage. Consideration will be given to using drills equipped with vacuum aspiration to further minimize risk of metallic debris contaminating wire bundles. Clean electrical components and wiring after completion of work per applicable Maintenance instructions.

38. **De-Icing or Anti-Icing**. In order to prevent damage to exposed electrical components and wiring in areas such as wing leading and trailing edges, undercarriage bays and landing gear, care will be exercised when spraying de / anti-icing fluids. Direct pressure spray onto electrical components and wiring can lead to contamination or degradation and thus must be avoided.

39. **Inclement Weather.** EWIS in areas below doorways, floors, access panels, and servicing bays are prone to corrosion or contamination due to their exposure to the elements. Snow, slush, or excessive moisture must be removed from these areas before closing doors or panels. During inclement weather, keep doors / panels closed as much as possible to prevent ingress of snow, slush, or excessive moisture that could increase potential for EWIS degradation. The level of damp present in a moisture laden atmosphere can be mitigated with the application of dehumidification rigs. Drying out the air has been shown to decrease the degradation of wiring and reduce failure rates of avionic systems.

40. **Component removal / installation (relating to attached wiring).** Excessive handling and movement during removal and installation of components may be harmful to EWIS. Use appropriate connector pliers (eg soft jawed) to loosen coupling rings that are too tight to be loosened by hand. Alternately, pull on the plug body and unscrew the coupling ring until the connector is separated. Do not use excessive force, and do not pull on attached wires. When reconnecting, special care will be taken to ensure the connector body is fully seated, the jam nut is fully secured, and no tension is on the wires.

41. When equipment is disconnected, use protective caps on all connectors (plug or receptacle) to prevent contamination or damage of the contacts, this is especially important on OFIS installations. Bags may be used if protective caps are not available. Use of plastic bags will be temporary because of the risk of condensation or the accumulation of fluids. It is recommended to

use a humidity absorber with plastic bags. Plastic bags are not to be used for flight.

42. **Pressure Washing.** In order to prevent damage to exposed electrical components and wiring in areas such as wing leading and trailing edges, undercarriage bays and landing gear, care will be exercised when spraying water or cleaning fluids. Direct high-pressure spraying onto electrical components and wiring can lead to contamination or degradation and must be avoided. When practical, wiring and connectors are to be protected before pressure washing. Water rinse will be used to remove cleaning solution residue after washing. Breakdown of wire insulation may occur with long term exposure of wiring to cleaning solutions. Although these recommendations are good practice and technique, the AMM will be consulted for instructions regarding pressure washing.

43. **Cleaning of EWIS (In Situ).** Extreme care will be exercised and procedures will be followed during cleaning to ensure safe and reliable performance of the function supplied by the wiring. Care will be taken to avoid displacement or disturbance of wiring during cleaning of non-aggressive contamination. However, in the event of contamination by aggressive contaminants (eg saltwater, battery electrolyte, etc) such displacement may be necessary. In these cases, wiring must be released from its installation so as to avoid undue stress being induced in wiring or connectors. Similarly, if liquid contamination enters the bundle, then ties are to be removed before separating the wires for cleaning. Although these recommendations for cleaning of EWIS are considered good practice and technique, the AMM will be consulted for detailed instructions. Abrasive cleaning methods are not to be applied; additional information can be found in AP101A-0005-1[71] and AP101A-0006-1[72]. Clean only the area and items that have contamination. Before cleaning, make sure that the cleaning materials and methods will not cause more contamination. If a cloth is used, make sure that it is clean, dry, and lint-free. A connector and associated contacts are to be completely dry before mating as any fluids remaining on a connector can have a detrimental effect upon the connector and system.

44. **Servicing, Modifying or Repairing Waste / Water Systems.** EWIS in areas adjacent to waste / water systems are prone to contamination from those systems. Care will be exercised to prevent any fluids from reaching electrical components and wiring while servicing, modifying, or repairing waste / water systems. Cover exposed electrical components and wiring during waste / water system modification or repair. In some instances, there may be a need for a weak acid solution to be periodically flushed through lavatory systems to enhance reliability and efficiency of operation. In view of the effect of acid contamination on systems and Structure, the system will be confirmed to be free of leaks before using such solutions.

45. **Servicing, Modifying or Repairing Oil Systems.** Electrical wiring interconnections in areas adjacent to oil systems are prone to contamination from those systems. To minimize the attraction and adhesion of foreign material, care must be exercised to avoid any fluids from reaching electrical components and wiring while servicing, modifying, or repairing oil systems. Oil and debris in combination with damaged wiring can present a fire hazard.

46. **Servicing, Modifying or Repairing Hydraulic Systems.** EWIS in areas adjacent to hydraulic systems are prone to contamination from those systems. To minimize the attraction and adhesion of foreign material, care must be exercised to avoid any fluids from reaching electrical components and wiring while servicing, modifying, or repairing hydraulic systems.

47. **Gaining Access (Entering Zones).** When entering or working on the Aircraft, care will be exercised to prevent damage too adjacent or hidden electrical components and wiring, including wiring that may be hidden from view (eg covered by insulation blankets). Use protective boards or support platforms for adequate support and protection. Avoid using wire bundles as handholds, steps and supports. Work lights are not to be hung or supported by wiring. If wiring must be displaced (or removed) for work area access, it will be adequately released from its clamping (or other restraining provisions) to allow movement without damage and returned after work is

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[71] Aircraft Wiring Standards and Practices.

[72] Aircraft Fibre Optics Standards and Practices.

completed.

48. **Application of CPC.** When applying a Structural CPC in zones containing wire and associated components (ie clamps, connectors and ties), care will be taken to prevent CPC from coming in contact with the wire and components. Dust and lint are more likely to collect on wire that has CPC on it. EWIS may only be protected with products approved for this type of application other compounds may have a detrimental effect upon the EWIS components. CPC will be applied iaw the ADS.

49. **EWIS Provision**. The quality of the installation can only be as good as the quality of the components fitted. The storage and handling of electrical components are key elements in the durability of the installation.

50. **General Storage Conditions.** The conditions of storage of supplies are important. The premises are to be clean, well ventilated and maintained at an even dry temperature to minimize the effects of condensation. In many instances the manufacturer will specify the temperature and relative humidity in which the products are to be stored. To ensure that these conditions are maintained within the specified range, instruments are used which measure the temperature and relative humidity of the storage facility. Guidance will be sought in the first instance from the Defence Logistics Framework, Defence Logistics Support Chain Manual. Limited guidance is also available within CAP 562, CAA Information and Procedures, Leaflet D-40 Storage Conditions for Aeronautical Supplies.

51. **Wire and Cable Storage Conditions.** Within the MOD there is a requirement for specific storage, handling, packaging and transportation instructions for wire and cable used in aerospace applications; these are identified in **Table 9**.

Table 9 - Packaging and Handling of Electrical Wire and Cable

Storage and Preservation	Handling	Packaging and Transportation	Remarks
To be stored in a cool dry location, away from radiated heat and exposure to direct sunlight. Wire and cable are not to be stored with oils, acids or chemicals. **Wire and Cable on reels will be:** a. Where diameter permits, stored on reels. Where this is not appropriate it will be stored in coils. b. Stored with the axis of the reel parallel to the floor. This applies to large diameter reels only, small diameter types ie up to a diameter of 45 cm may be stored on their sides. c. Stored so as to prevent any pressure being applied to the contents. d. Left in its natural lay, avoiding any unnecessary bending. e. Prevented from making any direct contact with	Packaged wire and cable are to be retained in its original wrapping. If a part issue is made, the remaining quantity will be re-packaged as effectively as possible in such a manner as to prevent the ingress of dirt or moisture. Only wire or cable that is marked or received with the original manufacturers' batch / lot number will be accepted into store. When putting cable onto a reel, the reel is not to be loaded so fully that the cable is level with the outer edge of the flange. A gap of approximately 50 mm will be left to prevent damage to the cable if the reel is rolled. On small reels a 25 mm gap is sufficient. When making Issues, the following points will be considered: a. All reels or coils of wire or cable will have a label attached identifying, manufacturers batch / lot details, NATO stock number and part number. All accompanying paperwork are to also include these details. b. Wire and cable are to be issued in strict rotation according to age, oldest stocks being used first. c. When transferring wire or cable from one reel to another, the barrel of the new reel will be at least equal in diameter to that of the original reel, to ensure contents are not	IAW Defence Logistics Framework	The responsibilities of logistics personnel with regards to the assessment of the condition of wire and cable in store is confined to a non-technical examination of stock. Additional advice may be sought from Air Commodities Delivery Team, Abbey Wood.

Storage and Preservation	Handling	Packaging and Transportation	Remarks
any sharp edges. **Wire and Cable on reels must not be:** a. Bulk stacked but stored in racks so that the lower layers are not subjected to crushing. b. Rolled over rough surfaces.	unduly stressed. d. Demands for wire or cable are, wherever possible, to be satisfied on an individual basis to avoid further decanting of materials at unit level. e. All issues are to be packaged in such a manner as to prevent the ingress of dirt or moisture. f. Any unreeling will be done from the front of the reel and not over the side.		

52. **Figure 28** below shows examples of poor packaging and handling. The left image shows the legs of a staple protruding through the wall of the cable reel thus damaging the cable. The right image shows unreeled cable supplied in a box rather than decanting onto an appropriate reel for transportation.

Figure 28 - Examples of Poor Packaging and Handling

53. **Storage of Cadmium Plated Connectors and Accessories.** Cadmium plated connectors and associated accessories are not to be stored in unventilated wooden or cardboard containers or in direct contact with wooden or cardboard materials, especially under storage conditions of high humidity or moisture. A corrosive reaction often occurs between cadmium plating and organic acids which form under these conditions.

54. **EWIS CS.** An EWIS CS is considered as an element of an AAA but could be undertaken at any suitable point. An AAA is a periodic, independent assessment of the effectiveness and applicability of procedures, management processes, Technical Information and documentation, established to assure a fleet's system's Airworthiness is maintained throughout its life. The AAA also includes the physical condition of the Air System, to ensure it is consistent with the management processes that have been applied to it, rationalizing the as flown, as maintained and as-designed conditions against the requirements of the ADS.

55. An EWIS CS can be considered as an element of the physical CS specifically directed at the wiring installation. This is a detailed tactile and visual examination of an EWIS against a predefined standard that may be non-intrusive or intrusive, or both, and would normally be considered by Air System DTs as an element of a LEP (RA 5724►34◄), AAA (RA 5723►32◄), and Wiring Husbandry Audits or at any other time that is deemed appropriate.

56. **Key Word Codes for CS Observations.** Through practical experience, a set of cause and effect codes have been identified to give the best understanding of the data being generated during an EWIS survey. Each observation is allocated an Effect code as well as a Cause code.

These are shown below in **Table 10**.

Table 10 - Key Word Codes for Survey Observations

Cause Codes	
CN	Contamination
DMG	Damaged
A	Assembly
C	Clearance

Effect Codes			
A	Assembly	BR	Bend Radius
C	Clearance	CR	Corrosion
DEF	Deformed	DET	Detached
FLD	Fluid	FOD	Foreign Object Debris
HD	Heat Damage	L	Lint
MT	Maintenance	MG	Missing
RPR	Repair	RTG	Routing
SPT	Split	SWF	Swarf
U	Unknown	WN	Worn

57. It will be noted that the Effect may be a consequence of a variety of Causes. Damage may result from several different factors such as chafe, routing, assembly, heat or Maintenance.

58. **Causes of Wire and other EWIS Component Degradation.** The following describe what are considered the principal causes of wiring degradation. Anyone who conducts an inspection program or develops or performs Maintenance programs are to be familiar with these factors and ensure their proper emphasis. EWIS materials degraded due to the mechanisms described here are to be considered.

59. **Vibration.** High vibration areas tend to accelerate degradation over time, resulting in “chattering” contacts and intermittent symptoms. High vibration of cable ties or string-ties can cause damage to insulation. Causes relative movement of adjacent components. In addition, high vibration will exacerbate any existing wire insulation defects.

60. **Moisture.** High moisture areas (above 60% relative humidity or areas subject to condensation) generally accelerate corrosion of connectors, terminals, contacts and conductors. Certain insulation types which contain aromatic polyimide material are susceptible to degradation from moisture. High moisture levels can also reduce the insulation resistance of materials and create conductive paths. EWIS component reliability and life are typically extended when installed in clean, dry areas with moderate temperatures.

61. **Maintenance.** Preventive and Corrective Maintenance activities, if done incorrectly, may contribute too long- term problems and degradation of EWIS. Certain repairs may have limited durability and are to be evaluated to ascertain if rework is necessary. Repairs that conform to the approved AMM or manufacturers’ recommended Maintenance practices are generally considered permanent and would not normally require rework.

62. **Repairs.** Repairs are to be performed according to the most effective, authorized methods available. Since wire splices are more susceptible to degradation, arcing, and overheating, the recommended method of repairing a wire is with an environmentally-sealed splice. Use guidance from AP113D-2008-1 Crimp Splices for Electrical Cables and the approved AMM for wire repair practices. OFIS repairs are to be carried out iaw with AP101A-0006-1 and only by suitably qualified personnel.

63. **Indirect damage**. Events such as pneumatic duct ruptures or duct clamp leakage can cause damage that, while not initially evident, can later cause wiring problems. When events such as these occur, surrounding EWIS are to be carefully inspected to ensure that there is no damage or potential for damage is evident. Indirect damage caused by these types of events could be broken clamps or ties, broken wire insulation, or even broken conductor strands. In some cases, the pressure of the duct rupture could cause wire separation from the connector or terminal strip.

64. **Contamination.** EWIS contaminants may be in solid or liquid form and can be:

a. **Foreign material.** Presence of a foreign material that is likely to cause degradation of EWIS, or the presence of a foreign material that is combustible or able to sustain a fire after removal of the ignition source.

b. **Solid contaminants**. Metal shavings, debris, waste and lint have been discovered on wire bundles after Maintenance, repair, or modification. Work areas are to be either protected or cleaned while the work is in progress to ensure all shavings and debris are removed. Solid contaminants can accumulate on wiring and other EWIS components and can penetrate their protective layers, or casing, causing internal degradation.

c. **Fluid contaminants.** Chemicals in fluids such as corrosion inhibiting compounds, cleaning agents, paint and refreshments, can contribute to EWIS degradation. In particular, fluids essential for operation (hydraulic oil, de-icing fluid, lavatory fluids, battery electrolyte) can damage EWIS components, such as connector grommets, wire clamps, cable ties, and wire lacing, resulting in chafing and arcing. EWIS components exposed to fluids are to be given special attention during inspection. Contaminated wire insulation that has visible cracking or breaches to the core conductor can eventually arc and cause a fire. Wire and other EWIS components exposed to, or in close proximity to, any of the chemicals listed above may need to be inspected more frequently for damage or degradation.

65. When areas or zones which contain both wiring and chemical contaminants are cleaned, special cleaning procedures and precautions may be needed. Such procedures may include wrapping wire connectors and other EWIS components with a protective covering prior to cleaning. This will be specifically considered if pressure washing equipment is used. In all cases, the manufacturer’s recommended procedures are to be followed.

66. Lavatory system spills also require special attention as history has shown that these spills can have detrimental effects on EWIS and have resulted in smoke and fire events. When this type of contamination is found, all affected components in the EWIS are to be thoroughly cleaned, inspected, and repaired, or replaced as necessary. The source of the spill or leakage will be located and corrected. These fluids are typically highly conductive and alkaline (pH values above 10) and damaging to EWIS components such as relays, switches, connectors, and wire insulation containing aromatic polyimide (Kapton®).

67. **Heat.** Exposure to high temperatures can accelerate degradation of EWIS by causing wire insulation oxidation, thermal damage, and loss of solvents which leads to loss of mechanical properties and / or cracking. Direct contact with a high heat source can quickly damage insulation. Burned, charred, or even melted insulation is the most likely indicator of this type of damage. Lower prolonged levels of heat can also degrade wiring. This type of degradation is sometimes seen on engines, generators, in galley wiring such as in water heaters and ovens, and adjacent fluorescent lights, especially ballasts. Sealed cockpits with a glass canopy in direct sunlight can reach elevated temperatures sufficient to damage EWIS components.

68. **Cold.** Exposure to extremely cold temperatures, such as those found at typical cruising altitudes, or wires exposed to cold temperatures, increases the rigidity of polymers in EWIS components such as wire insulation and cable ties, in those wires that have little or no current flow. Vibration or other types of movement during this time could lead to EWIS failures. EWIS located outside the pressurised fuselage such as undercarriage bays, wing leading and trailing edges, and horizontal and vertical stabilisers is routinely subjected to extremely cold temperatures.

69. **Severe Wind and Moisture Prone (SWAMP) Areas**. Undercarriage bays, wing folds, wing flaps and areas directly exposed to the environment are considered SWAMP areas on aerospace vehicles. The EWIS components in these areas require special attention due to the extremes in temperature and vibration / buffeting to which they are subjected.

Validate

70. Validation is a process of both reviewing current technical instructions and fault recordings with respect to EWIS. This is a normal function of RCM but is also triggered by an AAA or life / OSD extension. Additional physical validation can be undertaken, ideally a number of CSs are to be carried out for a higher degree of validation through comparison. This may be in the form of

Baseline Military Airworthiness Review, AP100B-01[73] Order 1.14, assessment or a dedicated EWIS CS. A dedicated EWIS CS is not restricted to these events. The TAA may wish to carry out a CS at any point in the Type’s life, especially if there are causes for concern regarding specific installations / conditions.

Recover

71. The ability to capture and process the available data required is paramount in establishing an effective EWIS Integrity Program. This will be tailored to Air System specific circumstances (ie Maintenance data, financial constraints, OSD, age, SOIU, etc). An EWIS Integrity programme will be considered essential as part of the introduction to service.

72. Execution of an EWIS program will assist in identification and justification of resources required to maintain EWIS Integrity and ultimately Airworthiness. Strategies to develop an EWIS Integrity action plan will vary across Air Systems, considering specific circumstances and may include full rewiring, targeted rewiring, training initiatives, automated wiring test, scheduled inspections, periodic data monitoring, improved chafe protection, and more. These processes may also be modified as required to provide metrics on the effectiveness of the implemented EWIS Integrity strategy (eg RCM analysis, zonal hazard assessment, etc). A properly applied EWIS Integrity Program will promote a reliable and airworthy EWIS which will ultimately mean lower through life costs and improved availability.

73. **Compromised System Configuration Control.** In the Canadian C-130 example at Annex A, configuration was identified as a causal element within the Incident. The recovery in this instance, and not dissimilar in normal recovery action involving technical instructions, required investigation into the correct installation. Then comparison with the installation document was rolled out across the fleet with a programme of recovery to ensure the installation was common across the whole fleet. A proactive EWIS Integrity programme would have highlighted a discrepancy in the installation configuration and resolved the issue before an Incident occurred.

Exploit

74. **Data.** Exploiting EWIS Integrity involves the use of data from other Air Systems and operators; however, the actual usage (rate, environment, etc), service operating envelope, and configuration will all be assessed to ensure that any data read-across data is relevant to UK Air System.

75. **Other sources of data.** Data and lessons learnt, shared through both the MAA EWIS working group or within the user community at SysI / type EWIS working groups, are to be considered. This can also include trend analysis of the data generated by the Station Wiring Husbandry co-ordinator.

76. **Disposal.** The exploitation can be expanded into the disposal element of the CADMID cycle. Specifically, where Types have a partial draw down rather than whole fleet reaching their end of life. This presents the opportunity in not only asset recovery to maintain the remaining fleet but provides a vehicle in which intrusive and forensic assessment of the EWIS installation can be undertaken. Rather than the dismantling of the airframes for scrap value, representative airframes could be targeted for ageing assessments that aide the continuing support of the remaining fleet.

77. As in the case of Ageing Air System Programme Laboratory (Sentry) the redundant airframe not only provided a facility for greater EWIS assessment, but availed itself to trial fits that made their implementation on an active airframe less intrusive and easier. Ground training evaluation / benefits were also achieved. Post asset recovery, the physical teardown of an airframe will be the last act once, where necessary, the greatest benefit has been gained from an installation assessment.

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[73] Royal Air Force Engineering Policy.

Annex A – EWIS Case Studies

A1 Royal Canadian Air Force C130 Hercules

A1.1 Background.

Flight Safety Message

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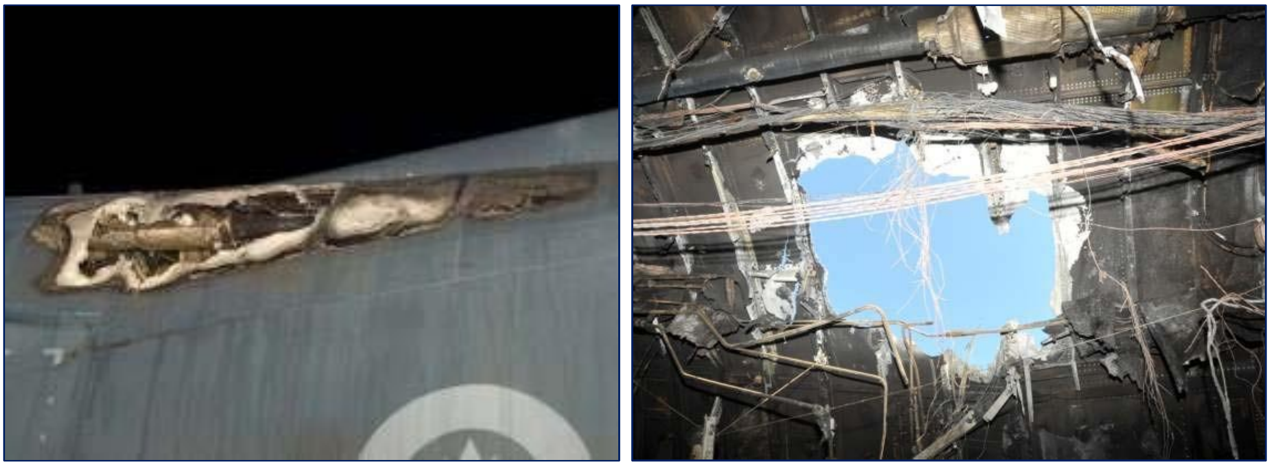
Injury Level: No Injury
Aircraft/Operated By: CC130342 / 435 SQN / 17 WING / 3435 /
Location: NAS Key West
Date/Time: 211400Z FEB 2012
Stage of Operations: LANDING - TOUCH & GO
Description: CARGO COMPARTMENT FIRE: At approximately 50 ft. AGL
following a take-off from a touch and go on RWY 07 at NAS Key
West the Loadmaster called "Fire, Fire, Abort, Abort". Aircraft
landed straight ahead, Tower notified, A/C Ground Evacuated via
Crew Door. Station Fire Dept extinguished the fire.
```

A1.2 This Canadian C-130 Incident occurred during a touch and go at Naval Air Station Key West. During the take-off just prior to the Aircraft becoming airborne, the Loadmaster, who was seated in the rear of the cargo compartment, heard an electrical buzzing sound and observed an orange jet-like flame shoot across the cargo ramp from left to right at floor level. Whilst reaching for the fire extinguisher an expansive orange fireball erupted, causing ►the Loadmaster◄ to protect ►their◄ head with ►their◄ jacket. Once the fireball receded, ►they◄ proceeded forward and alerted the crew to the fire while calling for the take-off to be aborted.

A1.3 Concurrently, the Aircraft had just become airborne and reached 10 feet above the runway. With sufficient runway remaining, the Flying Pilot landed straight ahead and aggressively stopped the Aircraft while the Non-Flying Pilot notified Air Traffic Control. Once the engines were shut down, all nine crewmembers quickly egressed and moved upwind of the Aircraft. Crash, Fire, and Rescue Services responded and expeditiously extinguished the fire. The Aircraft was extensively damaged, one crewmember received a minor injury during egress.

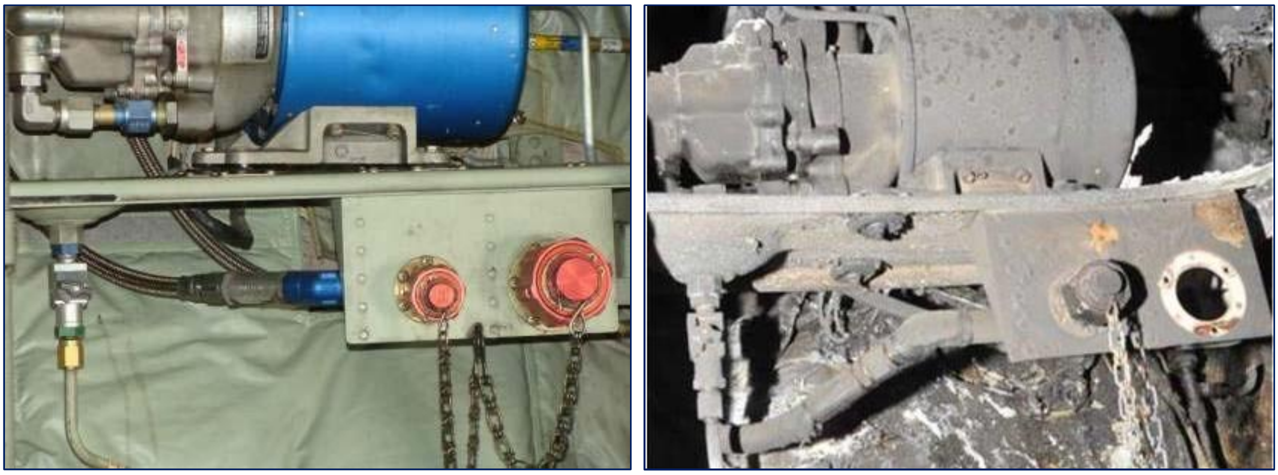
A1.4 **Investigation.** The investigation team identified that a 3,000 PSI stainless steel braided flexible hydraulic line associated with the auxiliary hydraulic system pump was breached where it was routed next to the Electrical Auxiliary Hydraulic Pump Harness, located on the left-hand wall of the cargo ramp. This resulted in a hull breach in the roof area over the ramp, burned through from a hydraulic fluid fire with possible fuel contributors from breached oxygen line and AAR fuel vent line in the ceiling area.

Figure 29 - Resulting Structural Damage



A1.5 Preliminary examinations suspected that the hydraulic line was the cause and that analysis, including visual, photographic, air pressure and scanning electron microscope was also undertaken. It determined that a small potential hole was discernible at the potential arcing region in borescope photos. Also, an air leak test detected an audible leak with only 0.5 psi applied. Energy-dispersive X-ray spectroscopy analysis of material surrounding the region of potential arcing showed considerable amounts of copper and tin consistent with the auxiliary pump wire.

Figure 30 - Area of Ignition



A1.6 The investigation identified that the auxiliary hydraulic ground test ports were added by a contractor and were not part of the original Air System configuration delivered from Lockheed Martin Aircraft Company. The Air Systems were purchased in different blocks with differing configurations. Also, that the modification configurations were not consistent for electrical and fluid lines, eg used 45°, straight or 90° elbows and harness routing.

A1.7 **Subsequent actions.** A fleet check was carried out to assess fluid lines clearance, EWIS clearance from fluid lines and verify correct routing and separation. The findings resulted in the replacement of damaged pressure lines, repairs carried out to electrical harnesses and the correction of separation and routing deficiencies. Additionally, an instruction was issued to standardise the mechanical and electrical configuration and replaced or repaired harnesses / wiring. Furthermore, zonal inspection routines were reviewed with regards to EWIS separation, and low- and high-pressure lines inspection.

A1.8 **Outcome.** As a consequence, awareness publications and briefs were generated to highlight the potential loss of assets and life, due to EWIS chafing hazards. These also stressed the importance of EWIS wire and harness separation, specifically with regard to fluid lines, as well as Structure or any other interference. This also resulted in the inclusion of EWIS awareness into technician trade Structure / training.

Chapter 10: Ageing Air System Audit

Introduction

1. This Chapter presents process and detailed guidance material relating to the scope and implementation of an AAA and must be read in conjunction with RA 5723[32]. ►Note – The guidance in Chapter 11 (Life Extension Programmes) is equally applicable to AAAs, particularly in respect to component / system selection, sampling and condition surveys. Refer to this guidance in addition to the AAA specific guidance detailed below.◄

Background

2. Air System Structure, Systems and Propulsion Systems need to function as intended throughout the operational envelope of the Air System, taking due account of the operating environment. The DO makes assumptions about usage, loads and the threats to Structural, System and Propulsion Integrity (PI) during the design and certification process. The assurance of IM in these areas is a through life activity[7].

3. During the life of an Air System, cumulative exposure to the threats to Integrity (such as overload, fatigue, environmental / AD, absence of configuration control, or Maintenance / supply errors), and the risk of them interacting, increase with time and usage. Additionally, calendar-based ageing mechanisms, such as the effects of environmental ageing and degradation, can compromise Integrity. However, the effects of ageing are not always identified or addressed by routine activities.

4. The AAA can be subdivided into Audits covering Air System Structure, Systems and Propulsion Systems, each considering different failure modes and Airworthiness consequences:

   a. Structural Integrity (SI) can be compromised by unexpected structural degradation. This often occurs in service due to interacting damage mechanisms that were either not anticipated or not considered in design and testing. Such interacting mechanisms may include the combined effects of fatigue with corrosion[74], dis-bonds, impact damage or multiple adjacent repairs. Furthermore, high life / usage Air Systems may be susceptible to WFD.

   b. SysI can be compromised by: Systems failure rates which exceed those assumed in the TASA; the unexpected interaction of failed systems; and the undetected failure of critical or emergency systems.

   c. PI can be compromised by system or component structural degradation. The way ageing effects manifest themselves is dependent on the material from which the components are manufactured and the threats to PI to which the components have been exposed.

5. Sources of information may include design evidence, component criticality analysis, zonal hazard analysis[75], functional hazard analysis, functionally significant item analysis, system safety assessments, results of Air System physical and Husbandry inspections, functional surveys and failure and reliability data.

6. The OEM may not be able to support an ageing Air System type due to obsolescence or changes in legislation, leading to material, processes and / or specification changes. As a result, effective obsolescence management[76] becomes increasingly important for ageing Air Systems.

7. Additionally, over time there may be loss of corporate knowledge, loss of configuration control, changes in assumed usage, evolution of regulatory requirements and the accumulated effects of several otherwise minor Integrity problems.

8. As a fleet ages and regulatory requirements evolve, the AAA is necessary to identify and

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[74] Refer to AAPWG Paper 012 – Understanding the Corrosion threat to Ageing Aircraft.
[75] Refer to AAPWG Paper 011 – Guidance on the Conduct of Aircraft Zonal Hazard Analysis (ZHA).
[76] Refer to the Defence Logistics Framework (accessible via the Defence Gateway).

assist with the subsequent quantification, mitigation and communication of the equipment contribution to RtL to the ADH-owned Hazards associated with operating the Air System.

Aim of AAA

9. An AAA provides assurance that the Airworthiness management of an Air System type is effective and appropriately adapting from the perspective of ageing[77]. Therefore, the aims of an AAA are to:

a. Conduct a periodic, independent assessment of the Airworthiness management of the fleet, with consideration to ageing.

b. Consider individually and collectively the SI, SysI and PI activities, often carried out in isolation, to assess the effectiveness of the fleet's IM.

c. Undertake an independent review of the continued applicability of procedures, management processes, assumptions and documentation that are in place to ensure Airworthiness, Integrity and functionality.

d. Undertake a detailed, independent CS of representative Air System from the fleet, unless an equivalent examination is conducted routinely.

e. Identify patterns or trends that suggest future Airworthiness or Integrity issues.

f. Identify significant Risks to the Airworthiness or Integrity of the Air System that would threaten the achievement of its planned Out of Service Date (OSD).

10. ►**Independence.** The key characteristic of the AAA is independence. The Air System condition survey, and the review of the Airworthiness procedures and processes, will be undertaken by organizations which are independent of those responsible for providing these Airworthiness aspects, unless the TAA can demonstrate that sufficient independence exists within that organization (ie 'Chinese Walls'). This means that the use of personnel already involved in providing Independent advice or assurance to the TAA (such as the ISA, ITE and IAA) will not be suitable to undertake any activity as part of the AAA.◄

Timing of AAA

11. The following points will need to be considered when deciding the timing of an AAA:

a. The '15 years after In-Service Date (ISD)' requirement is applicable to fleets which are acquired from new. Where fleets are acquired which have been previously owned or operated, then an AAA will be initiated at an earlier stage; advice may be sought from independent specialists, where contracted, and the Military Aviation Authority (MAA).

b. Consideration will be given to the scheduling and undertaking of discreet audit activity, prior to the '15 years after ISD' requirement and 10 yearly repeat Audits, where evidence suggests that ageing issues may be present.

c. Fleets acquired under short-duration arrangements would not usually be expected to undertake an AAA, provided no member of the fleet is anticipated to exceed 50% of its cleared life (in any parameter) during MOD service. However, the potential for contract extension and the resultant impact on Air System ageing will need to be considered. Advice from Independent specialists, where contracted, and the MAA will assist the TAA in deciding whether short-duration fleets are to be subjected to an AAA; this needs to be before Full Business Case (or equivalent) approval is sought.

d. If the original OSD is planned to be extended, the mid-life point (for conducting the first AAA) will be based upon the original OSD planned when the Type Certificate or initial Release To Service was signed.

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[77] Refer to AAPWG Paper 013 - Continuing Airworthiness Management: Its Contribution To Identifying Evidence Of Ageing In Aircraft.

Use of comparable programmes

12. Some Air Systems may have in place comparable programmes to AAAs that have been developed by DO / OEMs, civil operators or foreign armed services, which might fulfil many requirements of an AAA.

13. Where the subject fleet is a civil derivative and is operated in a manner comparable to the civil role, a comparison may be conducted between the documentation produced to meet the civil CAw requirements for ageing Air System Structure, Systems and Propulsion Systems and the AAA regulation[70]. The results of the comparison may reduce the amount of work needed to fulfil the AAA requirement; noting that the civil system focusses mainly on the physical condition of the Air System and the evolution of the Maintenance schedule.

14. In accepting other programmes as being suitable to meet the AAA requirement, TAAs / TAMs will need to satisfy themselves, through consultation with independent specialists and the MAA, that the programme meets the requirements of the Regulation[32], including both the Air System CS and the wider AAA aims regarding the continued applicability of Airworthiness procedures and management processes.

Management of AAA

15. The TAA may appoint an AAA Coordinator who is responsible for controlling the interfaces between the Audits and for coordinating the AAA results. A list of all Audits and the demarcation between them will be included in an AAA Coordination Document.

16. The TAA may appoint an Independent Audit organization to generate a plan for the conduct of the AAA which will be agreed at the Platform Safety and Environment Panel. The plan will outline each specialist area and will nominate respective personnel with the required technical knowledge for the task. The TAA, in consultation with the Air System type and sub-systems DO / OEM and CAMO, will commission the AAA upon accepting the plan. The Independent organization will work with the AAA Coordinator to liaise with the DO / OEM and CAMO during the conduct of the AAA.

17. The requirement to conduct an AAA and subsequent repeat Audits will be reflected in the Air System's TLMP (or equivalent documentation) and the TAA's approach to AAAs articulated in the Air System Integrity Strategy Document (AISD).

18. The Audit team will require appropriate access to records and information in order to carry out the AAA. The TAA will need to engage with DO / OEMs at least 6 months prior to the start of any AAA activity, to scope and generate the plan and agree a contractual method to ensure that the appropriate support is in place.

19. In the event the AAA will be carried out by the DO / OEM or an organization which is already engaged in managing, maintaining or advising on the Airworthiness of the fleet, then additional measures are necessary to ensure that the independence of the AAA is not compromised.

20. In the case of sub-systems, the sub-system DO / OEM may be tasked separately to undertake Audit activity as necessary.

21. An initial AAA report will be produced by the organization conducting the Audit, providing recommendations that will need to be assessed by the TAA and appropriate follow-up action initiated, including further risk-based follow-up Audits and Hazard mitigation. Advisors, DOs and OEMs, where contracted, may assist the TAA to interpret the AAA report and findings. The ADH needs to be informed of any Airworthiness risks to allow assessments to be made of the consequential RtL to ensure they are ALARP and Tolerable. The Risks are to be managed via the TAA's Safety Management System. Progress against the recommendations and associated risk mitigation will be monitored by the Project Safety Working Group (PSWG) or Integrity Working Group (IWG). Additionally, generic Air System Airworthiness and cross-Air System Risks identified by the AAA are to be reported by the TAA to the appropriate Airworthiness Management Group.

22. The AAA can only be complete once the final AAA Report, covering all Audits and detailing

the closure plan for all resultant actions and recommendations, has been produced by the Delivery Team (DT) and accepted by the TAA. Additionally, the TAA may consider the benefits of producing a Lessons Identified (LI) report and participation in the MAA's Ageing Air System Programme Working Group (AAPWG) to spread best practice and LI.

Scope of AAA

23. Careful scoping of the AAA is essential and will be undertaken well in advance of AAA initiation to ensure that Audit activities are integrated in order to; properly focus the Audit, address all aspects and avoid nugatory work. The Audit will be based on, but need not be limited to, the following:

a. Issues revealed by any earlier AAAs on the fleet.

b. Proximity to OSD: if nearing the OSD then the extent of the AAA will be set using a risk-based approach, while considering the possibility of OSD extension[35].

c. Continued validity of Life Extension Programme evidence where applicable[34].

d. Complexity of the Air System to be audited: generally, greater complexity requires more detailed planning and scoping.

e. Complexity of the organizational arrangements and responsibilities.

f. Potential for collaboration with other users.

g. Equipment managed by organizations external to the TAA, eg Commodity DTs. ►When considering Equipment Not Basic to the Air System[78] and commodity items it is essential that the TAA, Commodity DT, DO / OEM understand the aims and scope of the AAA. The Commodity DT may also have to consider the implications of the AAA items used across multiple Air Systems.◄

h. Effects of fleet size, roles, marks and fleets-within-fleets.

i. Availability and veracity of usage data.

j. Configuration control methods.

k. The Engineering and Asset Management System employed along with the associated Quality Audit arrangements for capturing tracked items.

l. Known or perceived repair or supply errors.

m. The completion and effectiveness of the required IM sampling programmes, for whole Air System or components with the level of effort appropriate to the percentage of Cleared Safe Life at which the AAA is being carried out. Although destructive sampling and forensic examination is not a mandated element of AAA, there may be benefits in coordinating the AAA and sampling programmes to optimise the level of effort.

n. In respect of the independent CS of the Air System, independence may be achieved through the survey being undertaken by a SQEP individual who is familiar with military Air System engineering practices but not currently employed on-type. If existing CAw processes, already incorporated into fleet procedures, eg Baseline Military Airworthiness Review, are used to support compliance, care will be taken that their scope is expanded as necessary in order to meet that required of an AAA. The use of functional performance checks of target systems will 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. The performing of functional testing before a condition survey can provide a valuable check of the adequacy of the tests carried out In-Service, by correlating faults found

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[78] ►Refer to RA 1340: Equipment Not Basic to the Air System.◄

during the condition survey with test reports.This physical CS is mandated, in order to:

(1) Check that the physical condition of the fleet reflects the official record.

(2) Detect hidden faults and those masked by poor Husbandry.

(3) Provide assurance that Husbandry, Maintenance and, ultimately, Airworthiness standards and procedures are acceptable.

(4) Check the condition of interconnections.

o. An assessment of the adequacy of procedures and Maintenance policies for, but not limited to, the following:

(1) Effectiveness and currency of AISD and plans.

(2) Management of fault arisings, trends and reports.

(3) Sampling Plan and access to strip reports.

(4) Production and management of Technical Instructions, Service Bulletins and Airworthiness Directives.

(5) Management of DO / OEM advice.

(6) Utilization of evidence from other users.

(7) Retention of Airworthiness documentation.

(8) MSR, Maintenance programme review or equivalent.

(9) Obsolescence management strategy and plans.

(10) Usage Monitoring.

(11) Supplementary Inspection Programmes.

(12) The ADS.

(13) Those items categorized 'on condition' that may not otherwise be routinely considered.

p. A review of the Equipment Contribution Log and Risk Register entries of any status, whether open, approved, managed or closed.

q. A review of Deferred and Incomplete Maintenance Logs for a representative selection of Air Systems from the fleet to check their significance, validity, safety, quantity and potential interaction.

r. The effectiveness of the depth Maintenance programme in rectifying Deferred and Incomplete Maintenance.

s. The effectiveness of MSRs to ensure that technical documentation is up to date and consistent.

t. The use of new techniques and technologies to capture ageing Air System issues across all Maintenance levels.

u. The existence, effectiveness and findings of any other ageing Air System programmes (such as those conducted under civilian regulations) which are applicable to the fleet. Such programmes may be of relevance to fleets based upon civil Aircraft.

v. A review of assumptions used in generating lives and inspection schedules, including monitoring and management of changes in operational conditions and usage.

24. The scope for the Structural, Systems and Propulsion aspects of the AAA may be proposed by the respective AAA or IWGs and will be agreed by the TAA, noting that many Air System components, such as landing gear, are pan-discipline systems. Proposals regarding the scope of any aspect of the AAA cannot compromise the independence of the Audit team in achieving the

AAA aims.

25. Emerging findings are to be reviewed periodically by the appropriate Working Group. Working Groups may report progress to the TAA, refine the scope of the Audit using a riskRisk-based approach and raise issues arising from an AAA to the appropriate Air System PSWG.

Scope: AAA – Whole Air System

26. Whilst the discipline-specific aspects of the AAA are pivotal to providing the necessary depth to scoping the Audit, a number of tools and methodologies exist to ensure that the breadth of the Audit takes into account the interaction between these individual disciplines.

27. **ZHA.** A zonal hazard is a form of common cause failure that can be described as an unsafe interaction between one system and another arising as a consequence of their relative spatial separation. Assessing equipment risk for zonal hazards has proved difficult because many Air Systems entered service before ZHA became an established technique or earlier analyses conducted may have been invalidated due to changes in Type Design, ie through modification or change of use.

28. Developing an appropriate strategy to assess the Risk posed by zonal hazards is influenced by life-cycle position, the availability of design information and the degree of change the Type Design has been subject to. For example, newer Aircraft commonly have undergone a ZHA, iaw the practice defined in Aerospace Recommended Practice (ARP) 4761[79], taking into consideration the design of the as-flown Air System. However, compliance with this standard alone may prove insufficient as it does not produce fully articulated zonal risks without further activity being undertaken. Furthermore, if an Air System has been subject to a change of use or has been In-Service for some time, then it is likely that a whole Aircraft ZHA will need to be conducted to provide the necessary evidence to demonstrate that the equipment contribution to risk to life resulting from zonal hazards is ALARP and Tolerable to the ADH.

29. Experience suggests that a whole Aircraft ZHA is best completed in a number of phases:

a. A Preparation Phase that focuses on ensuring that subsequent Hazard identification and analysis is conducted effectively;

b. A Hazard Identification Phase that will be conducted systematically to identify credible zonal hazards;

c. A Hazard Risk Assessment Phase that involves the determination of a representative probability for the accident sequence associated with each zonal hazard, determination of accident severity and subsequent assessment of Risk. To ensure that the Risk Assessment is as accurate as possible it is important that the probability values used are also as representative as possible.

30. To achieve this it is recommended that many information sources (eg In-Service Maintenance data, condition survey results, anecdotal information etc.) are utilised and qualitatively adjusted to produce a representative accident sequence.

31. Once completed, a full ZHA will give sufficient evidence to enable an improved understanding of the Aircraft aggregate Risk and thus aid the focus of an AAA. The ZHA can bring other benefits in that it can improve current Airworthiness standards by identifying Husbandry and condition issues; help develop a more effective Maintenance policy; and provide evidence to support future Airworthiness decisions, such as a Life Extension Programme.

Scope: AAA - Structural Audit

32. The TAA will need to consider MAA guidance[80,44] when setting the scope of the Structural Audit. In addition to the general AAA requirements, the Structural Audit will include, but need not

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[79] Refer to SAE ARP 4761 - Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment, Aerospace Recommended Practice.

[80] Refer to MASAAG Paper 104 – Ageing Aircraft Structural Audit.

be limited to:

a. Adequacy of all published Structural information for the Type Design, including:

    (1) Currency, completeness and accuracy of static loads and fatigue qualification documents, such as the Static and Fatigue Type Records, or equivalent.

    (2) Existence of an appropriately derived list of SSIs or equivalent.

b. Relevance, currency and results of Structural monitoring and Individual Air System Tracking, including any fatigue budgeting decisions and implementation.

c. In-Service Structural arisings and recovery programmes:

    (1) Effectiveness of response.

    (2) Extent and adequacy of trend identification and monitoring.

d. Existence and effectiveness of the Structural Examination Programme (SEP), and confirmation that all SSIs are included in the SEP.

e. Structural Configuration Management process, including:

    (1) Existence, adequacy, use and effectiveness of Structural configuration control databases and records of repair.

    (2) Assessment of through-life Airworthiness of repairs (eg their static strength and fatigue clearance). Confirm and consider the effects on strength, repair lives and inspection intervals of: environmental degradation, changes in usage severity, life extension, repair proximity and repair interaction.

f. Consider the need for a Repair Assessment Programme[81] and, where one is in place, the effectiveness of the corrective actions.

g. Existence and adequacy of a comprehensive Environmental Damage Prevention and Control (EDPC) Programme►64◄.

h. Susceptibility to WFD and the existence of programmes for corrective action.

i. Effective validation of assumptions used in generating Structural lives and inspection schedules, such as:

    (1) Operational Loads Measurement, Operational Data Recording and Manual Data Recording Exercise programmes.

    (2) SOIU reviews.

    (3) Destructive sampling and forensic examination.

    (4) Trending of Faults found during Preventive Maintenance for critical items / SSIs.

    (5) Assessment of SI implications of the actual standards of Maintenance and Husbandry.

    (6) Supplementary Structural Inspection Programmes.

j. Structural Equipment Contribution Log and Risk Register:

    (1) Effectiveness of process for management of Structural risks.

    (2) Continued validity of hazard mitigation assumptions, including inspections.

    (3) Review of all entries, whether open, approved, managed or closed.

Scope: AAA - System Audit

33. The System Audit will cover systems, assemblies, parts and interconnections that are

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[81] Refer to MASAAG Paper 106 – Repair Assessment Programme for Military Transport Aircraft.

affected by ageing and are critical to Airworthiness, for example:

a. Emergency systems and systems with a critical function.

b. Mechanical systems: flight control, fuel, hydraulic, cooling, pneumatic, landing gear, environmental control, air services, ice and rain protection, water injection, oxygen, nitrogen, water / waste, target towing, arrester, equipment and furnishings, propeller gearbox and pitch control systems.

c. Avionic systems: primary and secondary radars, data buses, electro-optics, photographic, defensive aids, navigation aids, communications, data links, electronic warfare, identification, traffic collision and avoidance, air traffic management aids, electrical power generation and distribution, weapon control and release, air data, displays, prognostics and health management, mission planning, flight control, and all wiring interconnections and connectors.

d. Electronic systems including Complex Electronic Hardware.

e. Secondary Power System, eg Ram Air Turbines and Battery Systems. Note that Auxiliary Power Units (APUs) are within scope of the Propulsion Audit.

34. In addition to the general AAA requirements, the System Audit will include, but need not be limited to:

a. Systems whose failure could affect another system (whether, or not, the latter had also failed) and hence adversely affect Airworthiness.

b. A CS of installed insulation, soundproofing and cladding materials for deterioration.

c. Existence of any evidence from thermal mapping.

d. Obsolescence issues affecting components within electronic control systems.

e. Whether the memory in any programmable devices is still reliable and appropriate for the task.

f. Whether the system protection from lightning strikes, High Intensity Radiated Fields (HIRF) and Electromagnetic Compatibility (EMC) is still acceptable, with no degradation in grounding or cable shielding.

g. Whether product software development tools (including rigs), knowledge, training programmes and SQEP are still in place to upgrade software if needed.

h. Appropriateness of design assumptions and certification basis, supported by evidence, which together underpin the Integrity of each system.

i. The TLMP and Integrity strategy regarding:

(1) The effectiveness of solutions to previous recommendations.

(2) The adequate planning and recording of future activities.

(3) Effectiveness and currency of SysI Strategy and Plans.

j. The existence, adequacy, use and effectiveness of the systems configuration control process including all usage history, life consumption, modifications, repairs and concessions.

k. The changes in operational conditions and usage during the life of the Air System and how the differences have been, and plan to be, monitored and managed.

35. Expendable stores, Air Launched Weapons and carry-on items are not covered by ►RA 5723[32].◄ Information on certification and release can be sought from the responsible DT or Defence Ordnance Safety Group.

Scope: AAA - Propulsion Audit

36. The Propulsion Audit will cover independent Audit of the Air System's engine(s), engine control systems, engine casing, functional and physical air vehicle / engine and propeller / engine interfaces (including fuel and oil system interfaces, electrical harnesses and thrust reverse system where not considered under the scope of the System or Structural Audits) and APU.

37. In addition to the general AAA requirements, the Propulsion Audit will include, but need not be limited to:

a. Documentation review. Confirm that all technical documents, including but not limited to the following, are up to date and consistent with each other and the ADS:

(1) Operating Conditions and Limitations, Engine Operating Conditions.

(2) Engine Technical Certificate, Type Approval Certificate or equivalent.

(3) Life Management Plan.

(4) Engine operating instructions.

(5) Maintenance manuals.

(6) Technical Instructions.

b. A review of Propulsion configuration control processes.

(1) Check the existence, adequacy, use and effectiveness of usage and life consumption data.

(2) Establish if there is a process in place for managing component repairs if conducted outside DO / OEM approval.

(3) Assess the effectiveness of the process for managing concessions.

(4) Assess the extent and adequacy of scrap procedures (to ensure that all scrap items are removed from service).

(5) Assess the process for managing cannibalisation and its adequacy, in terms of Configuration Management.

(6) Evaluate the quality and accuracy of electronic component tracking systems.

c. An assessment of product usage.

(1) Check that the product is being used as intended by the latest endorsed operating conditions, including operational and environmental conditions.

(2) Confirm that the DT has reviewed and checked that all the assumptions made during initial product qualification are still valid, including air vehicle to engine loads, off takes, engine bay clearances, vibration levels, thermals and intake effects, as appropriate. DO / OEM access may be required and will need to be arranged accordingly.

(3) Confirm that there is an adequate and working process in place to ensure that any modifications to the Air System or systems, which could influence the engine (including electrical changes that may have an impact on EMC capabilities), are brought to the attention of the DO / OEM.

d. A MSR.

(1) Review of on-condition Maintenance policy, including physical inspection of items not normally inspected, eg air vehicle / engine and propeller / engine interface components, electrical harnesses, casings, etc.

(2) Confirm that the Maintenance periodicity for each module and system has been verified and deemed appropriate by the engine DO / OEM following In-Service findings

and has demonstrated reliability.

(3) Review of Preventive Maintenance policy.

(4) Review of procedures that ensure that all Maintenance facilities are working to current Maintenance practices that are given in the ADS.

e. A review of component lifing policy.

(1) Check that the Life Management Plan, Maintenance Management Plan or Engineering Plan is the most up to date version issued by the DO / OEM.

(2) Verify that current life and usage monitoring systems are fit for purpose.

(3) Assess the adequacy of, and process for, managing life critical parts, including life extensions if applicable.

(4) Review possible changes in operating conditions and usage and identify potential effects.

(5) Ascertain if the DT has checked and confirmed with the DO / OEM that the assumptions made in deriving component lives are still valid for current operations. Confirm that all parts that have failed In-Service and hazarded safe flight have been provided with mitigation to prevent the failure re-occurring.

(6) Verify that all lifed parts have their lives tracked.

f. Identification of significant Airworthiness and Integrity issues. Assessment of current and projected risks to OSD, including but not limited to the following:

(1) A review of fleet operational statistics including Accidents, Incidents, in-flight shut down rates, engine rejections, aborted take-offs, performance, etc, to identify any worsening trends or patterns and age-related Faults.

(2) Review engine strip and build data to identify any worsening trends or patterns and age-related Faults.

(3) Consider significant safety events since previous AAA or safety review to identify any age-related Faults.

(4) A review of Threat Log and Risk Register entries and status, whether open, approved, managed or closed. DO / OEM hazard analysis (eg Failure Modes and Equipment Criticality Analysis, hazard reports) will be reviewed and checked for consistency against the DT Equipment Contribution Log.

(5) A review of the output of any sampling activities that have taken place since the previous Audit to assess whether any changes are needed in lifing or Maintenance policies.

(6) Consider potential Risks, including issues and solutions that can be gained from other world-wide operators of the same or similar products.

(7) Where events or risks have been closed on the grounds of Maintenance activity, confirm that the activity has prevented any re-occurrences of the finding.

(8) A review of Fault investigations (including all MOD Form 760) since previous AAA or safety review.

(9) Carry out a review of DT management of SI(T) from conception through to fleet satisfaction. Review a representative sample of SI(T) in detail.

(10) Carry out a review of DT management of Airworthiness Directives and Service Bulletins.

g. A physical examination.

(1) Based on analysis of Propulsion System repair and overhaul reports, target

examination on high-life, less frequently examined and on-condition components, which have been used in a similar manner to the rest of the fleet. The examination will concentrate on component deterioration with any resulting recommendations highlighted to the TAA accordingly. Once stripped, engine build standards may be compared against the ADS parts list.

(2) Review of general Maintenance and Husbandry standards.

(3) In certain circumstances the TAA may consider it acceptable for an independent examiner from within the DO / OEM to conduct targeted examinations. However, to assure independence, the examiner will not be associated with the design, Maintenance or In-Service support of the Propulsion System being examined.

h. If applicable, an Electronic Engine Control System review, including but not limited to the following:

(1) Assessment of obsolescence issues affecting components within the electronic control systems.

(2) Confirm that the memory in any programmable devices is still reliable and whether there is a need to refresh these devices.

(3) Confirm that the protection from lightning strikes, HIRF and EMC threats is still acceptable, with no degradation in cable shielding or product grounding.

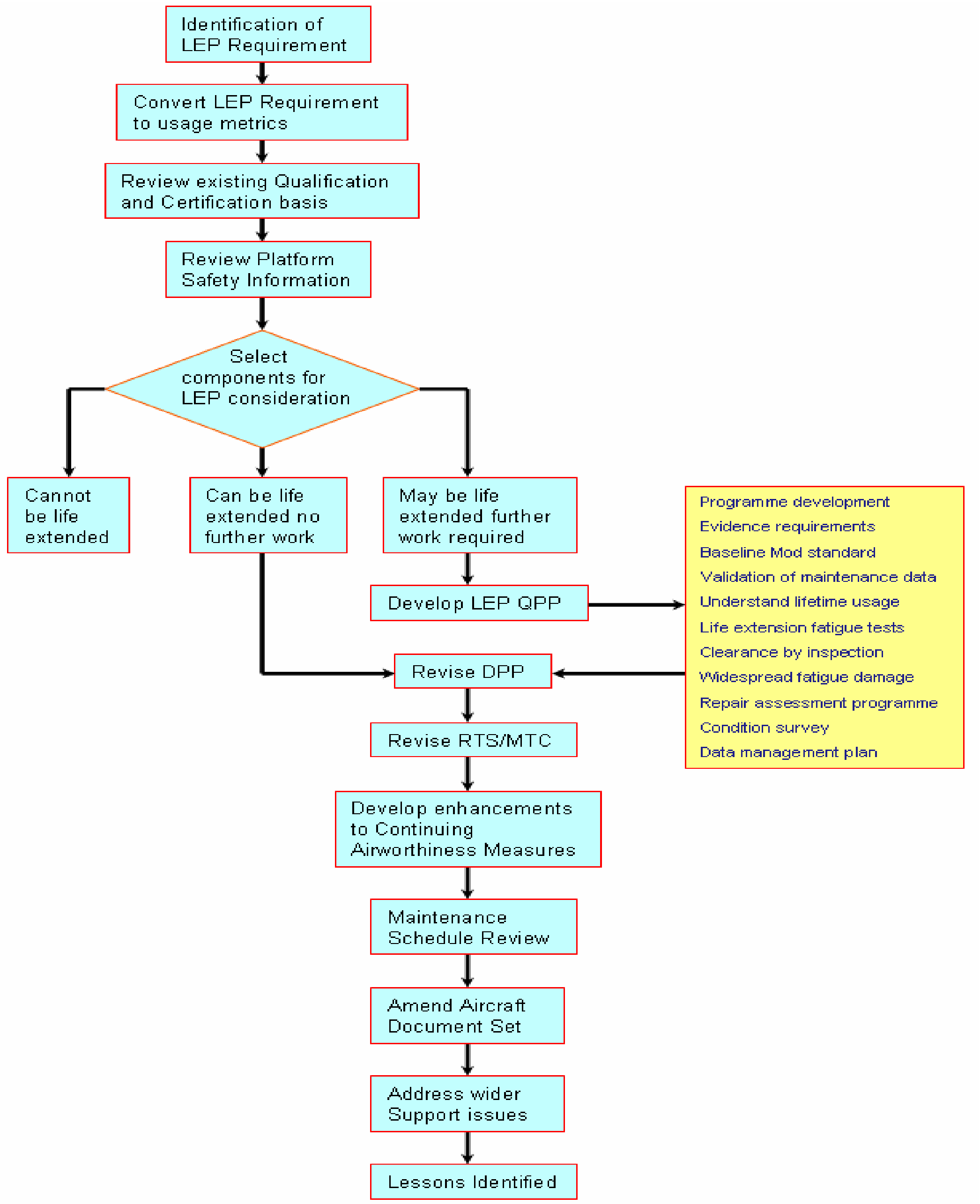
(4) Confirm whether product software development tools (including rigs), knowledge and SQEP are still available to upgrade software if needed.

Chapter 11: Life Extension Programme

Background

1. A Life Extension Programme (LEP) is a mechanism for mitigating the increased Risks of operating Air Systems beyond their original cleared lives. It may be considered as a requalification and recertification of the Air System type, to the revised life requirement; as such, a LEP must be treated as a change to the Air System's Type Design[21]. Life extension may be necessary because the fleet is required to be operated beyond its cleared limit in any applicable lifing parameter, or because the usage of the Air System In-Service is more severe than had originally been anticipated. A schematic for a typical LEP is at **Figure 31**. This Chapter must be read in conjunction with RA 5724[34].

Figure 31 - LEP schematic



2. Where the fleet is required to be operated beyond its intended OSD, but within existing cleared lives, this does not constitute a change to the Air System's Type Design[21] and therefore RA 5725[35] must be applied; Chapter 12 refers.

Threats to Airworthiness posed by Life Extension

3. The specific threats to the Integrity of Structures, Air System systems and Propulsion Systems are fundamentally no different when an Air System is operated during its life extension period than they were when operated within its original cleared life. However, the probability of occurrence and hence the level of Risk can increase significantly with continued use beyond the cleared life.

4. Without a LEP, this increased Risk may not be detected, and remedial action may not be initiated, before the level of Risk at which the fleet is operating becomes unacceptable. To ensure the LEP captures these potentially increasing Risks, it is essential that all the aspects contributing to the TAw and CAw of the fleet are considered. This includes the design and qualification of the fleet, usage, through-life Maintenance, modifications and repairs.

5. Many of the threats posed by life extension are widely known. For example, the increased Risk associated with operating fatigue-critical Structure, systems or propulsion components beyond their demonstrated lives is widely recognized and is enshrined in Ministry of Defence (MOD) Regulation. However, some Risks, such as susceptibility of Structures to WFD, the interaction effects of fatigue and corrosion, or the degradation of polymers are less well understood. Therefore, it is essential that the LEP captures the known issues as well as ensuring measures are in place to identify other potential issues that could compromise the Airworthiness of the fleet during the life-extension period.

6. Moreover, observation of many systems (see BS 5760[82]) has shown that the occurrence of non-systemic failures with time or usage may follow various patterns, often termed bath-tub curves. The three phases of the bath-tub curve are usually identified as:

   a. Infant failure or early life failure period, which is a period of decreasing failure rate in which quality related and learning effects predominate.

   b. Random failure period or useful life failure period, which is a period of effective constant failure rate in which failures are due primarily to externally induced high stresses such as shock loads, electrical overstress, etc or marginal design, which appear at a constant average rate throughout the life of the equipment.

   c. Wear-out period, in which failures occur due to age or usage-related phenomena such as fatigue, corrosion and wear.

7. The reliability relationships between failure rate, the MTBF (for repairable systems), or Mean Time To Failure (MTTF) (for non-repairable systems), and the reliability over a time or usage period are based upon the assumption that the equipment is only operated during the random-failure period and this will have been demonstrated as part of the original qualification of the system. The risk that systems are being operated during their wear-out period consequently increases with life extension.

8. These aspects and others described later in this Chapter need to be considered alongside the relevant changes that have occurred during the life of the fleet and those changes that often occur as a fleet nears the end of its original life. These may include:

   a. Changes in usage.

   b. Capability enhancement / upgrades.

   c. Development of fleets within fleets.

   d. Extension of preventive Maintenance cycles.

   e. Cancellation or delay in scheduled Maintenance reviews.

   f. Reduction in spares and repairs provisioning.

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[82] Refer to BS 5760 - Reliability of Systems, Equipment and Components.

g. Reduced modification action (including cancellation of cover modifications).

h. Reductions in Maintenance and support.

9. Each of these measures individually may have been assessed for their potential impact on the Airworthiness of the fleet but a LEP provides a mechanism to consider the cumulative effect of these changes. These issues are discussed in greater detail below.

Timely identification of the need to conduct a LEP

10. Great care is needed not to overestimate the effects that can be made by life management within a fleet. Historically, the initiation of a LEP has been delayed on several Air Systems because the likely effects of life management programmes within the fleet had been significantly overestimated.

11. Air System LEP are a requalification and recertification of the lifing basis for the Air System type, using In-Service experience in addition to traditional design substantiation approaches. Previous LEPs have underestimated the full extent of the data collection, usage monitoring, analysis, additional testing and pre-emptive and remedial measures necessary to maintain TAw of life-extended fleets.

12. A long-term approach in defining the LEP requirement is needed to ensure appropriate measures can be taken to ensure the Airworthiness of the fleet. Incremental or ‘creeping’ life extension requirements can cause an inadvertent increase in Airworthiness Risk if the incremental elements of the life extension are considered in isolation, rather than in their totality.

13. The Airworthiness implications of failing to initiate a timely LEP have been illustrated in several major programmes. In several cases, additional interim Airworthiness measures (such as detailed penalising inspections or pre-emptive component replacements) have been necessary because LEP evidence was not available in time to meet the fleet clearance requirements. This also had the knock-on effect of diverting key resources away from the primary LEP function to develop the interim measures. Moreover, in some cases, an increase in Risk has been accepted as an alternative to reduced availability.

14. Therefore, failure to initiate a timely and properly-funded LEP can pose a threat to the Airworthiness of the fleet. It is essential to keep under continual review the current clearances to ensure that sufficient life remains to meet the planned OSD. The requirement for a LEP may not always be a consequence of a discrete event, such as a decision to extend the OSD; it may be driven by continuous or incrementally increasing usage severity rendering the original OSD unachievable within the cleared life of the Air System.

Converting the Life Extension Requirement into Usage Metrics

15. The top-level life extension requirement, with an associated force strength or annual task, will be converted into appropriate life extension usage metrics (eg flying hours, FI, landings, cycles), using relevant fleet management assumptions; these assumptions need to be clearly recorded and endorsed by the TAA and ODH / AM(MF)jointly. Care needs to be taken to ensure that capability (such as fleets within fleets) and usage variations within the fleet are considered during the development of these metrics. These metrics need to be reviewed in line with any changes to the life extension requirement.

Review of Existing Qualification and Certification Basis

16. A review of the existing Air System qualification and certification evidence, including developments since introduction to service, is needed to ensure that the basis upon which the Air System is considered safe to operate is fully understood. This review will aim to identify key decisions and assumptions in the existing clearance basis that will be reviewed against the revised life requirement.

17. LEP have often identified shortfalls in the existing qualification and certification basis for the Air System, when compared with the standards expected at the time of LEP. In particular, the

qualification and certification basis for the modifications to the Air System during its service life have been found to be inadequate on occasion. Advice can be sought from MAA Certification Division.

Information Sources

18. The Air System Safety Case, Release To Service (RTS), Military Permit to Fly (MPTF) (In Service) and Military Type Certificate and associated Safety Case contain the high-level life-related limitations for the type. However, all the underpinning detail, including key assumptions and decisions, often made many decades prior to the LEP, is unlikely to be contained within these documents, although an Audit trail may have been created or referenced.

19. It is essential that the existing qualification and certification basis for the fleet is understood before well-formed decisions can be made as to what measures are required to extend the life of the type. There have been significant changes in Airworthiness requirements since many MOD fleets were originally certified; moreover, many fleets perform a range of roles not considered in the original qualification and certification. The implications of these changes in requirements and usage need to be understood before the LEP can be completed.

20. Estimates of the level of Risk to the fleet within the certification framework are often predicated upon usage assumptions (lightning strike and bird strike are examples from recent certification programmes). Changes in role, usage and life extension can have significant implications for these assumptions that are largely invisible at the higher level of the RTS / MPTF (In-Service).

21. Also, many fleets will have had significant modifications or upgrades since the initial certification of the type and the basis of these changes also needs to be understood. There have been examples where modifications have been made to fleets, often to meet essential operational requirements, where the formal qualification and certification of these modifications may not match current Airworthiness requirements. While the Risk posed by these modifications may be acceptable for the existing life requirement, life extension without remedial action may increase this Risk unacceptably.

LEP Implications of Historic Lifing Decisions

22. Experience from a number of LEP has identified instances where lifing recommendations were made by the DO for components likely to be considered safety-related or safety-relevant. However, decisions were made by the responsible MOD Authority at the time that these items would be managed in service, using an ‘on-condition’ policy, with no life limit applied. While the Risk taken may have been acceptable for the original life of the fleet, this may not be the case for an extended life. Moreover, the history surrounding this decision may have been lost and the basis of the original lifing recommendation may not be apparent to the current TAA, as the component had never been identified as a ‘lifed’ item. This can have added implications for MSRs.

Establishing Component Lives

23. Generally, in design, an iterative process is undertaken in establishing component lives against a design requirement, whereby conservative assumptions are made, and the design is assessed against the relevant design criteria. Where the required lives cannot be demonstrated with conservative assumptions, and assuming the design is considered suitable, further analysis, modelling, measurement or testing can be undertaken to refine these assumptions and gradually remove conservatism from the process. Once an adequate life (with a suitable safety factor) can be demonstrated, this iterative process can be stopped and the life declared, subject to a validation and verification exercise. For many components this may be a test under an assumed design spectrum, possibly with validation of loads by measurement. Deeper analysis, and hence increased complexity, is only invoked when it is required. A similar approach is usually used when undertaking a LEP but with the addition of In-Service evidence.

Review of Air System Safety Information

24. An initial LEP Safety Information Review will usually be undertaken to identify and assess the available safety-related information for the Air System. Additional analysis is needed where the available safety-related information is inadequate to identify, with confidence, components where failure could compromise Airworthiness. This initial LEP Safety Information Review will include all relevant Structures, systems and propulsion Integrity stakeholders (including TAA, DO, SME, maintainers and operators).

25. The military aviation inventory has been assembled over many years, with Air System from a wide range of OEM and procured to a similarly wide range of certification standards or codes, over that time period. Moreover, MOD Airworthiness Regulations themselves have changed significantly over the lengthy In-Service periods covered by many MOD fleets.

26. Therefore, it is reasonable to assume that there will be a significant variation in the detailed safety-relevant information available for each Air System and contained within the TASA. If there are shortfalls in this information, it may be necessary for additional testing and analysis to be undertaken to support the LEP selection process. The key issue is to be able to identify those Structures, systems or propulsion components whose failure could compromise Airworthiness; this is either from the loss of function of that component, such as the loss of a primary flight control, or the potential interaction effects, such as an increased Risk of fire or explosion.

27. Although the ongoing management of Risks to Air Safety is part of the safety management process, the different methods used to identify and manage these Risks can have implications for the LEP. For example, if a full-range of Structures, systems and propulsion safety assessments and zonal safety assessments or ZHA (See SAE ARP 4761[79]) including consideration of the design and the “as-flown” Air System, have been completed, then it is likely that there will be a clear indication of those components that need to be considered within the LEP. However, where the Safety Management System used for an Air System has been based upon generic risks combined with a partial or recent history of Accident and Incident reports, without an in-depth assessment of the design of the Air System and the as-operated configuration, it is likely that further analysis will be required to support the LEP decision making.

Selection of Systems and Components for LEP

Safety Assessment Considerations

28. The identification of which Structures and propulsion components and Air System systems / components need to be considered within the LEP is a critical decision. Once excluded from the LEP, it is unlikely that a system or component would be reconsidered for later inclusion.

29. For example, in one LEP, a significant, safety-relevant component was excluded from initial consideration based upon a flawed assumption. It was incorrectly assumed that an extremely high consumption rate would protect the fleet and prevent high-life items remaining in service, but the assumption was not validated. Subsequently, items with In-Service usage significantly beyond the original life clearance were located in the repair chain. Rapid remedial test and analysis action was required to provide evidence of the Airworthiness of these components.

Identification of Structures LEP Components

30. For Structures there is no universally accepted mechanism for identifying components that are significant and hence need to be considered within a LEP, based upon their consequences of failure. Although the focus of Structural Integrity Airworthiness regulation[7] is the Structural Significant Items (SSI) list, many DO have found difficulty in meeting the MOD’s requirements for the production of SSI lists and consequently the approach taken has been inconsistent. Hence, validation of an SSI list may be required if this list is intended to be used as the primary identifier for the LEP Structural components. However, in addition to the safety assessment sources, the Structural safety-relevant information that could provide a basis for this decision may include the following:

a. SSI list.

b. Safety of Flight Structure (SoFS).

c. Fatigue Type Record (FTR) (or equivalent summary of fatigue qualification evidence).

d. Static Type Record (sometimes termed Type Record) (or equivalent).

e. Grade A parts.

f. Primary Structure.

g. Class 1 Structure.

h. Vital parts.

i. Principal Structural Element (PSE).

j. Structural Airworthiness Limitation Items (ALIs).

k. Structural Trackable Parts Lists (STPL).

31. It is unlikely that any one of these sources or lists alone will provide all the necessary information to identify Structural LEP components. For an Air System managed using the processes mandated in the RA 5000 (Type Airworthiness Engineering) series, the Static Type Record (STR) and the FTR or equivalents will also provide useful information for identifying the significant Structure; the FTR will also identify the basis of the applied life limits for fatigue-critical Structure. The scope of the STR and FTR or equivalent documentation also needs to be understood as there may be significant Structural components that are outside of the scope of the type records. It is also noteworthy that many of the Air Systems currently in service, particularly those procured from the United States, do not have constituted STR / FTR documents, but this information may be available in alternative formats, often across several documents, such as Static Strength Statements, Durability Statements and Statements of Design. These may be identified in the Air System Structural Integrity Document, as part of the Integrity Baseline definition.

32. From a Structure’s perspective, LEP is often considered to be a fatigue life issue and static aspects may have been neglected. However, many Air Systems have seen significant mass growth in service and the implications of the global mass increase and local mass growth may not have been fully accounted for and may need consideration within the LEP.

33. Propellers, rotary-wing main and tail rotor blades, rotor heads and associated power transmission systems are also usually classified as Air System Structure.

34. Furthermore, it is unlikely that any one organization has the complete understanding of the design, Maintenance and usage of the Air System Structure. Therefore, the inclusion of staff from the DO / OEM, TAA, SME and maintainers (Forward and Depth) in the decision-making process for LEP Structural components can prove invaluable.

Identification of LEP Systems and Components

35. The Integrity of Air System systems has only quite recently been regulated using an Establish, Sustain, Validate, Recover, Exploit (ESVRE) approach[3] as used for Structure. However, system design has been focussed around the use of systems safety techniques such as Fault Tree Analysis (FTA), Failure Mode Effects and (Criticality) Analysis (FMECA) and ZHA, and their forebears for many years. Many of the safety-related activities undertaken across Air Systems today have their origins firmly in systems design development. Therefore, for relatively modern Air System, maintained within a robust safety management system, the identification of Air System systems for inclusion in a LEP, using consequence-of-failure criteria, may be a relatively straight forward task. Relevant information may be extracted from the existing qualification and certification evidence using the designation of essential systems, safety-critical systems, safety-related systems and other similar identifications.

36. However, LEP and AAA programmes have indicated shortfalls in the original qualification, certification and safety-related information available to support some legacy Air Systems. In

several cases information has been lost over time; this has been accentuated by relocation or changes of DO and TAA over many years and by creeping life extension requirements. In other cases, the substantiation of the original design, or the ongoing modifications to that design, appears not to have been considered, or documented, using methods expected today. In particular, evidence from recent AAA programmes indicates that the assessment of zonal hazards is a potential area of weakness for legacy fleets.

37. Where the Safety Information Review illustrates shortfalls in the safety-related information available to support a LEP of the Air System, remedial action may be necessary to identify the systems component to be considered for the LEP with sufficient confidence. In such circumstances, an appropriate approach may be to consider the consequence of failure of each system, both from the loss of the system function and from the interaction of that system with the Air System (eg the Risk of fire / explosion).

38. The use of a simple hull-loss model, to focus the consequence-of-failure assessment, can provide a useful guide in determining whether systems are included within the LEP. Moreover, it is unlikely that any one organization has the complete understanding of the design, Maintenance and usage of the range of Air System systems to be considered. In such cases, the use of a team comprising DO, equipment OEM staff, TAA, maintainers (Forward and Depth), SME and Operators can prove invaluable.

39. Generally, the Hazard (or Hazards) posed by the loss of a system function are well understood. However, the inter-system Hazards (such as fire / explosion) are often far more complex to assess adequately and an initial ZHA (or similar analysis / assessment) to identify the Hazards, may be required to support this decision-making process. It needs to be noted that a successful ZHA requires a range of skills, detailed Air System-specific system design knowledge and a deep understanding of Air System-specific Maintenance practices.

40. Within several programmes, systems redundancy alone has been argued, initially, as a reason for excluding systems from a LEP. Such an argument for excluding systems from the LEP may be unwise. Reportedly 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 analyzes 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 redundancy, closer scrutiny can reveal that these systems often have a “single element”, the failure of which will cause multiple channel failures. These can either be:

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

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

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

41. There are sufficient examples of air Accidents that could have been prevented by system redundancy to reinforce the view that redundancy alone is not a credible reason for exclusion of a safety-related system from a LEP (for example, in 1989, United Airlines Flight 232, a DC-10, suffered a centre engine uncontained failure which caused the loss of all three independent hydraulic systems; this common–cause failure was considered ‘impossible’ by the Air System Designer at the time).

42. Likewise, the use of data on the probability of a system failure as evidence to exclude a system from LEP may be equally unwise. Design failure probability data are limited by lack of exposure to the real-world environment and In-Service failure data are notoriously inaccurate. Additionally, the future failure probability rate cannot be assumed to be the same as the historical rate, as the system may well be entering a wear-out phase in its life. Without evidence to support the assumption of a relatively constant failure rate during the LEP period, such an argument may

be ill advised.

43. Once the systems to be considered within the LEP have been identified, the individual components within that system will need to be considered, using a similar process, to identify those components that need to be addressed.

Identification of Propulsion LEP Components

44. The Propulsion System is defined as the source of propulsive effort for the air vehicle. For fixed-wing Air System it will include the aero-engine, modules, components and accessories and usually a similar management approach is applied to auxiliary power units, gas turbine starters and gas generators.

45. For Propulsion Systems, components for LEP are likely to be critical propulsion components (Group A) or sensitive propulsion components (Group B). These are usually identified by FMECA / FTA / Failure Hazard Analysis (FHA) (or similar techniques) during the design process. These components are those whose failure could cause a hazardous event or a safety issue. In addition, information from In-Service RCM analysis and component failures may identify additional components for consideration within the LEP.

46. As with Structures and systems a review of all propulsion components, undertaken by the OEM, TAA, maintainers (Forward and Depth) and SME, to identify those that will be considered for LEP can prove invaluable

System Interfaces

47. The interfaces between disciplines, systems and components need to be considered carefully within a LEP and ownership clearly identified. It is largely immaterial whether interface components, such as oxygen bottle attachments or engine mounts are considered within the Structure, systems or propulsion areas, as long as they are considered for inclusion within the LEP. The issue of interfaces is often further complicated by components being managed by different TAA and being supplied by different OEM. Therefore, this is a clear Risk area within the LEP that may require careful management.

Components Excluded from the LEP

48. Once systems or components are excluded from the LEP it is unlikely that this decision will be reviewed unless an Incident or Accident occurs in service. Therefore, it is important that the rationale behind the risk-based decision to exclude a system or component from the LEP is well documented. Invariably, the risk-based exclusion would be based upon the low severity of the consequences of failure of the component, rather than a low probability of occurrence of that failure.

Categorisation of Life Extension Components

49. In the following sections, the likely key sources of information that could be used to support the LEP categorisation and provision of initial evidence to support the life extension requirements are described.

Design Data

50. The original design data will provide an invaluable insight into the potential to extend the life of components. Reviewed material may include documents such as the Statements of Design, Design Requirements and Design Standards. The aim of reviewing these documents is to understand the basis on which the component was designed, identify any relevant assumptions, such as loads, usage or environment, identify any dependencies such as Maintenance actions and to identify whether there is likely to be life-extension potential for the component against the revised life requirement.

Qualification and Certification Evidence

51. The evidence presented in qualification and reviewed during certification can provide

essential foundation information for a life extension. This will include the basis for any recommended limitations as well as providing an insight into potential areas where margins can be exploited or where increased risks may lie. For example, if qualification testing was conducted at higher loads than required or for a greater endurance than was necessary to demonstrate the design requirement, this information may be useful in assembling life-extension evidence. Also, particularly where components are used in a number of applications, the original design requirement may have been greater than required in service.

52. In some cases where original qualification and certification data are no longer available, the Design Standards applied at the time and evidence that the Air System met the design requirements can be a valuable source of information for assessing the life extension potential.

Usage Information

53. Many of the assumptions included in the life clearance of Air System components relate to the usage of the component in service. Moreover, the lives of the majority of components likely to be assessed within a LEP will be sensitive to changes in usage. The usage of Air System invariably changes through the life of the fleet and this through-life usage needs to be considered within the LEP. These changes are often reflected in Concepts of Operation documents for example. In addition, the SOIU, provides a good general indication of usage. Furthermore, previous issues of the SOIU are often retained within the document to provide some history.

54. Additionally, the significant difference between clearances and assumed usage needs to be understood in this context. For example, an Air System may be cleared for high-temperature operations, but it is likely that the design assumptions were predicated around operations in North-West Europe or the United States, for example, with occasional deployments elsewhere in the world. If this fleet were to be routinely deployed for long periods into a high-temperature and harsh environment, components that may be sensitive to environment changes may degrade at unexpectedly high rates (as has been seen with helicopter engines for example). In addition, these components may be subject to an ‘on-condition’ Maintenance policy and signs of degradation may also be unlikely to be detected during a zonal inspection. The Integrity of some elastomeric seals, for example, can be highly sensitive to repeated high-temperature excursions and these usage issues may need to be considered within the LEP.

55. Therefore, changes in usage, including the environment in which the Air System is operated can have significant implications for life extension. The significance of the usage aspects may also need to be considered at various levels, relevant to the operation or environment seen by the LEP component. For example, Structural damage has been identified on an Air System type in the Auxiliary Power Unit (APU) bay. This damage, caused by prolonged heating of the Structure, has been attributed to the APU routinely being run for around three times the assumed usage period, during operations. This mode of operations is not outside any limits but the implications for the Structure and systems located in the APU bay could be significant and such issues need to be captured to ensure the LEP presents a complete analysis of the Risks associated with life extension.

Concessions and Waivers

56. Concessions and waivers, which are used to record acceptable deviations from design, production or repair, have significant implications for LEP and have, without exception, proved to be problematic. When considering categorisation, the existence of concessions or waivers can affect the component category. Concessions or waivers could preclude life extension without further investigation or analysis, or the presence of widespread concessions or waivers may render life extension impractical. Moreover, the concessions or waivers may have been acceptable for the original life requirement but may not be acceptable, or there may be insufficient evidence to assess their acceptability for the life extension requirement.

57. Additionally, the lack of traceability of concessions and waivers has proven to be a significant issue for remedying issues exposed by the LEP reviews. In some programmes, trawling through many thousands of poorly-identified concessions and waivers has been a costly exercise. In one

instance, the majority of the concessions and waivers collated did not relate to the Air System under LEP. This was because there was no Air System identifier in the concession and waiver log. Consequently, all concessions and waivers raised during the production period for the Air System had to be reviewed initially for applicability. Thereafter, tracing the applicable concessions and waivers, deemed to be unacceptable for life extension, to a particular component or batch of components was an extremely complex task. Tracing concessions or waivers invariably required some physical inspection of the Air System to confirm or discount their presence. In some cases, it was not possible to identify the concessions to individual Air System or components and hence it was necessary to initiate precautionary and penalty remedial action across a number of Air System within the fleet.

Repair and Overhaul

58. Repair and Overhaul (R&O) strip or condition reports, spares consumption and interviews with repair organization staff can provide an invaluable insight into aspects that may need to be investigated further within a LEP. For example, many repair contracts are established using Inspect and Repair As Necessary (IRAN) principles and a report is usually assembled identifying the required repair action. In many cases, the information within this report is not collated or analyzed in any way across the repair line. Simple analysis of data over time can be used to detect the onset of wear-out of systems components. Similar signs can be used to identify the onset of distress in Structural components, such as an increase in corrosion or in fretting around rivets, loose fasteners or drop off in torque settings.

59. R&O staff may be well aware of signs of deterioration in the general condition and of specific issues for items returned for repair. However, individually these issues may not be significant enough for formal reporting action and hence they may not have been captured. A review of R&O findings and interviews with experienced R&O staff may well provide invaluable information to assess the categorization of LEP components and to identify those issues that need to be addressed for the Airworthiness of the Air System during the life extension period.

Repair Instructions (Including Repair Assessment Programme)

60. A review of repair instructions for both In-Service application and for support organizations (such as repair facilities) can provide relevant information for LEP categorisation. Analysis of the number and extent of repairs embodied in particular components, or locations can indicate emerging issues in these areas. This is valuable for initial categorization of components and the further analysis of those components with the potential for life extension.

61. From a Structural perspective, the underlying issues can be more complex to identify when general applicability (Topic 6) repairs have been developed and the repair instruction is no longer identified against particular Air System within the fleet (Topic numbers refer to the legacy military references). However, this information can usually be collated either from Maintenance records or from Unit Repair Teams, who typically maintain records of which Air System have been repaired. Similar issues can be identified from repair information from systems or engine components.

62. From a LEP perspective, the aim of the review is, initially, to identify signs of degradation that could compromise the Airworthiness of the fleet during the life extension period. For example, an occurrence of significant exfoliation corrosion on a wing rear spar was reported and repaired on an Air System in an ageing fleet, under consideration for life extension. This occurrence was identified as a ‘one-off’ and no wider measures were invoked. However, analysis of the readily available records identified that this issue was endemic across the fleet, but this had not been recognized appropriately in the CAw measures.

63. Additionally, a repair review can identify where the current repair approach is likely to be ineffective for life extension. For example, repeated, enlarged repairs in the same area across the fleet can provide an indication that the repair approach is likely to be ineffective for life extension and either an alternative repair approach or modification may be the most appropriate method of assuring the long-term Airworthiness of the fleet.

64. There have been several issues identified with repairs during LEP that are likely to have relevance to other programmes. In some cases, general applicability (Topic 6) repairs have been found to be inadequate for life extension, based primarily upon fatigue considerations. Moreover, repairs undertaken during previous ownership and repair schemes developed In-Service, based upon an existing DO scheme, have also required remedial measures, such as inspection or replacement. It is commonplace for older Structural repairs to have been designed statically with good fatigue practice, rather than with an accompanying fatigue analysis and this is basis for the RAP requirement in the AMC[81].

Accident and Incident Reports

65. Accident and Incident reports are managed within the FRACAS used by each Air System. However, there may be additional information within these reports that can be extremely relevant to LEP. Significant issues can become lost in time. Additionally, it is common for technical issues to occur in a cyclic nature, whereby measures introduced to address an issue become degraded over time as the impetus following an Accident or Incident becomes more distant. Moreover, trending of data over time by system, failure mechanism and even by individual Air System can help provide an indication of issues and Risks that could be considered within a LEP because the Risk posed by these issues has the potential to increase as a result of life extension.

Fault reports

66. Fault reports are considered to include Serious Fault Signals , Narrative Fault Reports (F760), Unsatisfactory Feature Reports (F765) and Mandatory Fault Reporting Instruction (MFRI) reports; routine component replacements are considered later under Maintenance data. Fault reports effectively provide the next step from Accident and Incident report in Heinrich's Pyramid[83]. Reported faults generally have the potential to become Incidents; Incidents have the potential to become Accidents. Furthermore, it is rare for an Accident attributed to technical cause not to have had previously reported related Faults. In many cases, either the significance of the reported Faults was not fully appreciated, or the corrective action was inadequate, with hindsight. Therefore, a review of fault reports to identify potential areas where Risks may increase as a result of life extension, including reported Faults where investigations were not undertaken, possibly due to proximity to OSD, can be extremely valuable within a LEP.

Maintenance Data

67. Maintenance is an essential element of CAw assurance. However, the importance of Maintenance as an Airworthiness measure and the significance of extracting information from accurate Maintenance data in the management of Airworthiness may not have always been fully appreciated in the past (see the Haddon-Cave Nimrod Review[84]). To undertake a successful LEP it is essential that the validity of the fleet Maintenance data is understood. For example, if it is suspected that Maintenance recording is often incomplete then using the lack of Maintenance arisings to support an Airworthiness decision within a LEP is likely to be wrong. Conversely, even if there are suspicions that the Maintenance recording is often incomplete, identification of an issue to investigate further within the LEP, from the Maintenance data, is likely still to be a valid decision.

68. Moreover, Maintenance data, even when validated, can be misinterpreted because of how it is processed into information and these issues can be relevant for LEP. For example, failure rates and consumption rates are often viewed in average terms across the fleet, such as MTBF or MTTF (for non-repairable items). However, this can be a very coarse representation of information and may not be appropriate within a LEP. In some cases, failures with the same average rate may have completely different failure-time distributions and the shortest times to failure, or some low percentile of the population, may be far more significant for a safety-relevant item. Also, failures may not be randomly distributed around the fleet. There may be populations among the fleet and

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[83] Refer to FAA System Safety Handbook, Chapter 16: Operational Safety in Aviation.

[84] Refer to The Nimrod Review: an independent review into the broader issues surrounding the loss of the RAF Nimrod MR2 aircraft XV230 in Afghanistan in 2006 report

these failures may be concentrated in a small section of the fleet or even individual Air System, due to differences in usage or variability between Air System. Consequently, the Risk for these Air System could be significantly greater than the average would suggest and hence the representation of Maintenance data may be significant in ensuring the correct information is gained from the data.

69. Despite the potential pitfalls of inadequate or incomplete data, a significant rise in failure rates of a particular component or system can be an indication that the system or component is entering the wear-out phase it its life and this may significantly influence the LEP action required. For example, replacement or modification may be a more appropriate solution than attempting to generate additional clearance evidence. In reality, when a variety of suitable options are available, cost and time are usually the deciding factors.

SI(T)

70. A review of the SI(T)[39] (ie Servicing Instruction (SI), Special Technical Instruction (STI), Routine Technical Instruction (RTI) and Urgent Technical Instruction (UTI)) raised during the life of an Air System can provide an incisive view into issues that may require further attention within a LEP. As previously discussed, technical issues are often cyclic in nature and a review of the history of SI(T) by system or component over time can identify issues that have not been fully resolved and where the Airworthiness Risk during a life-extension period may be unacceptable. Also, it is not always apparent how much significant technical history has been lost over time and it is rare for individuals to have experience of the complete history of an Air System undergoing life extension.

71. Repeated up-issues of SI(T) can indicate that the remedial measures are inadequate. Also, periodic instructions addressing the same issue can indicate an incomplete solution. Being unable to trace significant SI(T) to either modification action or changes in process or procedure can provide a possible indication of an unresolved issue. These issues are often well known to Maintenance technicians in depth organizations in particular.

72. The issue of previous history either being lost, or its significance not being recognized, was clearly illustrated with the fortuitous identification of widespread stress corrosion cracking in a fleet of Ageing Air System, which had been subject to a ‘creeping’ life extension over many years. The issue of stress corrosion cracking in the wing spar boom flanges had been well known in the past and extensive inspection and a subsequent life-time repair and refurbishment programmes had been undertaken. However, the fleet life had been extended well beyond the scope of the refurbishment programme and adequate remedial measures to manage this issue had not been introduced, despite this problem resulting in a fatal Accident in this Air System type, operated by another air force.

73. A complete formal review of the through-life SI(T) raised for the fleet may prevent such a significant issue being missed in the future. Full reviews of SI(T) over the life of ageing fleets, conducted during LEP, have revealed significant issues that required further attention to ensure ongoing Airworthiness.

74. SI(T), viewed alongside design and qualification data, can also illustrate aspects of the design that were proven by service experience to be inadequate. For example, initial analysis of a major Structural component during a LEP revealed that the test spectrum applied had demonstrated a fatigue life significantly beyond the initial clearance requirement for the fleet. However, In-Service experience revealed a catalogue of significant corrosion issues on a high-strength component dating back nearly 20 years. Without remedial measures to address the corrosion issues, the Integrity of this component could easily have been compromised by relying entirely on the design and qualification data to underwrite the life extension.

75. Moreover, there have been instances identified of modifications being embodied on Air System using SI(T). In some cases, subsequent cover modification action was also not carried out due to restrictions imposed on cover modifications at the time of modification classification. While this approach may have been acceptable for the original life of the fleet, it may not be acceptable for life extension and a review of SI(T) may highlight similar issues that may require further

investigation during the LEP.

Type Design Changes and Capability Enhancements

76. The Type Design change history of a fleet, including service modifications, can provide information highly relevant to a LEP. It can indicate where components were found to be inadequate for their intended service usage. This may include fatigue performance, resilience to environmental or accidental degradation or an inability to perform their required function. Additionally, there may be similar components on the Air System that have not been modified and may be at greater Risk during life extension.

77. In addition, Type Design changes recommended by the DO but not pursued or not classified, can provide useful information for possible life extension measures. The LEP requirement may make the Type Design change option a more attractive method of assuring Airworthiness in the longer term.

78. It is not uncommon for Type Design change action (including cover modifications) to not be taken or to be cancelled in the latter years of the life of the fleet. This is not unexpected, given the time scales often involved in taking a Type Design change from inception to fleet embodiment. The remedial action put in place may be suitable for the remaining original life of the fleet but may not be suitable for life extension. Moreover, loss of configuration control, caused in part by failure to embody cover modification, requires considerable concerted action to recover; success in achieving this recovery within LEP has been mixed. Therefore, a review of Modification Committee meetings can identify issues that require further investigation within a LEP.

79. It is rare for a MOD fleet to remain in service for its entire life without a number of enhancements being made to its capability, including those implemented in response to Urgent Capability Requirements (UCR). Investigations undertaken within LEP have found instances where long-term Airworthiness aspects of these capability enhancements may not have been given adequate consideration. This was particularly noted when the enhancements were not applied across the entire fleet (fleets-within-fleets issues are discussed further in the next section). In some cases, this may have been because the enhanced capability was not initially intended to be permanent, or that intended regularisation measures were subsequently cut from the ongoing programme. Irrespective of the reason for the lack of long-term consideration, it is clear that a review of capability enhancements and UCR to ensure the adequacy of CAw measures may be necessary.

Fleets Within Fleets

80. The issue of fleets-with-fleets (various portions of the fleet being of differing capability standard) has plagued the day-to-day management of military Air Systems and the implications are equally relevant to LEP (the establishment of a baseline Type Design standard for LEP is addressed later in this chapter). The fleets-within-fleets issue has been highlighted as a major impediment in several LEP.

81. Across several LEP there has been an unrealistic optimism in the ability to manage the consumption of life across the fleet to meet the life limits. This has usually been because the dominant driving factors that caused the fleet-within-fleets issue are usually still prevalent and life management is secondary to operational requirements. Therefore, where fleet management measures are going to be invoked to manage a fleets-within-fleets issue, these measures need to be introduced early in the life of the fleet to allow them to be effective and their success in meeting the alleviation requirement needs to be monitored.

Scheduled Maintenance Reviews and Extensions

82. The MOD policy is that the preferred method for developing Maintenance schedules[20] is using a RCM approach, based upon the Maintenance Steering Group 3 (MSG) standard and detailed in the JAP(D)100C-22.

83. From a LEP perspective, the information used to establish and develop the Maintenance

schedule through life can be very useful in identifying potential increases in Risk with life extension. However, the basis of the Maintenance schedules can also be variable across the fleets. Ideally, the process will have included risk-based identification of the SSI and FSI, (or Maintenance Significant Items (MSI) in some variations of the process). Thereafter, assessment will have been undertaken of the failure mechanisms, and vulnerability to ED and AD, within a zonal and surface area analysis. However, some Maintenance schedules have not been developed with this level of rigour and in many cases the MSG-3-based standard has been only partially applied.

84. Understanding the basis of development of the Maintenance schedule is important, irrespective of the approach taken, as this provides a clear indicator of the safety-related information likely to be available for the Air System.

85. A schedule review will usually be undertaken as part of the LEP to ensure that all the issues raised during the programme are adequately incorporated into the Maintenance schedules. However, as already discussed, it is also necessary to understand the MSR history of the Air System at the outset of the LEP. It is common for MSRs to be delayed or suspended as an Air System approached its OSD. The implications of this action can be accentuated significantly when ‘creeping’ life extension occurs and the original decision to delay or suspend the schedule review is not revisited. Additionally, this situation can result in a drop off in the raising of unsatisfactory feature reports (F765) because Maintenance technicians become aware that the management of the Maintenance schedules has been minimized.

86. Also, the Airworthiness assurance provided by a well-conducted MSG-based MSR can be limited by constraints or exclusions applied to the process to reduce their cost and time scales. Moreover, recommendations from previous schedule reviews, where they have been undertaken, may not have been accepted by the TAA or their predecessors and these decisions need to be understood.

87. All these actions may have been acceptable within the original life requirement for the fleet but for life extension, knowledge of this history is required, and the implications of these measures need to be understood within the LEP context. This is necessary to ensure that remedial measures are introduced where required to combat any increase in the level of Risk during life extension.

88. Additionally, throughout the life of most military fleets, there is a drive to extend the period of the scheduled Maintenance cycle (ie the major cycle), to increase availability and to reduce cost of ownership. It is not atypical for the Maintenance cycle period to double over the life of the fleet. In some cases, this extension may have been built upon sound foundations, using In-Service experience from validated Maintenance data to support a thorough RCM-based analysis. In other cases, it may have been driven by a high-level requirement.

89. The implications of these changes to the Maintenance cycle period, including the implications for increased latitude in Maintenance extension (ie Maintenance extensions are given as a percentage of the relevant cycle so a 25% extension could be twice the original latitude) need to be understood and the implications and any necessary rectification action need to be addressed within the LEP. This issue can be accentuated when the DO has limited visibility of the Maintenance schedule and may not have been involved fully in the extension of the schedule during the service life.

Sampling and Forensic Examination

90. Sampling and Forensic Examination programmes (referred to as Age Exploration programmes in MSG-3) are initiated when a greater understanding of the vulnerability of a particular component is required. Although sampling programmes are not used as frequently as might be expected, if they have been developed, this information is relevant to LEP. It illustrates that further understanding of the vulnerability of a component was required and any results captured are likely to have direct implications for LEP.

91. For Structures, the items that require sampling are identified in the Topic 5V. However, details of the actual Structural sampling undertaken may have to be extracted from a range of documents including Structural Integrity Working Group minutes.

Ageing Air System Programmes

92. AAA have been carried out on MOD fleets since the early 1990s. Initially, these Audits were focussed solely on Structural issues, but the remit of the Audit has since been widened to include systems and propulsion aspects. The content of the AAA has evolved considerably since its inception and hence it is likely that there will be a marked variation in the approach taken and the information available from an AAA, depending upon when it was completed and what aspects were included within the Audit. Nevertheless, an AAA has potential to provide much valuable information in support of a LEP in both LEP component categorization and in assembling evidence to support the life extension.

93. A review of the scope of the Audit, recommendations made, and remedial action taken could identify issues that may need to be considered further within the LEP. Issues relating to degradation of significant components are of particular relevance. Also, it would be unwise to assume that all recommendations made during an AAA have been implemented. In some cases, reviews undertaken during second AAA (AAA are to be repeated every 10 years) have identified outstanding recommendations from the first Audit.

Usage Validation Programmes

94. Usage validation programmes are mandated for MOD registered fleets (with a 2* exception case requirement). Although some fleets do operate a continuous OLM / ODR, generally, these programmes are periodic. A review of previous OLM / ODR reports is likely to identify issues relevant to a LEP. For example, components that are more highly loaded or have a more severe usage than expected may be less likely to reach the life extension requirement than design data may suggest, and this may affect their categorisation. Conversely, components that are more lightly loaded, or have less severe usage than expected, may be more likely to meet the life extension requirement than indicated by design.

Previous LEP-Related Studies

95. Any previous LEP studies are an obvious source of relevant information. Additionally, a review of the history of the Air System may identify studies that were effectively LEP but may not have been formally identified as such. Historically, life extension was often seen entirely as a Structural fatigue issue and programmes that did not address increases in metrics seen as fatigue related (eg FI for many FW Air System) may not have been clearly identified as life extensions.

Safety Panels, Integrity Working Groups, Committees, Strategies and Plans

96. There is a plethora of safety panels, Integrity working groups and committees that have, over the life of a fleet, been used to manage the Structures, systems and Propulsion Integrity aspects of the Air System. A review of the minutes or output from these groups can provide valuable information to support a LEP. It is not always clear why decisions were made in the past and the minutes of these meetings are often the only record of the basis for Airworthiness decisions and this can be highly relevant. The list of groups or committees will vary from Air System to Air System but is likely to include Platform Safety Groups, Integrity Working Group(s), TAw Meetings, Modification Committees, Local Technical and Faults Committees and Air System EDPC (formerly Corrosion Control Working Group). Additionally, in relatively recent years, Integrity plans and strategies have been developed and these may also contain information relevant to the LEP.

Other Operators' Experience

97. Other operators of a type, or similar type, particularly those with older fleets than the MOD, can often provide a useful insight into significant issues relevant to a LEP, and often assessment can be made of the effectiveness of any remedial measures applied. This is particularly relevant for United States-sourced Air System, where the UK is unlikely to be the fleet-lead operator.

Obsolescence Studies

98. Obsolescence management is an increasing issue for Air Systems, and this has been

recognized accordingly in the requirement for Obsolescence Management Strategies. From a LEP perspective, a review of Obsolescence Reports can provide a valuable collation of issues that are currently, or likely to become, significant for the Air System. Many of these issues may not be visible within the day-to-day management of the Air System as they may affect repair and overhaul facilities for example.

99. It is likely that an Air System-specific obsolescence review may be required within a LEP to consider the existing obsolescence management (refer to the Defence Logistics Framework[76], which ►is◄ considered AMC) and identify any gaps that may have Airworthiness implications during the life extension. For Air Systems with an integrated industrial support arrangement, this may be routine business but there may be exclusions from this arrangement, such as Government Furnished Equipment (GFE). Also, many Air Systems in the inventory do not have the benefit of these integrated support arrangements.

Environmental Issues Studies

100. Environmental issues can have significant implications for life extension, in a similar fashion to obsolescence. Many of the substances traditionally used in aerospace are subject to increasing control and many are or will be prohibited in the future. In some cases, these changes can have direct Airworthiness implications, for example, the restrictions on chromate-based corrosion protection or the removal of lead-based solders. In other cases, the issues may not be so well known, such as changes made to the chemical constituents of a fuel system elastomeric seal to remove carcinogenic substances.

101. A review of the Environmental Management Plan for the Air System may be required within a LEP to consider the existing plans and identify any gaps that may have implications for sustaining TAw during the life extension period.

Spares Provisioning and Component Repair and Overhaul Programmes

102. It is common for supply provisioning and component repair and overhaul programmes to be significantly reduced or cut entirely during the latter years of an Air System’s life. Such measures are taken to ensure that the necessary assets are managed in a cost-effective manner until OSD. However, these actions may have significant implications for LEP. An acute shortage of assets has practical Airworthiness implications, eg shortages of spares can lead to a gradual erosion of standards, particularly where In-Service limits are not well defined.

103. Recovering from the potential Airworthiness implications of spares and repairs provisioning decisions made in the latter years of an Air System’s life has proved to be a significant and ongoing challenge for LEP, and spares shortages are a good indicator of an area requiring further investigation within the LEP.

Non-Extendable Components

104. In some cases, it may not be feasible to extend the life of a component, and this may be clear from an initial review of the original qualification evidence or from In-Service experience. For example, the cleared life of a component may have been based upon test failure to a test spectrum that has been validated in service and an In-Service inspection approach may not be considered adequately safe, due to critical crack sizes below detectable levels. In such conditions, there may be no practical measures that could be taken to extend the life of the component and alternative measures such as replacement or Type Design change will usually be required.

Extendable Components

105. The list of components that can be extended without any further work is likely to be small. This approach is likely to require adequate qualification evidence for the required life extension in addition to validated In-Service evidence, to corroborate the qualification assumptions and condition of the component.

Components Subject to LEP

106. It would be expected that the majority of components are likely to be categorised as having some potential for life extension but requiring additional evidence to underwrite their requalification and recertification. In some cases, this may prove not to be cost effective, but this cannot usually be ascertained before further work is done to analyze the issues in greater detail. Guidance on the development of the LEP Qualification Programme Plan (QPP), to address the life extension evidence required, is detailed in the following section.

LEP QPP

Background

107. The LEP QPP is the umbrella under which the various elements of the LEP component requalification evidence generation are conducted. In most cases it may require a combination of approaches to gain sufficient requalification evidence for a particular component, such as OLM / ODR to measure the usage in service and additional testing, using a validated usage spectrum, to demonstrate the components capability, supplemented by directed inspections. Some components may not meet the life extension requirement and hence it is usual to undertake a preliminary study of the more complex proposed LEP solutions to generate a degree of confidence in the likelihood of success in the proposed approach. The LEP Component QPP needs to include forecast time scales for the availability of additional QPP evidence, identification of key technical risks and contingency options for higher-risk approaches.

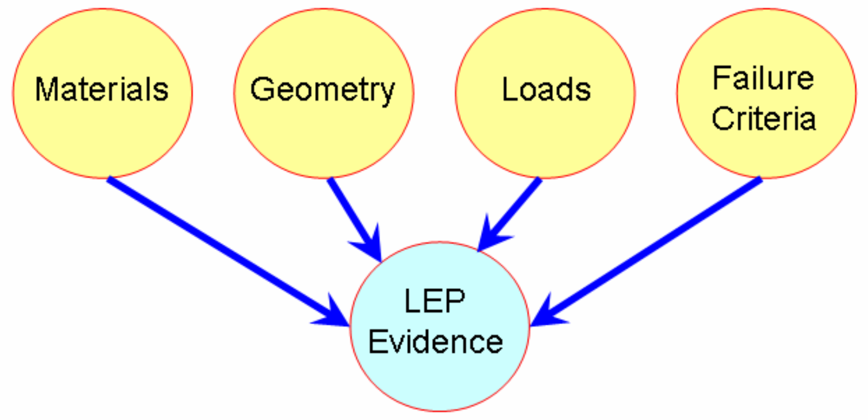
108. There is a wide range of approaches that can be taken to obtain the necessary requalification evidence and several of the more common methods used are described in the reminder of this section. Not surprisingly, many of the measures discussed below mirror the sources of data used to identify the LEP components and to understand their condition initially.

109. In addition to methods of obtaining clearance evidence, key issues identified in LEP to date are described and potential solutions are outlined.

Establishing the Clearance Evidence Basis

110. For each component within the LEP (determined by risk-basis on the consequences of failure), one of the first tasks will be to understand the evidence basis for the clearance of that component and how this may be affected by life extension. At the simplest level, the evidence required to support a component LEP can be considered to be divided into four source areas: understanding the material properties (eg fatigue strength, corrosion resistance or thermal conductivity), understanding the effect of geometry (eg cut-outs, joint configuration, wire bend radii, insulation thickness), understanding the loads (eg gust, pressure, vibration, thermal, impact) and understanding the failure criteria (eg residual strength, system leak, loss of function, buckling), as illustrated in Figure 32. This simple diagram can be useful in assessing the completeness of evidence available to ensure all aspects are covered for a particular component.

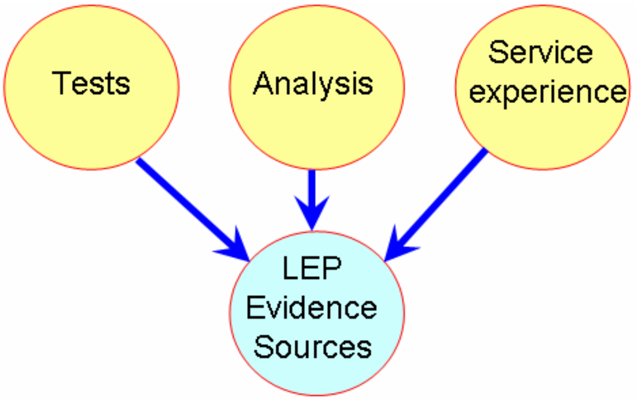
Figure 32 - Evidence Areas for LEP



Evidence Sources

111. The qualification and certification of Air System for LEP relies on a combination of test evidence, analytical evidence and service experience. Test evidence alone, without analysis to confirm that the test is representative, backed up by In-Service experience, is inadequate. Equally, analytical solutions, without test validation and in-service evidence, are also lacking. Therefore, although the following sections are divided into test, analytical and In-Service experience topics, these aspects need to be considered as complementary, as illustrated in Figure 33.

Figure 33 - Evidence Sources for LEP



Clearance Evidence from Existing Tests

112. The demonstrated clearance for the significant load-bearing Structure and for significant systems and propulsion components in military Air System is expected to be based upon testing, supported by analysis. The test specimens often range from near-complete Air System to stand-alone tests of individual components. This approach is underpinned by a pyramid of test and analytical programmes from materials data upwards. Within the LEP, it may be necessary to revisit the test-based clearance for LEP components to identify whether further clearances can be supported from the original test evidence.

113. The use of OLM / ODR (discussed later in this section) or other sources of loads and usage data to review the test spectra, is the main potential source of additional clearance and this approach has been used successfully in several programmes.

114. Care needs to be taken to ensure that any limitations in the loads and usage data used for the comparison, or in the tests themselves, are understood. For example, a particular loading action may not be represented on the test (eg undercarriage side load on touchdown) but this loading action may be recorded in the loads and usage data. Also, major tests necessarily include compromises as they cannot always fully replicate the loading conditions and simplifications need to be made in the generation and application of balanced load cases. In addition, as is often the case for fixed-wing Air System fatigue tests, high-cycle fatigue may have been represented by using an equivalent damage approach, with fewer low-frequency cycles of higher magnitude. The implications of these issues need to be understood in any approach to gain a greater clearance from existing test evidence.

115. There is no doubt that trying to gain a greater clearance from existing test evidence has its challenges and potential pitfalls. However, it has proven extremely valuable in gaining life extension clearances on many programmes.

Clearance Evidence from Supplementary Tests

116. In many cases, the testing undertaken during original qualification may not have fully demonstrated the ‘life’ capability of a LEP component (ie the component did not fail under test and was unlikely to do so). For Structural components, for example, an initial assessment of critical features can sometimes be gained from the FTR, or equivalent documents, which may identify a Fatigue Quality Factor (FQF) (or similar terminology). These provide an indication, from analysis,

of what factor would have to be applied to the fatigue spectrum to generate a failure; eg a FQF of 1.2 suggests that the current fatigue spectrum would need to be increased by 20% to generate a failure. Although feature and load spectrum dependent, a first-order approximation suggests a 20% stress factor would represent a life factor of approximately 2. Therefore, where the fatigue spectrum was replicated on test, such a component may have significant undemonstrated fatigue life capability and could be a potential candidate for further testing.

117. For many Structural, systems and propulsion components, indications of reserve capability of the component may not be readily available. However, where additional testing of components is a consideration, an initial analysis of the likely capability of the critical features in the component, under realistic loading spectra, can be a worthwhile investment. Conversely, careful consideration may be required before embarking on testing for components or features shown analytically to have little capability beyond the existing test-based clearance.

118. In anticipating likely life margins, it is also worthwhile to investigate the load cases that drive the design of the component. For example, from a Structures / systems perspective, a flying control system may be designed to a jam load case. The loads generated by this case may be far in excess of the usual service loads in the systems and this may provide confidence that further life capability can be demonstrated in the components in a system designed against this load condition.

119. Additionally, it is not uncommon for a Type Design change to a significant feature to be made and requalification undertaken by analysis, based upon the premise that the new feature was at least as good as the original feature. In such cases the full capability of the modified feature is usually not exploited unless further testing is undertaken.

120. Where test articles are still available, restarting or continuing test programmes is usually the most efficient method for gaining the additional clearance required. However, there is also a place for development of new tests. These have proven particularly valuable for LEP where inspection-based regimes are unlikely to be successful. For example, inspections may be impracticable for highly-loaded compact Structures (as often found on combat Air System) or where high-strength materials, with short critical crack lengths, are used (eg landing gear and gearboxes).

121. Using Air System or components from service, where test articles are no longer available, can often provide an adequate solution. This approach has been used successfully on several LEP. However, care needs to be taken to understand the damage state of the ex-service test article and pre-emptive repairs may be required. Additionally, account needs to be taken of the In-Service usage, although this is generally small compared to the additional testing requirement.

122. Several LEP have also used simplified tests, either using manufactured test articles or retired service Structure or components, to add to the body of evidence in support of a clearance. These tests have been used, for example, where the spectrum can be simplified to a few (or one) dominant loading actions and represented on simple tests to illustrate the progression of damage through a Structure. This can be particularly useful where the load redistribution and damage progression in a complex Structure is difficult to predict analytically.

123. Alternatively, simple tests to represent known In-Service occurrences, to understand their implication for LEP, such as misalignment of fuel pipes, or the effect on fatigue life of reductions in torque loading in a bolted joint, have proven invaluable on several programmes.

124. Materials and coupon tests can also provide invaluable and cost-effective information to support a LEP, where the existing data are inadequate.

Clearance Evidence from Analytical Solutions

125. As has already been discussed, test-based and analytical solutions are interrelated within the design and clearance process. Moreover, a competent Design Organization is likely to have an ongoing process of baselining its analytical tools to test results as part of its pyramid approach to design and qualification. Additionally, as previously discussed, modelling capability across a whole range of disciplines including Structures, systems design and analysis, aerodynamics and loads

has increased dramatically since many of the MOD Air System fleets were designed and hence advantage can be taken of these developments. These capabilities may also benefit from additional information, such a wind tunnel data, flight loads data and temperature and environmental surveys captured since the original design of the Air System.

126. Modern mathematical tools, such as Finite Element Analysis (FEA), were in their infancy when many of the MOD’s fleets were being designed and hence the tools used in design were often far less precise than those used today. Hence, the application of more sophisticated analysis tools, when used by experienced practitioners, with appropriate validation (eg against OLM / ODR results, strain surveys from tests or keyed into test failures) can prove extremely useful within a LEP. Caution needs to be applied when taking advantage of more sophisticated analysis tools, that the precision in the analysis is matched by the precision in the manufacture and the In-Service condition of the component in reality.

127. These tools can also prove extremely useful for analysing complex components where historically, the design assumptions for complex features may have been highly conservative to account for uncertainty in load and stress concentration interactions. In such cases, models, validated against test data, may provide evidence to support alleviations and potentially life extension. This approach has been used successfully in LEP.

Clearance by Inspection

128. Inspection, from visual to complex NDI, is one of the essential elements of a CAw programme for Structures, systems and propulsion components. Consequently, LEP have relied heavily upon inspections as a way of mitigating the risk of failure of components. Where alleviation from spectra review, test evidence, additional testing and analytical approaches are unable to generate a life extension clearance, an inspection-based approach is often considered.

129. However, it is important to ensure that an inspection programme has adequate foundations. The inspection has to be practicable and adequate access needs to be available to undertake the inspection with confidence. Where inspections are used to mitigate failures, there has to be perceptible signs of distress that correlate with the expected failure mechanisms and that can reasonably be expected to be identified under In-Service conditions. There also needs to be a suitable level of confidence that detection will occur before the Integrity of the component is in question. Where limits are applied to inspections these need to be measurable and the limit values need to be readily accessible to those undertaking the inspections. Inspection regimes also need to be supported by a test-evidence based approach to ensure damage nucleation and propagation are adequately understood.

130. Although inspections may initially appear to be the most cost-effective solution to LEP, this conclusion may not always be borne out in practice. As previously discussed, for highly-loaded compact Structure and high-strength material, an inspection-based approach may not be supportable for either access or short critical crack length reasons. Moreover, without sufficient investment in test and analysis to support the inspection-based approach, a highly conservative approach may be necessary. Hence, inspection thresholds and repeat inspection periods tend to be extremely short, with a significant burden on the front line. Additionally, safe-life Air System Structures, for example, were often not designed to be inspected and in many cases significant damage has been introduced into Air System while undertaking inspections. For example, repeated removal of fin and tail plane attachment bolts for NDI has introduced mechanical damage on several Air System types.

131. For a certified clearance-by-inspection it is necessary to understand:

a. The detectable damage size (eg crack), with a defined level of confidence.

b. The damage growth rate and direction of growth in the materials and features present, under a representative load spectrum.

c. The failure criteria.

132. For damage tolerant designed Structure, this information will be part of the design and

qualification process and the crack-free period will have been demonstrated by a full-scale fatigue test. However, for safe-life designed Structure and for many systems and propulsion components, it is unlikely that this information is readily available and hence this may need to be generated to support a directed inspection-based clearance (zonal inspections are not considered adequate to support inspection-based clearances).

133. Inspection is also the primary method for detecting corrosion. Corrosion, with the potential for corrosion-fatigue interaction, is one of the key threats to Air System during life extended periods and corrosion development is notoriously difficult to predict analytically with any accurately. For well-designed Air System with a good choice of materials and barrier systems, corrosion will often occur at locations where the barrier system has been breached by mechanical damage and detection will be highly reliant upon inspection regimes and effective remedial action.

Usage monitoring (including Manual Data Recording Exercises (MDRE))

134. Usage monitoring can be important for two aspects of LEP clearances. Firstly, as already discussed, it can be used as a method of gaining an understanding of how a component is used in service. Secondly, the introduction of additional usage monitoring can be used to reduce the safety factors applied to a component life during the life-extension period, if the dominant loading actions can be monitored on a fleet-wide basis.

135. From the perspective of understanding the usage in service, it is rare for all the available usage information available on an Air System to be fully exploited. This is increasingly prevalent in more modern Air System, which usually have onboard monitoring systems or have the capability to capture onboard data relatively easily. Therefore, it may be extremely useful to review the data available against the LEP component usage assumption to identify those aspects that can be validated from the existing data set.

136. In some cases, it may be adequate to supplement the available data with MDRE. These are more usually undertaken on RW Air System where a manual recording of parameters such as flight conditions, rotor start and stop, and air-ground-air cycles is undertaken. Also, a similar manual flight condition recording is used as the main Air System usage monitor on some large military fixed-wing Air System. Such programmes can offer a cost effective and rapid solution and can be particularly useful in identifying events or conditions that are difficult to define deterministically from existing Air System data.

137. The introduction or development of a monitor to reduce the required safety factors on usage to gain the required life-extension clearance has been considered on several LEP. In reality the decision is usually made on economic grounds rather than Airworthiness considerations. Often the main impediment is that the life remaining is too short to allow the reduced lifing factor to provide sufficient margin (ie the decision is effectively too late). Nevertheless, in some cases the adaptation of an existing monitor to capture the main loading actions of an additional feature may be appropriate, once validated. For example, OLM / ODR data may show an adequate correlation between store attachment fatigue and flight parameters already captured within the Air System monitoring system (such as normal acceleration and roll rate). In such cases the introduction of an additional, validated, algorithm for stores attachment monitoring may be appropriate, as long as the overall fatigue substantiation process for the potential monitor location is understood.

138. Helicopter HUMS are now widely fitted across MOD fleets. These systems often capture a great many flight parameters but in many cases much of the captured data is not used to support CAw. However, a discrete exercise to use these data to support LEP could provide invaluable information to understand In-Service usage.

139. It is also important to recognize that In-Service usage may have changed significantly during the life of the fleet and this may need to be included in any lifing assessments.

Operational Loads Monitoring (OLM) / Operational Data Recording (ODR)

140. OLM / ODR is effectively the next step in understanding usage, when adequate information cannot be obtained from existing data; OLM / ODR has proven invaluable in several LEP. Many of

the revised clearances provided could not have been achieved practicably without usage spectra derived from OLM/ ODR data, as has already been discussed. Traditionally, OLM / ODR have been primarily focussed on validation of Structural loads or usage. However, understanding the loads and usage is equally applicable to life extension of systems and propulsion components. For example, airbrake deployment data was used on one LEP to support the life extension of the airbrake jack. There is certainly room for this integrated approach to be developed further, particularly within fixed-wing Air System where there is often unnecessary segregation in data capture between Structures, systems and propulsion disciplines.

141. Guidance on the conduct of OLM programmes is provided in MASAAG Paper 109[85] and many of the principles identified are equally applicable to ODR programmes. Central to the guidance is the establishment of clear requirements at the outset. If there is an ongoing OLM / ODR capability in the fleet, then this can usually be modified to meet the requirements of the LEP. If there is no OLM / ODR capability in the fleet, it may take several years before useful information can be obtained from the programme and hence it is prudent to initiate an OLM / ODR programme as soon as possible to support the LEP.

Directed Surveys

142. LEP have shown the importance of using on-Air System and off-Air System directed surveys (eg hydraulic components undergoing bay Maintenance) and interviews with key personnel to validate the primary assumptions made within the programme. A LEP needs to be based upon reality rather than the assumption of reality and there may be issues that affect the LEP that are not apparent from documentation or where their significance has not been identified.

143. Involving experienced technicians, particularly those undertaking deeper Maintenance on and off-Air System, is an invaluable exercise within a directed survey. For example, it was identified during one LEP directed survey that lifed major sub-components were regularly moved from one component to another while undergoing a bearing replacement procedure during Maintenance. The primary component had an Engineering Record Card (ERC) but because the subcomponent had no unique identification number there was no record of these changes. This component was required to undergo life extension and it had been previously assumed that the component parts remained together.

Sampling or Forensic Examination

144. Sampling or teardown programmes have been used as a primary tool in Structures and systems LEP for many years. They are also used widely to validate life predictions on critical propulsion components.

145. Structural sampling / teardown was traditionally focussed primarily on identifying areas of corrosion, particularly in hidden Structures. The design assumptions are made assuming un-corroded samples and there are no allowances made in the design codes for the occurrence of corrosion in Air System Structures. Barrier systems (eg surface finish) are specified and qualified in design and it is assumed that these barrier systems are maintained in service. It is also assumed that corrosion in service is detected, corroded material is removed by blending or polishing and the barrier system is restored. Thereafter, the long-term effect of the corrosion is considered to be as a consequence of the material removed, rather than a stress concentration at the bottom of a corrosion pit, for example. The evidence from sampling and teardown programmes, as well as service Maintenance data, is essential to identify hidden corrosion issues, or corrosion issues that have not been dealt with adequately, either of which could call into question the life extension certification for the fleet. Improved corrosion control and recovery actions are among those likely to be included in enhanced CAw measures, identified during a LEP.

146. In recent years, the remit of Structural sampling / teardown has been widened to include detection of fatigue damage (including WFD), particularly when Air System have exceeded their

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[85] Refer to MASAAG Paper 109 - Guidance for Aircraft Operational Loads Measurement Programmes.

safe lives or where there is limited confidence in the SI assurance evidence for the fleet (such as fatigue test limitations). Detailed guidance on the conduct of Structural sampling / teardown can be found in MASAAG Paper 105[41] and details of potential Structural sampling areas, based upon SSI, are detailed in the Topic 5V (or equivalent) publication.

147. Sampling has also been used to support a wide range of systems LEP from hydraulic components, flying control cables to electrical wiring looms; in each case valuable evidence has been assembled during these programmes. For many components, sampling is the primary method for gaining a detailed understanding of the condition of the component in service and this is essential for the LEP to retain its validity. For example, for many Air System types there are known areas where Air System wiring is subject to adverse conditions and hence potential degradation, such as Severe Weather and Moisture Prone (SWAMP) areas and areas in close proximity to engines, hot Air Systems, hydraulic systems and fuel systems. It is not always apparent from visual inspection whether the Integrity of wiring insulation has been compromised. Sampling and testing of electrical wiring, against original specifications, can provide essential information either to support the LEP clearances or to identify the need for remedial action.

148. In addition, a sampling programme undertaken with an AAA highlighted issues with flying control bearings being identified as ‘sealed for life’, which had been taken to mean a maintenance-free life; however, no associated life had been identified for the bearings. Further investigation identified that these were low-maintenance bearings rather than maintenance-free and control restrictions on several other Air System types, operated in civil aviation, had been attributed to failure of similar bearings.

149. A key issue for sampling / teardown programmes will ensure that they are well focused and address all the requirements. Also, it is rare that one organization fully appreciates all of the skills or holds all the knowledge necessary to undertake a successful sampling / teardown programme and hence involvement of DO, TAA, SME and maintainers (forward and depth) has proven extremely valuable in previous sampling programmes.

Maintenance Actions

150. The introduction or adjustment of Maintenance actions, such as reapplication of existing or improved protective or barrier coatings, lubrication or torque adjustment can be valuable tools within a LEP. Although it is impossible to prevent entirely the degradation of materials, the pace of this degradation can, in many cases, be dramatically reduced by Maintenance actions.

151. Although it would be expected that most feasible maintenance actions may have already been included in the Maintenance schedule, using an RCM-approach, this may not be the case, particularly where the Maintenance schedule has had limited RCM analysis or has not been amended for some time. For example, failure mechanisms that could be alleviated by Maintenance actions may be apparent in service and these mechanisms may not have been anticipated during the Maintenance schedule development or subsequent reviews.

152. The widespread corrosion found on Air System systems components during AAA and CS[86] suggests that there are improvements that could be made using relatively simple Maintenance actions and LEP may be an opportune time to implement such changes within the CAw programme.

Type Design change

153. Where a life extension cannot be demonstrated for a component and there are no valid Maintenance actions or inspections that could be used to support the revised clearance, Type Design change action may be an appropriate method for assuring Airworthiness. Where these options have been considered in LEP, the Type Design change proposal had often already been developed prior to the LEP but had not been either classified or embodied.

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[86] Refer to SAAG Paper 001 - Lessons identified from initial Ageing Aircraft Systems Audits and Condition Survey Programmes.

154. Also, where the life extension period is sufficient, it is often valuable to review potential Type Design changes to LEP components on a cost-of-ownership basis.

155. Additionally, there is now a wide range of fatigue enhancement measures that can be used to improve the fatigue performance of Structures, systems and propulsion components. These include: cold working of holes with and without interference fasteners, shot peening and laser peening, shape re-profiling and material deposition methods. Several of these processes are now used routinely in new Air System designs and some have been applied retrospectively as fatigue enhancement measures on MOD Air Systems.

156. In the right location, and with confidence that the technique can be applied consistently, several of these fatigue enhancement measures are attractive options for life extension. However, the fatigue life improvements demonstrated by these approaches can be sensitive to the load level and the applied spectrum (eg constant amplitude or variable / spectrum loading). Therefore, representative test data are necessary to allow certification of these methods in LEP.

Replacement

157. Replacement of items that are not adequate for life extension, with components to the same standard is an option that has been used widely in LEP.

MFRI

158. MFRI can be a valuable tool when it is necessary to gain a greater understanding of the issues affecting a particular component during or after a LEP, particularly where there is reduced confidence in the Maintenance data for that component.

Concessions

159. Identifying concessions, locating them In-Service and providing evidence that they are adequate for the life extension period has proven extremely challenging for several LEP and is likely to be an issue for most programmes.

160. From an Airworthiness regulation perspective, the issues are relatively simple – all related concessions need to be shown to be adequate for the life extension period. The challenge for a LEP is to produce a solution that is realistic and affordable. For larger fleets there may be many thousands of concessions with little or no traceability to Air System tail numbers or major components. These concessions may have been assessed against the original design requirements for the Air System but may not be adequate for the LEP requirement and evidence from LEP has shown this to be the case.

161. A successful approach adopted within a LEP was to subject the concessions to a staged filtering process to reduce the task to a more manageable size, without compromising Integrity. For example, concessions not applicable to the MOD fleet were removed and concessions on fixed Structure on Category 5 Air System were also removed. Thereafter, a staged analysis approach was undertaken whereby concessions that clearly met the LEP requirement, using conservative assessment methods, were identified and cleared and those remaining were subject to progressively more in-depth analysis.

162. Where clear evidence of the fatigue life of a concession was not available, approaches such as clearance by comparison with more highly stressed features on the Structure or component were used (eg a blended machining error or local thinning could often be passed by comparison against nearby attachment holes). For those concessions that could not be cleared by this approach, a more detailed analysis was undertaken. This included the development of individual fatigue spectra, limited FEA (for assessment of complex stress concentrations or local loading effects) and simple coupon testing.

163. This approach was also supplemented by technical instructions to identify those concessions in service with visible cues. Detailed analysis of often incomplete service Maintenance records was also undertaken to identify possible locations for unidentified concessions. In many cases, this allowed the Risk to be ring-fenced down to a manageable number of Air System where remedial

actions, such as inspections or component replacements were undertaken.

Tracking of lifed items

164. Lifed items are tracked using either ERC or equivalent systems. ERC, in this context, refers to all component manual and electronic records which identify the Type Design status, application of instructions, repairs and usage. LEP have identified significant issues with decisions made at introduction to service as to which components will have ERC. In several cases, significant, interchangeable components, with fatigue life limits, were found to have been introduced into service without ERC. Consequently, it was extremely difficult to identify life consumed and Type Design status of these components with any confidence and in many cases penalty life values had to be implemented to assure Airworthiness.

165. The default position has often been to assume fleet leader values; however, with persistence a more realistic approach can usually be developed using a combination of validated Maintenance data (even when incomplete), repair records, previous SI(T) (where component serial numbers are often identified), Type Design change histories and accepted statistical methods. In several cases this more complex approach (as opposed to assuming fleet leader data) has prevented the effective grounding of large proportions of the Air System fleet undergoing LEP.

166. Following a LEP, it has generally been necessary to increase significantly the number of components that are subject to life tracking, using appropriate metrics (eg flying hours, FI, landings, cycles, starts, deployments etc).

LEP Baseline Configuration

167. The maintenance of configuration control is a particularly challenging aspect of day-to-day Airworthiness management. However, the complexity of this issue increases significantly with the advent of a LEP. Firstly, it is necessary to understand the configuration of the Air System to be subject to life extension. In some cases, it may be necessary to establish several baseline Type Design change standards; this may be the case when Air System were introduced to service in blocks or tranches or when fleets-within-fleets issues are prevalent (as previously discussed). Experience has shown this is not a trivial exercise, particularly when considering Air System equipment, role equipment, and commodity item configuration, as well as Air System configuration.

168. Additionally, Type Design changes not considered of direct Airworthiness significance at classification (ie below B/2 classification[87]), may not have been actively managed within the fleet and the fleet cofiguration status for such changes may not be clear. However, embodiment of such changes may, in some cases, be essential because the pre-modification standard has been shown to be inadequate to meet the life extension requirement. Hence it may be necessary to verify the configuration of the fleet and implement appropriate management of these changes thereafter.

169. This issue can be further complicated where equipment Type Design changes have not been subject to cover modification action. In such cases it may not be possible to identify the configuration status of the fleet or off-Air System assets, without physical inspection. As previously discussed, in the extreme, component changes may have been introduced under SI(T). Further complications arise where the changed component is interchangeable and the SI(T) has been recorded against the Air System, rather than the component. In such cases there may well be no alternative to a visual inspection of the fleet and off-Air System assets to identify their configuration status, where this is possible.

170. Even in programmes where the documentary evidence suggests that the management of Type Design changes within the fleet is adequate, it has proven invaluable to undertake physical checks of the Airworthiness-significant Type Design change state, to validate these assumptions. In some cases, significant Airworthiness Type Design changes, identified as fleet embodied and hence within the LEP baseline standard, were found not to have embodied on several Air System within the fleet. In particular, the configuration of early production run Air System, or pre-production

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[87] Refer to Def Stan 05-057 Annex E - Air Domain Modification Classification Categories.

Air System, as they have been termed in some fleets, is a potential area for investigation.

Widespread Fatigue Damage Assessment

171. WFD is the simultaneous presence of cracks at multiple Structural locations that are of sufficient size and density such that the Structure will no longer meet the residual strength requirements. The likelihood of WFD in Air System Structure increases with usage. WFD results from many cracks that are generally too small to be reliably detected using existing inspection methods. These cracks could grow together more rapidly than might be expected, so that failure could occur before another inspection is performed to detect them. The simultaneous presence of fatigue cracks that may grow together, with or without other damage in the same Structural element, such as a large skin panel, is known as MSD. The simultaneous presence of fatigue cracks in similar adjacent Structural elements, such as frames and stringers, is known as MED. Some Structural elements can be susceptible to both types of damage, which potentially could occur at the same time. If undetected, either type of damage could lead to catastrophic failure due to reduction of the strength capability of the Structure.

172. The Risk of WFD has now been recognized by the civil regulatory authorities as the limiting Structural factor in continued operations of damage-tolerant large Air System and there will increasingly be requirements to establish an effective Limit of Validity (LoV) beyond which the Air System will not be operated.

173. However, the Risk of WFD is not restricted to large airliners and is equally likely in any regions where similar features are subject to similar stress levels and hence there is a need to assess the Structure of an Air System for its potential vulnerability to WFD and then to take appropriate remedial action. GM on WFD can be found in MASAAG Paper 116[88].

‘On-condition’ components

174. A large proportion of system components are maintained In-Service using ‘on-condition’ criteria, with no published ‘hard’ lives. This has proven to be a key issue in systems life extension, where it has not always been appreciated that the clearance for components to remain in service using an ‘on-condition’ approach is still bounded by the demonstrated original design qualified and certified life limits.

175. Therefore, where these components are deemed to be safety critical, safety related or safety relevant (a range of terminologies are generally in use), the ‘on-condition’ approach needs to be requalified and recertified for the life extension period. The continued function and reliability of the component needs to be demonstrated for the life extension period to ensure that the component is not entering a wear-out period, as previously discussed. Also, the addition of evidence from service experience is an essential element of the analysis. It is not uncommon for In-Service experience to indicate significant shortfalls in the validity of the original qualification and certification. For example, the ‘on-condition’ approach may have been based upon design MTBF rates which have proven In-Service to be extremely optimistic.

Commodity Aspects

176. LEP have highlighted how many components used on an Air System are managed outside of the direct control of the TAA. In previous LEP there have been a number of breakdowns in communications and lack of understanding between the agencies involved in managing this vast range of assets. This is an area that may require considerable attention within a LEP to ensure that Airworthiness-related issues are adequately addressed for all safety-relevant components fitted to the Air System, irrespective of how they are managed.

177. Therefore, it is essential that the TAA, Commodity DT, DO and commodity DO / OEM understand the aims and approach to be taken within the LEP and are supportive of the

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[88] Refer to MASAAG Paper 116 - Widespread fatigue damage in military aircraft.

programme. The Commodity DT may also have to consider the implications of the LEP for multi-user items.

Condition Survey

178. A CS of a representative sample of fleet-leader Aircraft can be an invaluable tool in validating the LEP assumptions, particularly for those ‘on-condition’ components. Corrosion, for example, has been identified as one of the key threats to Integrity within a LEP. A CS programme can be used to validate assumptions that corrosion areas have been identified and addressed. Additionally, CS can be used to highlight cumulative Airworthiness issues that may become significant during the life-extended period and may not have been initially recognized or may have been erroneously dismissed as ‘Husbandry’ issues. For example, a recent CS identified widespread inadequate S-class (electrostatic discharge protection) electrical bonding in an Air System fuel system due to a combination of incorrect assembly and corrosion. The failure of an individual bonding strap was unlikely to be significant, but the cumulative failure, resulting in the loss of electrical bonding over a large section of the fuel system, was significant.

179. The LEP is aimed at identifying both known and unknown issues that could affect the Airworthiness of the fleet during the life-extended period and CS can be an invaluable tool in identifying early signs of issues that, if not addressed, may develop into Airworthiness issues. GM on the conduct of CS can be found in SAAG Paper 005[89].

Data Management Plan

180. A LEP can generate an enormous volume of data and information that is primarily Airworthiness-related documentation. The data paths within the programme are also likely to be highly complex, involving a range of DO, OEM, MOD (technical and commercial) and SME organizations and could be far more extensive than those used in day-to-day business operations within the TAA. Therefore, a joint-organization data management plan may be necessary to ensure the retention of essential Airworthiness-related information for the LEP period of the fleet.

Enhancements to CAw Management Requirements

181. LEP have highlighted shortfalls in the CAw measures in place leading up to a LEP and have also identified additional measures necessary to retain Airworthiness post-LEP. It is important that any additional requirements are promulgated in the appropriate publications and highlighted within organizations responsible for supporting the fleet. In addition, many of the issues are likely to be generic and may be valuable to other MOD organizations either planning or engaged in LEP.

182. In previous programmes, it has proven valuable to brief personnel at Commands, Forward and Depth, concerning the key changes emanating from the LEP. Personnel at Forward and Depth are often unaware of the enormity of a LEP and may not fully appreciate the significance of some of the myriad of instructions that they may receive over the course of a LEP.

Maintenance Schedule Review

183. It is likely that significant changes to the Maintenance schedule in both content and periodicity may result from the LEP. Therefore, a full MSR, using RCM/MSG-3 and detailed engagement with the DO and Forward and Depth personnel, can provide a coherent approach to incorporating these changes. This can be particularly important where MSRs have not been undertaken, or have been limited in their scope, in the years preceding the LEP.

Air System Documentation Amendment

184. All relevant documentation in the ADS[90], including the Support Policy Statement (SPS), will need to be reviewed and amended to reflect the revised component and Air System life limits and any additional requirements.

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[89] Refer to SAAG Paper 005 - Condition Survey - Aircraft Interconnectivity.

[90] Refer to RA 1310 – Air System Document Set.

Wider Airworthiness-related Support Implications

185. There are also a great many wider Airworthiness-related support functions for consideration within a LEP, alongside the direct Air System issues. These issues can be very Air System specific and will vary with the support arrangements that are in place. However, these may include:

a. Continued DO support.

b. Spares provisioning and continued commodities support.

c. Retention of type-specific skills.

d. Special-to-type tools and support equipment.

Chapter 12: Out of Service Date Extension Programme

Introduction

1. This Chapter presents process and detailed guidance material relating to the development and implementation of an Out of Service Date Extension Programme (OSDEP). An OSDEP is a mechanism for identifying and mitigating any increased Risks of operating Air System beyond the declared OSD as published in the Airworthiness Strategy / RTS / Military Permit to Fly (In Service). It can be considered a re-validation of the IM activities for Structures, Propulsion and Systems as well as a review of the Air System Equipment Contribution Log and a validation of applicable Airworthiness decisions. This Chapter must be read in conjunction with RA 5725[35].

OSD Baseline Configuration

2. Even in programmes where the documentary evidence suggests that the configuration management of Type Design changes within the fleet is adequate, it has proven invaluable to undertake physical checks of the Airworthiness-significant configuration, to validate these assumptions.

3. In some cases, significant Airworthiness Type Design changes, identified as fleet embodied and hence within the OSDEP baseline configuration, were found not to have been embodied on several Aircraft within the fleet. In particular, the configuration of early production run Aircraft, or pre-production Aircraft, as they have been termed in some fleets, is a potential area for investigation.

4. Validation of an individual Aircraft Type Design change will ensure that a common standard exists and where any additional Risk is present, it can be identified, mitigated accordingly and applied to other Aircraft in the programme.

Threats to Integrity Management

5. The specific threats to the Integrity of Structures, Propulsion and Systems are fundamentally no different to when an Aircraft is operated within its originally declared OSD. However, the probability of occurrence and hence the level of Risk may increase with further use.

6. Without an OSDEP this increased Risk may not be detected and the level of Risk at which the fleet is operating, may no longer be ALARP and Tolerable.

7. All IM activities will be conducted iaw RA 5726[77]. Furthermore, the validity of an AAA will also be considered iaw RA 5723[32].

Additional Operating Risk

8. A top-down review of the Equipment Contribution Log will be conducted by a SQEP personnel to ensure that the increase in exposure resulting from the OSD extension leads neither to an increase in the severity nor to a disproportionate increase in likelihood of any RtL.

Validation of Airworthiness Decisions

9. Previous Airworthiness decisions will be re-evaluated to cover the extension and the Airworthiness Strategy updated accordingly[91]. The scope of this will be clearly identified and consideration made against the maturity of ongoing IM activity and the proposed extension period. A proportionality judgement will be made and explained if the extension is for a relatively short amount of service life.

10. In particular, worthy of consideration are the issues that typically arise where an Air System has a repeated OSD extension, including the following:

  a. Reduction in personnel and resource allocated to TAA activities.

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[91] ►Refer to RA 5010 - Type Airworthiness Strategy.◄

b. Knowledge management and sustainment by the Design Organization.

c. Changes to Preventive Maintenance cycles.

d. Cancellations of, or delays to, scheduled maintenance reviews.

e. Reduction in spares and repairs provisioning.

f. Embodiment, or delay to safety Type Design changes.

g. Status of deferred Maintenance across the fleet, including Lims, Acceptable Deferred Faults and the impact on other CAw Management tasks in RA 4947[92].

h. Review of fault investigations.

i. Reductions in Maintenance and support (eg No. of Depth Lines).

j. Impact of changes of usage.

k. Capability enhancement / upgrades.

l. Development of fleets within fleets.

11. Each of these measures individually will have been assessed for their potential impact on the Airworthiness of the fleet and an OSDEP provides a mechanism to consider the cumulative effect of these changes upon the IM of the fleet and ensure that a clear focus is retained. This can be achieved by conducting an extensive review of previous records from relevant Airworthiness and safety related meetings (IWG(s), Air System Safety Working Groups, Structural Examination Programme, Platform Safety Panel and Airworthiness Management Groups (AMGs) etc). Any costs, including those associated with the tasks above, will need to be considered within the annual budget cycle.

Documentation

12. Typical evidence to support an OSDEP will include, but is not limited to, the following:

a. Extant IM processes.

b. Formal activities including AAA.

c. Minutes from IWGs.

d. Integrity Strategy Documents and Management Plans.

e. TASA Reports.

f. Minutes from Platform Safety Panels.

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[92] Refer to RA 4947 - Continuing Airworthiness Management - MRP Part M Sub Part G.

Chapter 13: Advisory Group Papers

Military Aircraft Structural Airworthiness Advisory Group (MASAAG)

1. MASAAG paper 103: structurally significant items and their use in reliability centred maintenance schedules for British military aircraft

2. MASAAG paper 104: recommendations for the future shape of the ageing Air System Structural audit

3. MASAAG paper 105: teardown inspections, guidance and best practice

4. MASAAG paper 106: repair assessment programme for military transport aircraft

5. MASAAG paper 109: guidance for aircraft operational loads measurement programmes

6. MASAAG paper 116: widespread fatigue damage in military aircraft

7. MASAAG paper 118: the interaction of corrosion and fatigue in aircraft Structures

8. MASAAG paper 120: guidance on helicopter operational data recording programmes

9. MASAAG paper 122: development of a protocol for acceptance of new NDT capability in the air domain

10. MASAAG Paper 123: development, validation, verification and certification of Structural health monitoring systems for military aircraft

11. MASAAG Paper 124: guidance note on the qualification and certification of additive manufactured parts for military aviation

Systems Airworthiness Advisory Group (SAAG)

12. SAAG Paper 001: lessons identified from initial ageing Air Systems audits and condition survey programmes ►(Withdrawn)◄

13. SAAG Paper 002: MOD aircraft electrical wiring

14. SAAG Paper 005: condition survey - aircraft interconnectivity

Propulsion Airworthiness Advisory Group (PAAG)

15. No papers issued.

Ageing Audit Programme Working Group (AAPWG)

16. AAPWG paper 010: a framework for ageing air system audits

17. AAPWG paper 011: guidance on the conduct of aircraft zonal hazard analysis (ZHA)

18. AAPWG paper 012: understanding the corrosion threat to ageing air system

19. AAPWG paper 013: continuing Airworthiness management: its contribution to identifying evidence of ageing in aircraft

20. ►AAPWG paper 014: marinisation of air systems – learning from experience◄

Fuels and Lubricants Airworthiness Advisory Group (FLAAG)

21. No papers issued.