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MoD Aircraft Electrical Wiring Interconnect System Integrity

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EXECUTIVE SUMMARY

The Electrical Wiring Interconnect System (EWIS) is the electrical arterial infrastructure running throughout the aircraft; it connects the systems and any deterioration of its condition could impact on their proper operation. The electrical wiring interconnect system can be considered as the electrical analogy to structure. This paper argues that build standards and maintenance policies have not kept pace with the changes in the materials used for electrical interconnect components, including wire insulations. Although wire is not the only component in an electrical wiring interconnect system, it has been the main focus in recent times and hence is the subject of this paper. The paper sets out some of the history of the move from the thicker to the thinner-walled insulations and then outlines some key recommendations for enhancing the integrity of electrical wiring interconnect systems fitted to MoD aircraft.

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ABBREVIATIONS

AAA	Ageing Aircraft Audit
ADS	Aircraft Document Set
DE&S	Defence Equipment & Support
ETFE	Ethylene Tetrafluoroethylene
EWIS	Electrical Wiring Interconnect System
ISD	In-Service Date
JAP	Joint Air Publication
JSP	Joint Service Publication
MAA	Military Airworthiness Authority
MAP	Maintenance and Airworthiness Processes
OSD	Out-of-Service Date
PEEK	Polyetheretherketone
PT	(Defence Equipment & Support) Project Team
PTFE	Polytetrafluoroethylene
RA	Regulatory Article
SME	Subject Matter Expert
SWAMP	Severe Wind And Moisture Prone

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1 INTRODUCTION

This paper discusses the background and problems associated with modern thin-walled wire insulation used in aircraft before setting out recommendations for enhancing the integrity of the overall Electrical Wiring Interconnect System (EWIS) fitted to MoD aircraft. The EWIS is the electrical arterial infrastructure running throughout an aircraft, connecting and, potentially, impacting on all systems. The materials utilised within EWIS installations have changed significantly over the years, including the addition of 'thin wall' electrical wire types. These modern wire types are being utilised in new build aircraft and introduced into existing installations as replacements for older, obsolete, constructions. They may provide advantages in terms of lower weight and volume but, as they age, they present a different set of maintenance challenges. This paper argues that build standards and maintenance policies have not kept pace with material changes.

2 BACKGROUND

2.1 HISTORY

Historically, electrical wiring was seen as relatively unimportant within the military aircraft environment where it was ostensibly seen as 'fit and forget', with repairs and maintenance carried out only 'on condition'. With the advent of modern weapons and guidance systems, aircraft wiring installations took on greater prominence. Where previously, tens of metres of wire might have been sufficient for each aircraft, there may now exist a requirement for many kilometres. To combat this increase, wire manufacturers sought new insulation materials with which to reduce wire diameters, and therefore weight, whilst seeking to maintain, or improve upon, the electrical and mechanical properties of existing wires types. This activity gave birth to what has become known as 'Thin Wall' wire. New wire types utilised a number of different insulation materials with a whole host of properties; however, the leading material to emerge from research was an aromatic polyimide insulation material supplied under the trade name Kapton® by Dupont. The Kapton® polyimide polymer is a result of a polycondensation reaction between pyromellitic dianhydride and diaminodiphenyl ether. A by-product of the chemical reaction is the release of water, as polyimide film is anhydrous.

Polyimide film was manufactured as a tape that was then wrapped around the conductor to form a wire insulation which possessed exceptionally good dielectric properties and high physical strength. These qualities allowed the thickness of the wire insulation to be reduced significantly, in some cases down to six thousandths of an inch. This size reduction, in turn, greatly improved heat dissipation, thus permitting conductors to carry larger currents than previously managed. In effect, smaller gauge wires could be designed and utilised in installations to manage similar electrical loading. The resultant wires were therefore much thinner and lighter than previous types; moreover, they showed vastly improved mechanical performance in laboratory tests, easily meeting the specific requirements of the standards of the day.

Wire types utilising polyimide insulation with silver-plated copper conductors were approved for use on UK military aircraft in 1972 with the issue of Specification EL 2124[a], followed by EL 3001[b] for tin-plated conductors in 1981. Other polyimide insulated wire types gained approval under PAN Standards as the main airframe wire for all marks of Tornado and the Mil-W-81381[c] standard for Harrier GR5. By the mid 1980s, polyimide was the wire insulation of choice for most aircraft manufacturers. It should be remembered that other insulation materials were available but none seemed to match the polyimides' all round mechanical and electrical properties.

2.2 THE PROBLEM WITH POLYIMIDE

The honeymoon period during which polyimide was seen as the panacea for wire insulation constructions was however, short lived. Reports began to emerge of users experiencing failures of their systems, sometimes catastrophically, as a result of chafing and damage to wiring looms, particularly in environmentally hostile areas of the aircraft, typically referred to as Severe Wind and Moisture Prone (SWAMP) areas. Investigation into these reports revealed that the cracking and flaking of the insulation was caused by material failure mainly through exposure to moisture, a feature known as hydrolysis[1]. Further research identified that rates of material breakdown were accelerated by increases in temperature and/or stress. Hydrolysis is not unique to polyimide insulation; however, the potential failure resulting from insulation breakdown in the case of an aromatic polymer can be much more dramatic than would normally be experienced with other polymer types.

Momentary short-circuit arcs between a defective polyimide insulated wire and another conductor, such as an adjacent defective wire or the airframe, can create temperatures in excess of 1000°C. This temperature is sufficient to pyrolyse[2] the insulating material and, in the case of polyimide, the pyrolysis product is carbon, which is capable of sustaining the short circuit arc. The problem with materials such as polyimide is the amount of free carbon that is available when pyrolysis takes place. Under specific conditions, a sustained arc may propagate along the wire through continuous pyrolisation of the polyimide insulation, a phenomenon known as arc tracking. The magnitude of the arc tracking event will be governed by the power and impedance of the electrical circuit and any protection devices that may be fitted; in extreme cases arc

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1 The chemical breakdown of a material due to reaction with water

2 The chemical decomposition of a material by the action of heat

tracking can result in fire and/or explosion. Laboratory testing has shown that any of the modern insulation materials can, under the right conditions, produce an arc but will not, necessarily, track. PEEK (Polyetheretherketone) insulated cables have been found to be even more likely to suffer arc tracking than pure polyimide insulations.

Alternative insulation materials like aliphatic polymers such as Ethylene Tetrafluoroethylene (ETFE) and Polytetrafluoroethylene (PTFE), release pyrolysis products, when subject to intense heat, that are gaseous. As these products evaporate, they will leave the surface of the insulation apparently unchanged; however, to some extent, the thickness of insulation will have been reduced. Arc resistant materials, such as PTFE, erode more slowly when an arc is struck, causing the conductor to break down faster, thus changing the circuit impedance and stopping the arc; it is this property that has been utilised in the construction of arc resistant hybrid cables.

In specific circumstances, 'non-tracking wires' such as ETFE can sustain an electrical arc for a considerable time, mimicking the arc tracking event but, to do this, an exact balance between available voltage and circuit impedance would be required, whereas in the case of pure polyimides, arc tracking can occur under a wide range of electrical conditions. The characteristic feature of ETFE arc tracking seems to be the rate at which the ETFE is destroyed in an arc, rather than the erosion of the cable's conductor; hence the very narrow range of conditions under which tracking takes place.

Polyimide material is golden in colour and can be mistaken for the conductor when exposed; whereas, in reality, it is only the lacquer topcoat of the insulation construction that has been removed due to damage. The lacquer topcoat in the early constructions was only in place to allow identification marking on the wire. Although the removal of the topcoat lacquer does not degrade the insulation properties of the wire, this abrasion makes actual chafes harder to differentiate from scuffing of the lacquer, which has major implications for maintenance. The lacquer degradation is more prominent in high maintenance areas and can lead to a maintenance staff ethos of 'it's always like that'. Wire insulation constructions that utilise polyimide are further characterised by inherent stiffness, which makes handling and installing the wire much more difficult. This characteristic can lead to latent failures being introduced in transit or during rework.

News of the potentially catastrophic arc tracking failure mode spread rapidly and numerous articles and features appeared on the subject, some quite vitriolic in their condemnation of what became widely, albeit erroneously, referred to as 'Kapton® Wire'. There were a number of films and video clips produced showing experiments to induce arc-tracking in wiring looms. These demonstrations of the effects of wire failures focussed almost exclusively on the potential for serious fire and explosion which could result from arc-tracking events and the extensive collateral damage caused by the thermal and electrical 'avalanche'. Indeed, there is a strong suggestion that more prominence and publicity was given to the possible effects of failure than to the causes of the wire damage. Despite this somewhat misguided approach to dealing with the polyimide insulation issue, one aspect could not be ignored: whilst polyimide had exceptional insulation properties and great physical strength, keeping it in safe and serviceable condition requires additional measures, thus attracting a hitherto unknown price tag.

2.3 THE SALUTARY LESSON OF THE HARRIER

In 1991, whilst in the overhead of its Main Operating Base, a Harrier GR5 aircraft experienced a total electrical failure. Showing exemplary airmanship, the pilot landed safely, when subsequent investigation revealed that the rear avionic equipment bay had been completely burnt out. The aircraft was subsequently categorised as being beyond economical repair. Having identified that a contributory cause of the incident was the breakdown of the Mil-W-81381 polyimide insulation, the reaction across the Harrier community was as swift as it was dramatic. Each aircraft was extensively examined to identify the areas in which the EWIS failed to meet extant in-Service standards. In parallel, and in response to an almost visceral rejection of polyimide insulation, a major Design Authority modification was developed which effectively replaced the majority of the fuselage wiring and all the high power Mil-W-81381 cable types with a Mil –W-22759[d] ETFE[3], Tefzel® alternative.

It should be noted that the insulation material was only a contributory factor and it should not be considered in isolation. There were major issues with the EWIS installation design, which also required immediate action. In fact, without these

[3] ETFE or XETFE cross-linked ETFE, can also be used in thin-wall construction, and is generally considered to be less rigid and to possess poorer heat-resistance and abrasion properties.

installation design issues the likelihood of failure might have been dramatically reduced. A series of Design Organisation inspections were carried out to identify the scale of the problem and these resulted in a number of modifications and subsequent maintenance changes.

3 STANDARDS

It should be understood that, over the past 2 decades, there have been a considerable number of ‘thin wall’ wire type insulation constructions utilised in a wide range of aircraft types. Once it was realised that these early constructions were found wanting, wire manufacturers, material suppliers and aircraft design authorities embarked on a series of trials to find a replacement construction that would meet the needs of modern aircraft and that could also be used as a safe, reliable and cost-effective replacement in older airframes. The task was to find an insulation material that would provide the benefits of polyimide without the now known drawbacks. It was soon realised that there were no materials that could directly replace polyimide and so trials were carried out, mixing it with other materials to make up a reliable insulation construction. The main combination used in replacement wires became polyimide and PTFE, where insulation was produced as a sandwich and these types of wire were generally named Hybrids. The latest option available is the Smooth Tape Hybrid Composite where a new type of polyimide tape is manufactured with a PTFE layer grafted to each side of it; the polyimide, sandwiched in PTFE, is then applied as a number of wraps to a conductor. This latest type is the wire of choice for Joint Strike Fighter and is described in a number of standards including Defence Standard 61-12 Part 33/008[e] and Mil-W-22759/180 - 192.

4 A PARADIGM SHIFT

The serious nature of a number of aircraft incidents in the 1980s and 1990s, coupled with an extensive education campaign, did, undoubtedly, provide the catalysts for a culture change across the Royal Air Force (and, later, within the wider Military Air Environment community), in respect of the way in which electrical wire was treated, both on and off-aircraft. Twenty or so years later, much of that culture remains, but it is questionable whether similar paradigm shifts have taken place for all platform types and across other operating environments. Training programmes have been revised to highlight and educate personnel across the MoD and beyond about the problems associated with EWIS installations. However, it is also questionable whether the instruction given during basic, pre-employment and refresher training and through the briefings provided on some units by Unit Wiring Husbandry SNCOs[4], is delivered and reinforced at a level commensurate with the scale and severity of the current issues surrounding the MoD's ageing EWIS. Or, indeed, is sufficient emphasis given to bring about and embed the cultural changes necessary to safely manage modern types of aircraft wiring and the cluster of new engineering issues associated with it.

Where earlier 'thick wall' wire types required little or no maintenance and were repaired 'on condition', the new 'thin wall' types require a regular and meticulous maintenance regime if future catastrophic failures are to be avoided. Recent history would suggest that this strategy/requirement has not been fully understood or developed and has not, therefore, been universally adopted. Hurriedly embarked upon platform life extensions and unforeseen usage changes are unlikely to have fully considered the impact upon EWIS installations, nor have life extension programmes always given appropriate consideration to the additional risks introduced by extending the life of wiring of all insulation types.

Whilst the above actions addressed the immediate on-aircraft issues, a raft of other measures were initiated to educate and inform a wider audience of the problems

4 Aircraft Wiring Husbandry is covered in MAA Regulatory Article (RA) 4551, with acceptable means of compliance in MAP-01 Chapter 12.1.1. In the December 2011 issue of MAP-01, it would appear that during the transition to the MAP, the requirement for a Unit Wiring Husbandry SNCO has been deleted; although Chap 12.1.1 para 3.2 does still require stations, ships and units to provide appropriate education and training. Additionally, Chap 12.1.1 para 3.3 requires Project Teams to include specific details of their aircraft wiring husbandry requirements within Support Policy Statements.

associated with EWIS installations in general. These actions included the publication of a new chapter in each MoD aircraft's Topic 1 series, clearly identifying the makeup of wire insulation constructions, describing the handling techniques associated with them and specifying the clearances required when the particular type of wire is installed. Widespread publicity was campaigned in the workplace, utilising media such as Air Diagrams, and was augmented by the establishment of a Wiring Husbandry Coordinator on operating stations. Where such posts remain, a Wiring Husbandry Coordinators holds a prominent position on the Station, reporting directly to the Senior Electrical Specialist Officer. He or she is responsible for briefing all aircraft tradesmen on the hazards associated with the degradation of EWIS installations and for training the unit's electrical tradesmen on wiring installation practices, inspection techniques and damage limits.

Training has been extended beyond aircraft tradesmen[5] to include all personnel involved in the handling and transportation of cables. If cable bend radius limits are disregarded or if excessive flexing of the wire is allowed at any stage during packaging or transportation, cracking and splitting of the insulation can occur even before the cable is installed into the aircraft. Similar latent failures can be introduced by poor engineering practices, for instance when new wiring is 'pulled through' cleats, clamps or lightening holes during installation, instead of being carefully laid into looms.

[5] MAP-01 Chap 12.1.1 para 3.2.3 refers.

5 THE CHALLENGE FACING INDIVIDUAL PROJECT TEAMS

In-Service standards for EWIS vary considerably across platforms, and each Project Team (PT) must consider its own platform in isolation, as 'one size does not fit all'. Evidence shows that the MoD is receiving aircraft into service that have issues with the sustainability of the EWIS build standards and that maintenance requirements are not always considered during design. The MoD should take the opportunity to examine EWIS build at appropriate points during manufacture to ensure that installations meet the agreed 'as required' standards. The MoD needs to become the intelligent customer in this area to ensure platform through-life EWIS reliability and safety. A policy for pre-delivery examinations should be set that will require projects to monitor EWIS installations as they are placed into aircraft during build.

The in-Service challenge facing the PTs is threefold. First, the PT must be able to identify the EWIS standard which is to be applied to its fleet. This is not likely to be a straightforward task and will not be as simple as looking at the aircraft documentation to identify the current standards for that particular type. However, the documentation should be reviewed for consistency of maintenance activities and terminology. The 'as designed' standard is a function of the date of design, as aircraft are generally built to the standards which exist during design, but not necessarily throughout the build period which can last for many years after the design was frozen. As an example, in the case of the Sentry aircraft, the EWIS was installed in 1991/2, but was done so to a 1965 design standard[f]; however, as previously described, aircraft wiring knowledge had evolved considerably over this intervening period. Of particular relevance, the associated wiring standards had changed beyond recognition, not least to reflect the handling, installation and maintenance requirements for the wiring following the widespread introduction of thin-walled insulating materials[6].

Secondly, the in-Service maintenance standards for the EWIS on each aircraft type are set out in the Aircraft Document Set (ADS) and should be a reflection of the current

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[6] The 1965 standard merely called for 'Wires to be installed and routed in order to be protected against chafing'. The current standard is much more prescriptive and detailed, calling for minimum clearances of ⅜" and setting out exact actions to be taken if this clearance cannot be achieved.

design standards[7,9]. The dichotomy facing a PT is how to enforce an airworthy 'as maintained' standard when there is often significant disparity between that standard and the 'as designed' and/or 'as built' standards. This disparity is exacerbated by a number of factors including the age of the fleet, elapsed time between design and build, variable build quality, system deterioration over time caused by inadequate maintenance, less than satisfactory in Service trade practices, poor component availability and the environment in which the aircraft is operated.

Thirdly, as an engineering task, it would prove extremely difficult, if not physically impossible, for most fleets to recover existing EWIS installations to meet current military wiring standards. In addition, the cost, time and impact on aircraft availability of even trying to do so would be likely to prove unacceptable in many quarters. Consequently, PTs should consider setting an 'as required' standard for their aircraft. This 'as required' standard should take into account the proximity of the aircraft to its Out of Service Date (OSD) and balance the airworthiness risk associated with that standard against cost, time and availability factors. However, safety must be paramount at all times, and so an imminent OSD should never be considered an excuse to reduce standards without a full understanding of the impact that such a relaxation would have on the Platform Safety Case.

Understanding the actual EWIS issues seen on the aircraft is another major task for the Project Team. The practices associated with the collection and interrogation of EWIS data should be reviewed. Until data is correctly recorded and systematically retained for future analysis there can be no way of consistently considering the impact of EWIS maintenance. Evidence from multiple aircraft types also indicates that EWIS fault arisings are not routinely entered into maintenance databases. Furthermore, when they are entered, such entries are not made in a suitably complete format to enable Project Teams to subsequently review and analyse fault histories.

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7 The 'as maintained' standards to be applied to the Sentry EWIS are contained AP113A-0003-1, which is derived from NAVAIR 01-1A-505-1, Technical Installation and Repair Practices - Aircraft Electrical and Electronic Wiring; this in turn is a reflection of the International Aerospace Standard for Wiring, SAE AS50881 Revision B, issued 1998.

6 A WAY AHEAD

Military Airworthiness Authority (MAA) Regulatory Article (RA) 5723 calls for an Ageing Aircraft Audit (AAA) to be carried out 15 years after a military aircraft's declared In Service Date (ISD) and, thereafter, at 10-yearly intervals, with the requirements for a 'Systems Sub-Audit' discussed in detail in paras 24 – 30 of the associated Guidance Material RA5723(1)[8]. Within these requirements[h], RA5723(1) sub-paragraph 26.b indicates that the Systems Sub-Audit is to include all wiring interconnections and connectors. Chapter 12[i] of the MoD's Maintenance and Airworthiness Processes (MAP-01) also provides guidance on a number of aspects of EWIS maintenance. In essence, the MAP-01 recommends that the EWIS be treated as if it were a system in its own right. However, given that much of the mechanical pipework is installed in close proximity to the EWIS, it is considered that a more appropriate approach might be to combine mechanical and electrical interconnectivity to form a single 'system' for inspection and survey purposes.

In a recent paper by dstl, entitled 'Lessons Identified from Initial Ageing Aircraft Systems Audits and Related Programmes', it was recommended that an independent aircraft EWIS Condition Survey should become a specifically identified requirement of an AAA[9,j] Whilst not setting out the parameters of this Condition Survey, dstl argued that the aim of an Ageing Aircraft Systems Audit[10] is to assess the performance of the measures put in place to maintain an airworthy aircraft, and suggested that part of that assessment should include whether the 'as flown' aircraft matches the 'as prescribed' aircraft. Cross-referencing the 'as flown' versus the 'as prescribed' aircraft to the 'as designed', 'as built' and 'as maintained' standards of the EWIS (and potentially the mechanical interconnectivity) reveals a certain synergy. Therefore, a non-intrusive

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8 The requirements of the Ageing Aircraft Audit are defined in RA5723, with the Systems Sub-audit elements expanded upon in RA5723(1).

9 'Lessons Identified from Initial Ageing Aircraft Systems Audits and Related Programmes' SAAG Paper 001 Draft dated 23 November 2009.

10 RA5723(1) states that the AAA should be a periodic, independent, assessment of the airworthiness of the fleet as it ages. As part of the AAA, Systems Integrity activities should be considered individually and collectively, in order to assess the effectiveness of airworthiness management. Furthermore audit should include an independent review of the continued applicability of relevant procedures, management processes, technical information and documentation and a detailed independent physical examination of the condition of a representative aircraft from the fleet. Aims of the AAA should be to identify patterns or trends and any significant airworthiness and integrity risks to the aircraft.

Condition Survey of aircraft system interconnectivity during the Systems Sub-Audit of an AAA could be used to measure the integrity of the EWIS (and mechanical interconnectivity) elements of the aircraft's systems. The Interconnection Condition Survey must not be carried out in isolation. In parallel with planning the survey, which should be carried out against the current in-Service standards, a strategy for recovering the aircraft, following the survey, must be considered. This strategy could be used to determine the 'as required' standard and methodologies mentioned earlier. Experience from a number of MoD platforms suggests that there is likely to be considerable variation of standard amongst the various requirements placed upon the tradesmen within the ADS. Over time, terms such as 'inspect', 'survey' and 'examine' tend to lose their distinct meanings, with the result that inconsistent terminology is used, resulting in the lowest standards being adopted by default. In addition, review of a number of different ADS suggests that the definition and application of zonal inspections has become unclear.

7 RECOMMENDATIONS

Recommendation 1: Wiring Husbandry training during basic, pre-employment and refresher training is delivered and reinforced at a level commensurate with the scale and severity of the current issues surrounding EWIS. Additionally, such training is given sufficient emphasis to bring about and embed the cultural changes necessary to safely manage modern aircraft wiring.

Recommendation 2: Maintenance and modification actions should consider the implications of utilising a replacement wire type. Where a 'thin wall' type replaces an earlier 'thick wall' type, a regular and meticulous maintenance regime will be necessary to minimise the risk of future catastrophic failure.

Recommendation 3: Platform life extension and usage changes should fully consider the impact upon EWIS installations. Where appropriate, consideration should be given to the additional risks introduced by extending the life of wiring of all insulation types.

Recommendation 4: A policy for pre-delivery examinations should be set that will require projects to monitor build standards for EWIS as they are installed into aircraft during manufacture.

Recommendation 5: PTs should review the ADS for consistency in the use of terminology to describe the required maintenance activities.

Recommendation 6: PTs should identify the 'as required' EWIS standard suitable to meet the needs of its individual platform(s), whilst taking cognisance of the aircraft's proximity to the Out of Service Date and the airworthiness risk associated with setting that standard. An adjacent OSD should never be considered a valid reason to reduce standards.

Recommendation 7: PTs should review management practices associated with the collection and interrogation of EWIS data[11] and also of its storage for future analysis.

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[11] A recent check of a number of MoD platforms suggests that approximately 5 -20% only of EWIS fault arisings, which have a mandatory requirement for a LITS Asset Journal Event (AJE) to be completed, actually have the AJE submitted. Of those submitted AJEs, a good proportion is so poorly completed, that proper analysis is impossible.

Recommendation 8: Given that much of the mechanical pipe work is installed in close proximity to the EWIS, it is considered that it would be appropriate to consider the mechanical and electrical interconnectivity as a single system for inspection and survey purposes.

Recommendation 9: In accordance with the guidance in sub-paragraph 21.i of RA5723(1), PTs should include a detailed, independent physical examination of the condition and husbandry standards of representative aircraft from the fleet, within the scope of their AAA.

8 SUMMARY

What is undeniable is that 'thin wall' wire types will remain in the MoD's inventory and be utilised across new and ageing aircraft fleets alike. The challenge facing the MoD, and the PTs specifically, is to establish the 'as required' state for their EWIS installations to ensure that safe and airworthy standards are maintained through to OSD.

There are a great number of factors affecting EWIS integrity, ranging from wiring husbandry to the precision termination process; however, the MoD has made great inroads into EWIS safety by putting into place a number of key policies. The DE&S focal point, Avionics Repairable (AvR), within the Air Commodities PT, acts as the MoD Subject Matter Expert, and continues to work towards improvements in this area through the provision of direct guidance to platform PTs as well as by working with MoD training establishments. Whilst the MoD's position in this field is one of reasonable strength, it must not be taken for granted and due attention must now be given to continuous improvement in order to ensure sustained aircraft safety and availability.

REFERENCES

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[b] Procurement Executive, Ministry of Defence Assistant Directorate, Electrical Engineering Development Specification No: EL 3001 for Cable, Electric, 135 deg C, lightweight, tin plated, sealed-lapped-tape construction, KTTP type (metric units)

[c] US Department of Defense, Military Specification Mil-W-81381

[d] US Department of Defense, Military Specification Mil-W-22759/180 - 192

[e] Defence Standard 61-12 Part 33/008

[f] Military Standard Mil-W-5088C

[g] International Aerospace Standard for Wiring, SAE AS50881 Revision B, issued 1998.

[h] UK Ministry of Defence, Military Airworthiness Authority (1 July 2011), Regulatory Article Guidance Material RA5723(1)

[i] UK Ministry of Defence, (December 2011), Maintenance and Airworthiness Processes MAP-01 Chapter 12

[j] ‘Lessons Identified from Initial Ageing Aircraft Systems Audits and Related Programmes’ SAAG Paper 001 Draft dated 23 September 2009

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