Chapter 1: Introduction

In June of 1998 the Air Transport Association (ATA) formed the Aging Systems Task Force (ASTF) to review the effectiveness of maintenance on electrical interconnect systems and assess the condition of these systems on aircraft whose type certificates are older than 20 years[1]. This action was in response to concerns that existing procedures, directives, and inspections may not be sufficient to prevent unsafe situations associated with the degradation of aircraft wire. As part of this effort 8 model-specific working groups were formed to perform detailed visual inspection (DVI) of DC 8, DC-9, DC-10, 727, 737, 747, A300, and L1011 aircraft.

The task of these model-specific working groups was to perform special visual inspections during scheduled maintenance visits in order to uncover any systematic electrical interconnect problems not currently addressed by existing maintenance programs. Those working groups inspected 81 aircraft using 8 different inspection protocols and at least as many independent teams of inspectors.

The results of these inspections provided data only on physically observable faults. These inspections did not exclude the possibility of undesirable latent or invisible degenerative conditions. This data must be obtained by supplementing and comparing visual inspection results with enhanced *in situ* testing, and nondestructive and destructive analysis.

In recognition of this fact the Aging Transport Systems Rulemaking Advisory Committee (ATSRAC) and the FAA agreed July of 1999 to jointly sponsor this type of follow-on effort. The effort was to be funded by the FAA Technical Center, with ATSRAC member organizations responsible for populating the working group responsible for implementation and oversight, providing inspectors and other expert personnel, and facilitating access to aircraft. The charter for the Intrusive Inspection Working Group is included as Appendix 1.1.

This report describes the Working Group's efforts and the results of the intrusive inspections.

Description of the Project

While the inspections of the ATA model-specific working groups were *extensive* (covering 8 model types and including nearly 100 aircraft), the tasking for the intrusive inspection working group was more *intensive* in nature (covering fewer aircraft, but with more sophisticated testing and inspection). Hence, instead of inspections focused on model-specific "hot spots", this project focused on generic applications representing a range of service environments from benign to severe.[2]

The inspection and testing protocols involved 3 distinct tasks: 1) detailed visual inspection with or without invasive follow-up, 2) nondestructive testing (NDT), and 3) laboratory analysis. The coordination of these processes within this intrusive inspection program is shown conceptually on the diagram on the next page. Just prior to the detailed visual inspection the aircraft zones were to receive a "close visual inspection" in accordance with the model-specific inspection protocols developed by the ATA. This close visual inspection was to facilitate the comparison of results from this effort with results from the non-intrusive inspections. A complete and formal description of the inspection and testing protocols is included in Appendix 1.2.

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1 The group was later cosponsored and re-chartered by the Aging Transport Systems Rulemaking Advisory Committee.

2 The inclusion of (presumably) benign environments allowed us to establish a degradation benchmark for comparison with the accelerated degradation in more severe environments. When possible new or unused wire specimens were used to establish a baseline from which to measure the degradation of the specimens taken from the aircraft.

Six aircraft meeting certain wire type-, age-, and retirement- requirements were selected for the project. These aircraft are shown in Table 1 below.

Aircraft	A300	DC-9	747	DC-9	L1011	DC-10
Inspection	9/99	12/99	2/00	5/00	6/00	6/00
Year Mfr	1978	1967	1973	1971	1972	1979
Hours	39,713	74,558	100,241	66,801	63,618	61,334
Cycles	27,078	100,017	20,348	75,446	26,256	18,818
Retired	7/99	9/99	5/99	12/99	6/99	5/00[3]
Wire Type[4]	Polyimide	PVC/G/N	Poly-X	PVC/G/N	Polyimide	XL-ETFE

Table 1-1: Subject Aircraft Data

Of the five targeted general purpose wire types:

- Polyimide (e.g. Mil-W81381[5]),
- PVC/Glass/Nylon (e.g. Mil-W-5086),
- Extruded XL-Polyalkene/PVDF, (e.g. Mil-W-81044/6 to /13),
- Poly-X (e.g. Mil-W-81044/16),
- XL-ETFE (e.g. Mil-W-22759/32 to 45 and 41 to 46),

only Polyalkene was not represented (as a general purpose wire) in our six selected aircraft. Polyalkene represents less than two percent of the current fleet of transport category aircraft (See Appendix 1.3: Fleet Wire Type Utilization).

Other wire types taken coincidently with the primary wire type were selectively analyzed using the same protocols. Because the history of these wires is often not known (e.g. some may be post-manufacturer modifications or additions), and because the quantity of such wire collected is small, wire-type specific conclusions pertaining to these other wire types are limited.

In each aircraft fourteen characteristic specimens were identified for on-board, nondestructive testing and subsequent laboratory analysis. These specimens were defined as:

9 cabin interior specimens:

- 2 lower cabin, thick bundle[6], 4 feet, straight, no conduit or sheath, multiple wire gauges
- 2 lower cabin, thin bundle, 4 feet, straight, no conduit or sheath, multiple wire gauges
- 2 upper cabin, thick bundle, 4 feet, straight, no conduit or sheath, multiple wire gauges

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3 This aircraft was decommissioned, but not retired. The aircraft is scheduled to return to service as an MD-10.

4 The primary general-purpose wire type for this aircraft. Other wire types were present either as special purpose wire or as post-manufacture modifications or repair.

5 Military specifications are mentioned here for illustrative purposes only. The wire installed in commercial aircraft adheres to many different commercial specifications, roughly equivalent to the military specifications, but not as readily available.

6 Thick bundles have 25 or more wires bound tightly. Thin bundles will have 4 to 24 wires bound tightly

- 2 harness segments with multiple branches and turns[7], at least 4 connectors, to be removed with all connectors, clamps, brackets, conduit, sheathing, etc. in place
- 4 power feeder cables or bundles, 4 feet or maximum available length, no conduit
- 6 passenger service unit (PSU) cables, max available length.
- 6 cockpit instrument cables, maximum available length.
- 2 contaminated bundles from below lavatories or galleys
- 2 bundles in sheathing or flexible or rigid conduit maximum available length.

5 unpressurized area specimens from wheel wells, hydraulic service center, wing spars, or tail cone. Whenever possible, the full set of inspection locations was to include more than one distinct unpressurized area of the aircraft.

- 2 thick bundles, infrequent-maintenance[8], no conduit or sheathing, 4 feet or max available length
- 2 thin bundles, infrequent-maintenance, no conduit or sheathing, 4 feet or max available length
- 2 power feeder cables, no conduit
- 2 harness segments with multiple branches and turns, at least 4 connectors, to be removed with all connectors, clamps, brackets, conduit, sheathing, etc. in place
- 2 bundles in sheathing or flexible or rigid conduit, max available length

Each inspection began with the development of specific work cards in order to:

- clearly define the zones to be inspected,
- clearly identify specimens within the zones,
- provide any additional description of the nature or extent of the inspection.

Whenever possible, the locations identified were contained within the locations specified by the non-intrusive inspection protocols (see Appendix 1.2, Sub-Appendix 1.2.1).

All six visual inspections proceeded largely in accordance with the original protocol. Chapter 2 discusses the inspections and inspection results.

In conjunction with the visual inspection, Boeing personnel tested electrical system grounds[9]. The results of this testing are discussed in conjunction with the on-board testing in Chapater 3.

On board Nondestructive testing followed execution of the visual inspections. The first four aircraft were inspected by two techniques:

Lectromech's DelTest™: Voltage is applied to one end of a wire and the length of the wire is locally saturated with a conductive solution to foster the measurement of leakage current. The presence of leakage current is indicative of breached[10] wire insulation.

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7 The complex harness may be cut at one or more ends, but would whenever possible be separated from the aircraft at the connectors with connectors intact.

8 Infrequent-maintenance implies that the wires are disposed in a way that does not allow for routine servicing (e.g. no connectors.

9 Primary or structural grounding (the bonding of structure to structure for the purpose of lightening protection) was not within the scope of this groups mandate.

Eclypse Corp's Automatic Test Equipment: This test was to establish configuration and to verify that the state of removed wire has not significantly changed in the removal process. Even in the absence of baseline parameters for the original installation, some anomalous conditions were thought to be identifiable with this technique. Test performed were Insulation Resistance Tests (at three different voltage levels), and 2 Wire, and 4 Wire Tests (at three different current levels each).

Only Deltest was applied to the last two aircraft. Chapter 3 discusses the testing procedures and results in detail.

Other organizations were invited to participate in the inspection informally and without compensation. MTC, Olympus, and CM Technologies demonstrated their products on the first DC-9 in Ardmore, OK.

At the conclusion of on-board testing wire specimens were removed, packed and shipped to the FAA Aging Aircraft Validation Center at Sandia National Labs for further analysis. The Validation Center and other designated performing organizations (Raytheon, USAF Wright Labs, FAA Technical Center) subjected the specimens to some of the following destructive testing:

- ***Qualitative Tests:*** enhanced visual and optical microscopy (Sandia, Raytheon, 10x or greater), x-ray (USAF)
- ***Mechanical Behavior Tests:*** modulus profiling (Sandia), cut-through testing (Raytheon, ASTM D3032 section 22), wrap or wrap back (Raytheon, SAE AS 4373/710), notch propagation (Raytheon, SAE AS 4373/707), insulation tensile strength and elongation (Sandia), mandrel bend test (Sandia).
- ***Assessment of Degradation-Indicative Parameters***: infrared spectroscopy (Sandia), solvent swelling (Sandia) density measurements (Sandia), inherent viscosity (Raytheon).
- ***Electrical Tests:*** dielectric voltage withstand after wrap or wrap back test (Raytheon, SAE AS 4373/710), (high voltage) wet dielectric - voltage withstand (Raytheon, SAE AS 4373/510), conductor resistance. (Raytheon, SAE AS 4373/404), insulation resistance (Raytheon, SAE AS 4373/504)
- ***Thermal and Aging Tests***: flammability (Raytheon, FAA 60° Test), lifecycle (Raytheon, SAE AS 4373/808), cross link proof test (Raytheon, SAE AS 4373/812), lamination sealing (Raytheon, SAE AS 4373/810).

The laboratory testing and results are described in detail in Chapter 4.

Description of the Data Analysis

The data from the visual inspections, on-board testing, and laboratory analysis were analyzed to achieve two primary objectives:

- to assess the adequacy of visual inspection for detecting deteriorating wire installations, and
- to determine the condition of wire in aged aircraft.

Specifically excluded from this analysis was any comprehensive reassessment of the certification basis of the wire installations. In other words, the analysis excludes any assessment of flaws

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[10] For lack of a better term, we use the word 'breach' to indicate any unexpected potentially conductive path through the wire insulation. This may include exposed conductor at the end of a cut wire or non-environmental splices, as well as insulation damage.

assumed to have been adequately handled by a manufacturer's certification process whose assumptions remain valid.

Findings were first segregated by the immediacy[11] of their potential threat. Direct threats to aircraft safety were subsequently divided into degenerative and non-degenerative groups. Indirect threats to aircraft safety and non-degenerative conditions have been retained in the database and forwarded to ATSRAC Working Groups 3, 4 and 5 for their review, but were not specifically analyzed as part of this effort.

The determination of the adequacy of visual inspection for detection specific degenerative conditions was assessed by comparison of the visual results with the on-board testing and laboratory assessment. This assessment is the subject of Chapter 5.

Chapter 6 contains an analysis of wire degradation relative to potential influence factors including: wire type, and service environment.

Chapters 5 and 6 together provide the basis for the report's conclusions and recommendations in Chapter 7. In Chapter 7 age-related conditions were categorized as unique, infrequent, or common. Each class was handled separately, using a modified Failure Hazard Assessment (FHA) – Preliminary System Safety Assessment (PSSA) approach referred to here as a General Threat Assessment (GTA).[12] The threat assessment procedure gives consideration given to:

- Aggravating or contributory factors
- Wire insulation type
- Estimated probability of the existence of the observed condition

Conclusions and recommendations of the report give consideration to:

- Visual detectability
- Efficacy of other inspection or testing

[11] See Chapter 5 for definitions of the terminology.

[12] The FHA/PSSA approach described in SAE ARP 4761 was established to support the initial design and certification of aircraft systems and is largely a top-down approach. The analysis used by the Intrusive Inspection Working Group starts with a fixed design with a well- known service history. This approach is essentially bottom-up. Furthermore the analysis addresses many conditions which – in there current state – cannot yet be considered failures or even flaws.