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Aircraft Wire System Laboratory Development: Phase I Progress Report

Mike Dinallo and Chris Lopez
Applied Accelerator & Electromagnetic Technologies Department
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-1152

Abstract

An aircraft wire systems laboratory has been developed to support technical maturation of diagnostic technologies being used in the aviation community for detection of faulty attributes of wiring systems. The design and development rationale of the laboratory is based in part on documented findings published by the aviation community. The main resource at the laboratory is a test bed enclosure that is populated with aged and newly assembled wire harnesses that have known defects. This report provides the test bed design and harness selection rationale, harness assembly and defect fabrication procedures, and descriptions of the laboratory for usage by the aviation community.

Acknowledgement

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Introduction

Because of aged wiring concerns for commercial passenger aircraft, the Federal Aviation Administration (FAA) has sponsored development of a laboratory to support the commercial aircraft industry in the evaluation and development of nondestructive inspection (NDI) wire diagnostic techniques. The laboratory is in development at the FAA's Airworthiness Assurance NDI Validation Center (AANC), operated by Sandia National Laboratories. The laboratory goal is to provide the FAA and industry with capabilities to begin comprehensive evaluations of new and existing diagnostic inspection and monitoring methods for aircraft wire systems. In November 2002 an initial test bed came on-line. The test bed is populated with aged and newly assembled wire harnesses containing various types and severities of wiring anomalies. The test bed has already been used by several industry developers of wire system diagnostics and has additional users scheduled. This report documents the design rationale and capabilities of the aircraft wire system laboratory.

Background

The Aging Transport Systems Rulemaking Advisory Committee (ATSRAC) sponsored a survey of aircraft wire systems that included Boeing 727, 737, and 747 and Douglas DC-8, DC-9, and DC-10 commercial passenger aircraft. These surveys (ref.1) found wire-defect types that included insulation and shield chafing, wire insulation breaches, varying degrees of insulation cracks, insulation enbrittlement, conductor damage, over-pressured harness clamps, excessive bend radius, chemical corrosion, heat-induced insulation charring, faulty wire splices, and faulty terminating connector assemblies.

A wiring system test bed was developed and contains wire harnesses that were extracted from the above-mentioned aircraft types. Both naturally occurring and fabricated defects of the types identified in the ATSRAC reports are present in the sample wire harnesses. The test bed also has newly assembled wire harnesses, using Boeing and Douglas wire harness assembly and installation procedures, Mil-Spec tooling, and other good wiring practices (refs. 2–5). The aged wire harnesses (extracted from retired aircraft) have been selected from various locations consistent with the surveys in the ATSRAC reports. These locations include the electronics bay and rear face of the cockpit breaker panels; wheel well areas; leading and trailing wing edges; rear cargo bay (under lavatory and galley); rear fuselage; and tail cone sections. Wire harness samples from the pressurized passenger cabin areas are also included.

The test bed is an aluminum enclosure that has five levels of trays containing 40 harnesses and can readily accommodate dozens more per tray. The harnesses are routed on Boeing 727–737 dimensioned air-frame segments (ribbed structure, with curvature). Included in the enclosure is a tray reserved for precision transmission lines, for calibrations purposes; and a tray reserved for more complex wiring system installations (branching, distribution panels, powered systems). The test bed harness enclosure is described in detail in the next section.

The laboratory development project is a three-year effort. The first-year task of bringing on-line a test bed capability was met in November 2002. The test bed contains the rudimentary wiring defects mentioned above. The second-year tasks include development of a humidity-controlled harness test chamber, installation of wire system components/systems (such as arc and current fault circuit breakers) in the reserved test bed trays, and provision of additional/upgraded defect types, including very long harness lengths. The third year will include adjustments/improvements to the laboratory based in part on recommendations from aviation community diagnostic developers and users.

Test Bed Enclosure Design

The test bed enclosure design is a modular, metallic enclosed structure that has several levels of trays for wire-harness placement. A modular design was selected for the following reasons:

- allows attachment of additional enclosures to accommodate longer harness lengths and provides powered electrical/avionic systems connected to harnesses
- permits different/additional tray levels for wire system simulation purposes
- provides a good electrical reference for instrumentation
- permits addition of hermetic seals to have controlled environments, such as humidity, temperature, electromagnetic noise, and corrosive contaminates from the variety of chemicals and fluids used on commercial passenger aircraft.

The enclosure is made of an aluminum strut frame with aluminum flat panels (1/8 inch thick) attaching to all sides. It is 10 feet in length and 5 feet in height. The general dimensions of the side, top and bottom panel(s) will be 5 x 5 sq-ft. The dimensions of the panels at the front and rear (enclosure width) will be 5 feet in width and 1 foot in height. Figure 1 shows a detailed drawing of the enclosure. The strut frame structure support four additional flat panels spaced at a height of 1 foot. Figure 2 is a photograph of the enclosure at a partial level of assembly. It can be seen in Figure 2 that the lower four cable trays provide a ribbed-structure, metallic ground-plane for harness support and electrical characteristics related to transmission lines. These segments were made by Foster and Miller Metal Works and are used in the test bed. The segments were fabricated to represent Boeing 727 and 737 aircraft ribbed-fuselage structure. Figure 3 is a photograph of a sample segment.

The removable panels are a quick-connect–disconnect type. The front and rear panels have penetrations to allow harness termination connector panel mounts. The dimensions of these penetrations are in accordance with selection of specific connector types. Lifting portals are welded to the bottom exterior of the enclosure for transportation purposes. The enclosure is mounted on three pairs of neoprene castors for mobility. The fully enclosed test bed is shown in Figure 4. Trays are labeled from 1 to 5, with 3 rows and 22 columns for harness placement per tray.

In addition to the enclosure drawing shown in Figure –1, a complete set of Pro-E→ design drawings is available for additional enclosure fabrication and costing purposes.

Wire Harnesses Types

The test bed has retired and newly fabricated harnesses that include single- and multi-conductor insulated wires that are twisted with and without shielding. Wiring ranges from high-current power cables (awg 8) to small-diameter signal wires (awg 22). Figure 5 is a photograph of inventoried harnesses from Boeing and Douglas retired aircraft. These aged harnesses were obtained from several locations on the aircraft including the EE bay, wheel wells, wing edges, cargo sections, and fuselage. All extracted harnesses are tagged for identification of in-service location and aircraft number, and they were documented on videotape prior to removal. Annex A lists the harnesses acquired.

Based upon the ATSRAC reports, an initial selection of newly fabricated wire harnesses includes the following wire types: polyimide, Mil-W-81381; PVC/GN, Mil-W-5086/1,2; Poly-X, Mil-W-81044/16; and XL-ETFE, Mil-W-22759/32 to 46. Annex B provides a detailed description of each wire type with illustrative diagrams. Newly fabricated harnesses are assembled in accordance with Boeing and Douglas documents (ref. 2, 3), using military specified tooling (ref. 4), by an IPC–A–610C certified technician (ref. 6). Figure 6 is a photograph showing a typical wire and connector just prior to final assembly. Annex C lists all connectors used (new or acquired from aircraft) in the test bed. These fabricated harnesses will be installed in the test bed with typical features such as ties, clamps, branching, and grounding lugs. Users of the test bed are sent a complete description of each harness that includes connector type (model #), each wire type (military or manufacturer #), and a photograph of connectors for each harness (bow and aft) with the pin numbering pattern entered. Annex D provides this listing.

Wire Anomalies Fabrication

An important task of the first year project was the development of techniques to simulate a range of defects in a reproducible manner, including varying degrees of insulation or conductor damage for a specific defect type. The following wire defect types are included in the test-bed wire system:

- Wires with opened or broken conductors
- Wire insulation chafed to various degrees
- Breached wire insulation
- Cracked or brittle insulation
- Partial strand-conductor breakage
- Over-pressured wire fastener clamps
- Wires with excessive bend radius
- Heat induced or chemically corroded wire damage
- Faulty wire splices
- Faulty connectors.

For each defect type, a specific fabrication procedure was developed. A defect descriptor chart is provided in Table 1 and describes the defect type and severity. Annex E documents these procedures with illustrative photographs. The procedures were developed and documented in sufficient detail to allow accurate reproducibility. Figure 7 shows a sample using these procedures to fabricate defects. The tools used in these procedures are a standard wire stripper, feeler gauges, and a common knife for insulation cutting. A Dremel tool is also used to produce abraded or chafed wire insulation or metallic shielding. Other defect fabrication tools include a torque wrench for creating over-pressured clamps and a heat gun with a wire-positioning fixture for producing charred insulation. These procedures permit consistency of a given diagnostic method to detect and locate similar as well as different types of defects. Defect procedures, severities, and types are modified based on comments/recommendations made by the community users. Photographs of all the defect types present in the test bed are shown in Annex F.

Test Bed Characterization

The placement and type of defects in the wires have been documented at the AANC and Sandia. This information is not available to users of the wire system laboratory. Additional characterization of the wire harnesses using transmission line parameters in terms of per unit length resistance (R), inductance (L), capacitance (C), and conductance (G - resistive loss through the insulation material) will also be documented for supporting user investigations. Characterization of the harnesses in terms of transmission line parameters will be carried out after installation of well-defined transmission line geometries being designed into the first or top tray of the test bed enclosure. Characterization of these transmission lines first, using standard commercial instrumentation, will permit a validated method for characterizing the test bed aircraft harnesses. The well-defined transmission line types used for harness characterization calibration are single and twin flat-wire conductors imbedded in polyethylene and nylon, and single and uniform twin-axial coaxial-shielded cables. Polyethylene and nylon have relative dielectric constants ranging from 2.1–2.3 and 4.2. Both single and two-conductor configurations are needed for common (wire-to-airframe) and differential (wire-to-wire) mode purposes. An Agilent 4294A Impedance Analyzer is being used for frequency domain measurements of these parameters (not to investigate the capability for defect detection). Similarly, a Tektronix time domain reflectometry (TDR) model 1502C is being used to corroborate this information for both differential and common mode parameters within the harnesses.

When it is established that these transmission line parameters are well defined, it is intended to place minute insulation defects into the transmission lines to support users in determining sensitivity thresholds of their diagnostic instrumentation.

Wire System Laboratory Usage

Use of the wire laboratory and test bed is scheduled through the AANC facility manager, Gerald Langwell (Sandia National Laboratories, Albuquerque, NM). A short user request form will be sent to scheduled visitors prior to arrival and addresses equipment needs, safety issues or other participant requirements. The AANC will provide support, when requested, such as working space, tables, electrical power cords, ladders, maintenance stands, common hand tools, etc. These and other required tools or hardware must be identified prior to visits. Users will also be sent a description of each of the harnesses in the test bed (see listing in Annex D) and supplied with a complete description of the state of the test bed. At the laboratory, displays provide a hands-on and visual aid of the harness type, pedigree, construction and assembly procedures. These displays include:

- Aged/retired harness pedigree
- Illustrations of wire descriptions
- Defects fabrication procedures
- Photographs of defect types
- Wire-to-pin/socket-to-connector assembly and actual wire defects.

Upon completion of testing, each user is required to document preliminary results of a given diagnostic process on an AANC supplied wiring anomaly form, a sample is provided in Table 2. The intent of this form is to provide an initial/preliminary document to the AANC on results and also serves as a duplicate record. Note that the number of anomalies is reduced to three categories to simplify particular defect type (DT – defined in Table 1) identification. Also note that the form encourages the user to make a recommendation (based on the diagnostic results) on whether a maintenance action is required, or requires further inspection. The AANC provides an information sheet on what a user reports on the condition of each wire compared to actual wire anomalies that are present. This information is supplied only to the user and the AANC sponsor. A sample AANC Graded Report Summary is shown in Table 3. Both these forms are discussed during the visitor orientation briefing.

There is no requirement for users of the wire laboratory to provide details of their technology to AANC personnel. However, if a need or circumstance arises that requires some degree of informing AANC personnel on how particular methods or instrumentation operate, users of the wire laboratory that have proprietary methods and instrumentation can request AANC personnel to execute non-disclosure agreements. Such agreements will require review by Sandia legal personnel, so advance coordination is recommended. This has effectively been carried out numerous times since the inception of the AANC facility. The AANC performs unbiased technology evaluations with equal consideration of all technologies regardless of their origin, sponsorship or ownership.

All Department of Energy (DOE) developed technologies to be evaluated at the AANC will be carried-out by two evaluators that are independent of the DOE and the AANC. One evaluator will receive adequate training on the use of any DOE developed technology, and a second independent evaluator will execute a non-disclosure agreement for use of the wire laboratory defects log-book necessary for performing post-test data analysis.

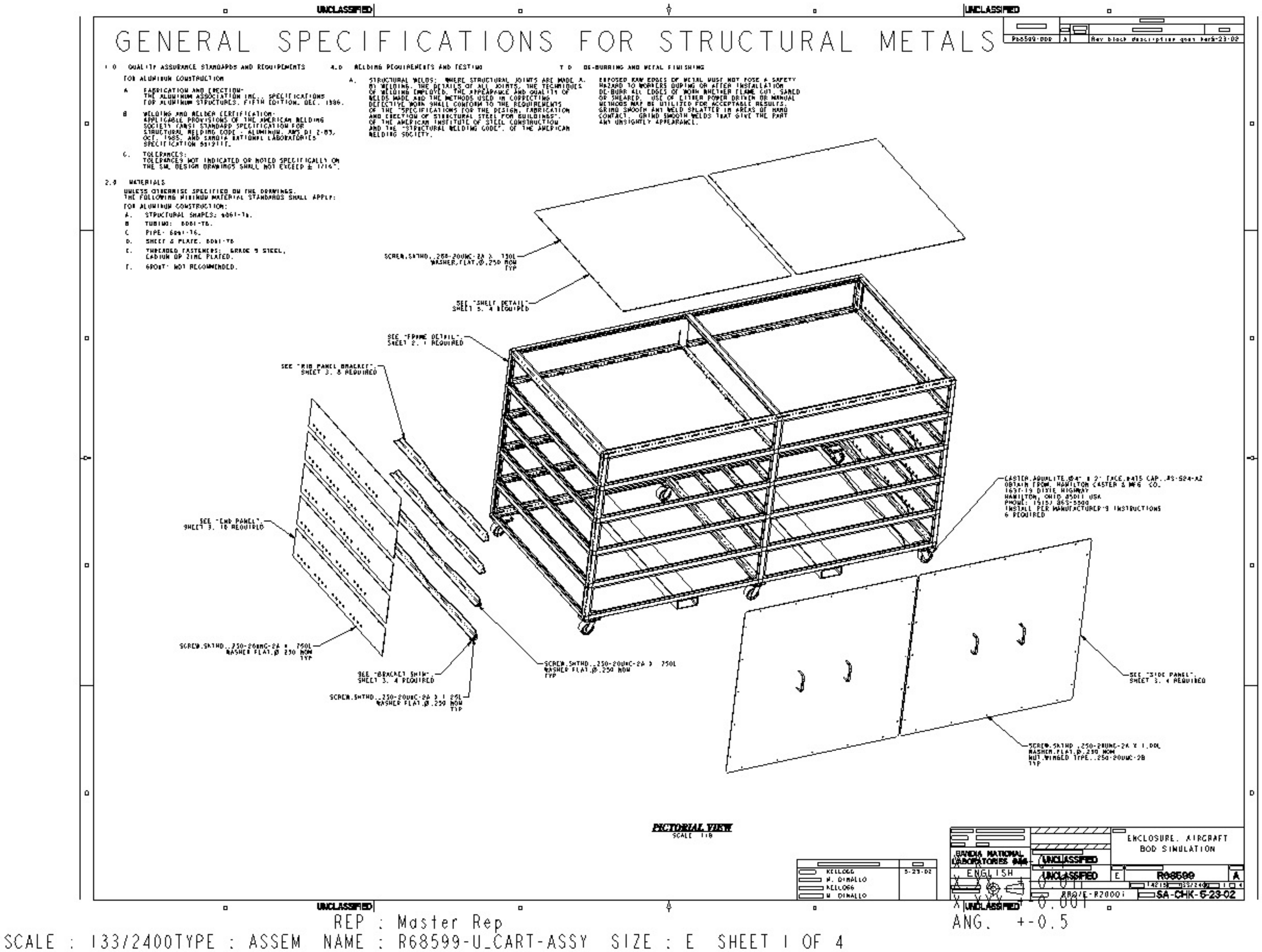

Figure 1. Design Drawing of Test Bed Enclosure

Figure 2. Partially Assembled Wire Harness Enclosure

Figure 3. Boeing 727/737 Type Ribbed-Structure Segment Fabricated by Foster-Miller

Figure 4. Assembled Wire Harness Enclosure

Figure 5. Extracted Harnesses from Retired Aircraft

Figure 6. Wire Harness to Connector Assembly Display

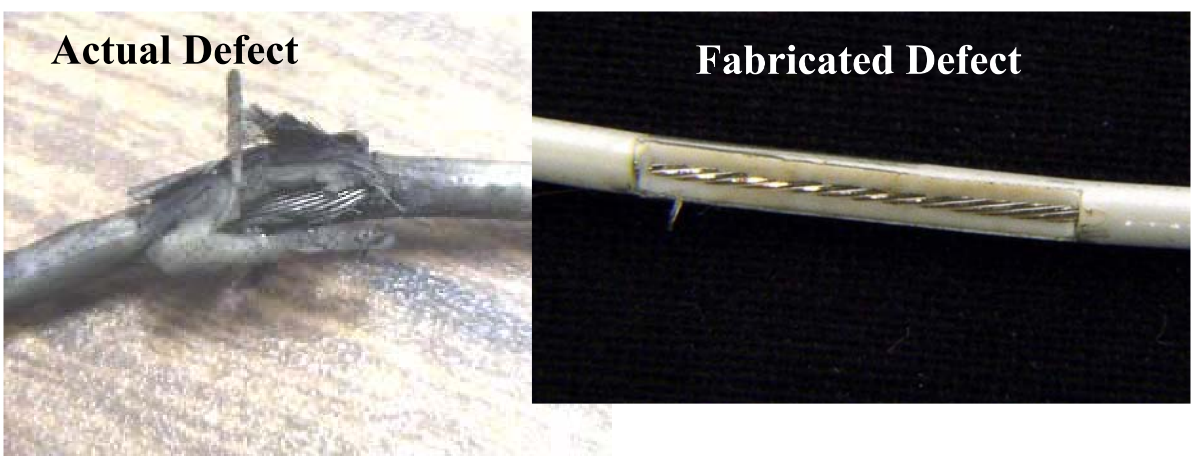

Figure 7. Comparison of Actual and Fabricated Defects Using Annex E Procedures.

Table 1. Defect Descriptor Table

Defect Type	Identifier Code	Severity Code	Comments (Parameter Data)
Abraded or Chafed Insulation	DT1	% of Insulation Radius Removed, Linear Extent, Angular Extent	Severe: 100%, 1", 180^0 Medium: 100%, 0.25", 90^0 Minute: 50%, 0.5", 90^0
Breached Insulation (360^0 Exposed Conductor)	DT2	Linear Extent,	Severe: 1" Medium: 0.125" Minute: 0.03125"
Cracked Insulation	DT3	Linear Extent, Density, % into Insulation	Severe: 4", 100/inch, 100% Medium: 1", 25/inch, 100% Minute: 1", 5/inch, 50%
Conductor-Strand Breaks	DT4	% of Strand Breaks (with no contact)	Severe: 75% Medium: 25% Minute: 5%
Over-Pressured Clamps	DT5	Clamp Specification, Torque Applied	Severe: 100 inch-lb Medium: 50 inch-lb Minute: 25 inch-lb
Bend Radius	DT6	Degrees from Initial Routing	Severe: 180^0, No Loop Area Medium: 180^0, Harness Separation 2x Diameter Minute: 180^0, Harness Separation 5x Diameter
Faulted Splices	DT7	No Crimp, Too Many Splices, Exposed Conductor	Type I: Insulation Heat Shrunk, No Crimp Applied Type II: Exposed Wire-To-Wire Joining Type III: Over-Heated Insulation Shrinkage Type IV: Too Many Crimps per Wire
Heated Insulation	DT8	Heating Duration, Temperature	Severe: Blacken, Frayed Insulation Medium: Blacken, Contorted Insulation Minute: Slight Discoloration, Insulation Not Contorted
Conductor Opened	DT9	With Contact (WC), No Contact (NC)	Severe: No Contact Medium: 50% Contact Minute: 90% Contact
Conductor Shorted	DT10	Moderate or Hard Contact	Severe: O-Lug Torqued To Rib, Wire-to-Wire Soldered Medium: Same as Severe with 0.1-Ω Intervening Minute: Same as Severe with 10-Ω Intervening
Corrosion	DT11	Light, Medium, Severe	In Progress

Table 2. Sample Preliminary User Provided Report

AANC Test Bed

Wiring Anomaly Report

Harness Location (Tray , Row, Col)		Connector (Bow, Aft) (Model #)	Anomalous Wire/Pin ID	Anomaly Categories Insulation (DT 1-3, 8); Continuity (DT 4,7, 9, 10); Installation (DT 5, 6) #1	Severity	Action	#2	Severity	Action	#3	Severity	Action
1	2, top, 19	Bow	1 to 13	Continuity	Open	Visual						
		MS24264R16B24P N		96" from Aft		Inspect						
			17 to gnd	Insulation	Unknown	Visual						
				57" from Bow		Inspect						
2	2, top, 21	Aft	7 to 16	Installation	Minute	No						
		MS24266R20B39P8		53" from Bow		Action						
3	3, top, 8	Aft	16 to gnd	Insulation	Exposed	Visual	Installation	Unknown	Visual			
		MS24266R18B8PN		23" from Aft	Conductor	Inspect	64" from bow		Inspect			
4	4, top, 5	Bow	27 to 41	Continuity	Short	Visual						
		MS24264R22B55P7		19" from aft		Inspect						
5	4, top, 13	Bow	7 to 1	Insulation	Aged	No						
		MS24264R14T7P6				Action						

Personnel:____________ Company:_____________ Date:_______________ Technology:_____________________

Comments:____

Table 3. Sample AANC Report Summary

Visitor: XYZ Corp (Personnel: Engineer; Technician)
Date of Visit: November 14 –15, 2002 **AANC/Sandia Personnel:** Christopher Lopez, Mike Dinallo
Test Objective: Demonstrate ability of diagnostic system to locate defects (model – first product, serial # 42b).
Test Conditions: Tested all enclosure harnesses. (Relative Humidity 33%, Temperature 75^0F)

Harness Location (Tray, Row, Column)	Harness Types (General Description)	Connector[1] Accessed For Testing	Pins Evaluated	Detected Defects (Pin)	Reported Wire Condition (Type : Severity/Value : Location (inches)) Actual	Diagnostic Result	Comments
3, 2, 14	17 pins, single and STP[2] wires	Aft	17 - pins	6, 9	6 to 9: shorted: 37”	6 Shorted to 9: <10mΩ : 37”	Identified shorts of pins evaluated except missed 1 shorted defect
4, 3, 2	5 pins, only single wires	Bow	5 - pins	2 4	Insulation breach : severe: 96” bend radius: severe : 53”	insulation: severe: 103” installation: severe : 53”	Identified anomalies of pins evaluated
2, 3, 6	24 pins, only single wires	Bow	24 - pins	13 7	continuity (DT4):medium:73” open: hard : 87”	continuity : NR : 73” opened: > 1MΩ: 83”	Identified anomalies of pins evaluated
3, 3, 22	55 pins, single and STP[2] wires	Aft	55 - pins	23, 32, 14	Heated insulation:severe:107”	insulation: NR : 107”	Identified anomalies of pins evaluated Other evaluated wires/pins had defect(s) not identified

[1]All connector types are rotate-to-snap (lock-in), pins or socket, loose or panel mount.
[2]Shielded Twisted Pair. [3]Severity Not Reported.

General Observations: Out of 101 pins/wires evaluated, having 13 anomalous conditions, 4 were undetected; the locations had errors less than ±5%. Approximate diagnostic measurement time was 8 hours.

Disclaimer: The information provided does not constitute endorsement or validation of any diagnostic equipment or methodology by the FAA, Sandia, the DOE or any of its contractors.

References

1. *Intrusive Inspection Final Report,* December 2000, and the *Aging Transport Systems Task 1 and 2 Final Report*, August 2000. Both reports were sponsored by the Aging Transport systems Rulemaking Advisory Committee, chartered by the FAA. http://www.mitrecaasd.org/atsrac/index.html.

2. Boeing Company, *D6-36911 Electrical Wiring Assembly and Installation Procedures,* 9-26-96.

3. *Douglas Process Standard Individual Commercial Aircraft Electrical Installation,* DPS 1.834, 8-2-91.

4. Military Specification DTL 22520G and Mil-C-22520/1 – 39, Crimp Tools, Wire Terminations, General Specifications, September 12, 1997.

5. *FAA Advisory Circular 43.13-1B*, Chapter 11, 9-8-98.

6. “Acceptability of Electronics Assemblies,” Association Connecting Electronics Industries, IPC-A-610C Standard, January 2000.