

Chapter 6: Analysis of Wire Degradation

As discussed in Chapter 5 this report focuses on degenerative wire conditions with the potential to cause fire or unacceptable common mode failure. These conditions (highlighted in Table 5-1) represent a total of 137 of the total 960 findings¹. Though relatively few in number, such conditions can (if not well managed) have a significant impact aircraft safety.

Data Synthesis

All data and statistics presented in this chapter are derived from only six aircraft. Though the statistic may suggest the possible presence of a phenomenon, they should not be considered indicative typical wire performance in any absolute or relative sense.

A comparison of the results of different inspection and testing techniques inevitably requires the equivalencing of similar but not identical quantities. For example, the identification of a visual finding as a crack may be supported by visual evidence of other material failure, whereas the identification of a breached wire by testing was insensitive to the genesis of the breach (i.e. whether it is material failure or trauma). Furthermore a partial crack in the insulation would not have been identified by the in-situ testing but could have been visually observed. The working group used its best judgment to establish a proper equivalence between the results of inspection and testing. Nevertheless another group could have judged differently resulting in slightly different interpretation of the data.

Table 6-1 shows, by aircraft, the findings for visual and Deltest NDT testing per thousand finds and per thousand feet respectively. The visual and NDT findings are with respect to all found conditions in all zones and all found conditions on preselected specimens respectively. A plus, “+”, after each percentage pair indicates that lab testing produced additional findings of significance and a double plus, “++”, indicates many additional lab findings of significance. (e.g. 4.3 percent of all findings on the A300 were vibration damage or chafing, there were 0.15 vibration damage chafing finds per thousand feet of tested wire on the 747. There were some additional lab findings of cracked insulation on the DC-9-1 and -2 aircraft.)

	Degraded Splice or Repair		Heat Damage, Burnt Insulation		Vibration Damage, Chafing		Cracked Insulation		Arcing		Insulation Delamination	
	Vis	Test	Vis	Test	Vis	Test	Vis	Test	Vis	Test	Vis	Test
A300	0.0	0.50	0.0	0.00	4.3	0.00	1.4	0.38	0.0	0.13	1.4	0.13
DC 9	1.0	0.25	1.0	0.00	15.6	0.00	14.6	+	0.0	0.0	0.0	0.00
747	0.9	0.15	0.0	0.00	5.7	0.15	7.5	0.60	0.9	0.0	0.0	0.00
DC 9	0.0	0.00	8.9	1.01+	10.8	0.00	12.1	+	0.6	0.5	0.0	0.00
DC 10	0.0	0.00	0.0	0.00	5.5	0.00	0.0	0.00	0.0	0.0	0.0	0.00
L 1011	0.0	0.28	0.0	0.00	1.9	0.28	5.8	1.39	0.0	0.0	1.0	0.00

¹ Each inspector finding was classified into one or more categories. Excluding redundant classification (e.g. non-traumatic abrasion and vibration damage, chafing) there were a total of 960 classified conditions from 624 inspector findings.

Totals	0.3	0.24	2.6	0.07	7.8	0.07	8.2	0.42	0.3	0.07	0.3	0.03
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Table 6-1: Significant degenerative conditions by aircraft

Table 6-2 shows a cross tabulation of significant degenerative conditions with specimen category: Internal infrequent-maintenance bundles (LCL, UCL, IPF and CDT), Internal serviceable (ICH, CPT, PSU), and external (ENL, ENS, EPF, ECH, ECD). Numbers are sum total of all specific specimen findings (visual and Deltest), modified by lab findings (+ for some, ++for many). The last column represents Eclipse findings that are not directly traceable to individual flaws (+ for some anomalous test results, ++for many). The bundles LCS and CTM are not represented in Table 6-2². Table 6-2 also includes notation indicating additional Eclipse test findings or laboratory findings (a plus “+” for some additional finds, a double plus, “++”, for many additional finds).

	Degraded Repair	Heat Dmgd, Burnt Insulation	Vibration Damage, Chafing	Cracked Insulation	Arcing	Insulation Delamination	Eclipse
Internal Infrequent-maintenance	1	0	1	1	0	1	+
Internal Serviceable	5	0	0	2	0	0	+
External	1	2+	1	9+	2	0	++

Table 6-2: Significant degenerative conditions by specimen category

Table 6-3 shows, by wire type, the findings for visual inspection on preselected specimens and the findings by Deltest NDT testing per thousand feet. A plus, “+”, after each number pair indicates that lab testing produced additional findings of significance and a double plus, “++”, indicates many additional lab findings of significance. For all aircraft except the DC-10, it was assumed that the wire type is equivalent to the predominant wire type (a good approximation). Since the DC-10 used two general-purpose wire types (XL-ETFE and polyimide), its wire type was determined bundle by bundle (but not wire by wire).

	Degraded Splice or Repair		Heat Damage, Burnt Insulation		Vibration Damage, Chafing		Cracked Insulation		Arcing		Insulation Delamination	
	Vis	Test	Vis	Test	Vis	Test	Vis	Test	Vis	Test	Vis	Test
PVC	0	0.5	3	5.5+	7	13.2	9	13.5+	0	0.3	-	-
Polyimide	0	0.0	0	0.0	0	3.1	0	3.6	0	0.0	0	2.4
XL ETFE	0	0.0	0	0.0	0	5.5	0	0.0	0	0.0	-	-
Poly-X	0	0.9	0	0.0	1	5.7	1	7.5	0	0.9	-	-

Table 6-3: Significant degenerative conditions by wire type

² See Appendix 1.2 for a definition of the wire specimen codes.

Any analysis of the synthesized data in Tables 6-1 through 6-3 must take into account the scarcity of findings. The data is suggestive of areas that should receive further focused attention, but it should not be interpreted as a quantitative estimate of what degradation-related wire conditions might exist on the fleet of revenue service aircraft.

Analysis of Wire Type Effects

It is clear from the inspection and testing data. That there are typical characteristic flaws for each type of wire. It is also clear that other factors in addition to wire type (e.g. service history) played a major role in determining the state of the wire.

PVC - Polyvinyl Chloride/Nylon Insulation: Because PVC/Glass/Nylon wires do not have the fire resistance of later generation wire, their degenerative conditions deserve special consideration. For the two aircraft, the vast majority of the wire degenerative conditions, and especially the cracked insulation conditions seems indicative of the low hydro-retention and thermal performance of the insulation material and particularly of the polyamide (nylon). However, comparison of the data for the two DC-9 aircraft with PCV/Glass/Nylon insulation (especially the heat damage data), clearly illustrates the point that factors other than wire type have a major effect on the state of wire.

Aromatic Polyimide wrapped insulation: The degenerative condition data for this wire wrapped insulation show relatively low levels of vibration and chafing damage conditions, indicative of this insulations good mechanical performance. The Aircraft data show a wide variation between the two aromatic polyimide aircraft inspected in regard to cracking reported: The L1011 exhibited significantly more cracking. This has to be correlated further with the inspection data, which show a great deal of topcoat damage, on both the FEP (A300) and Liquid H (L1011) topcoats³. The soft FEP topcoat degradation probably attributable to mild traumatic damage (rubbing or scuffing), whereas the Liquid H coating was indicative of material hardening and/or lack of adherence (flaking). Other factors, such as polyimide's resistance to notch propagation must also be considered as explanatory factors.

XL-ETFE – Cross-Linked Ethylene Tetra Fluoro Ethylene (e.g. Tefzel): The cross-linked ETFE data in Table 2-2 shows that the aircraft thermal, fluid and chemical contamination environments did not adversely influence the aging characteristics of this insulation. The results of the Insulation Resistance test and the Dielectric Withstand Voltage test done in the Sandia and Raytheon laboratories confirm that there is very little change in the insulative properties of the ETFE material as a result of exposure to these environments.

Poly-X - Extruded Aliphatic Polyimide insulation: This wire insulation displayed characteristic radial cracking mode. This was later verified with Sandia Laboratory testing. There was evidence of arcing found as well.

Bundles with Mixed Wire-Type: Commercial aircraft use a variety of wire types in their wire systems. The wire types identified for this study have different performance characteristics from one another. The Navy conducted comparative study of three wire types in 1982, which included vibration and environmental testing of wire bundles of different insulation types. The tests conducted demonstrated that wires of different insulation types, mixed in bundles, could experience changes in dielectric strength due to the wearing of the insulation under certain conditions.

³ Liquid H topcoat a thin layer of modified polyimide or modified polyimide/amide coating applied as a liquid over the underlying tapes then heat cured.

Historically, the FAA has issued Advisory Circulars 25.16, 29.2B, 25.10, and 43.13 (1991-1998), which address the mixing of different wire types within the same bundle. Each of these Advisories and other Congressional/Regulatory letters, all recommend against mixing of different wire types in bundles due to the potential for wire on wire abrasion. Based on all of the FAA's documentation and the Navy's tests done in 1982, it is only prudent to carefully consider the various wire insulation types in all applications when designing and maintaining wiring systems. The inherent differences in the performance and chemistry of the wire insulation types should be ample reason to conclude that mixing of certain wire types in the same bundle could be hazardous to aircraft safety due to the potential for arcing and fire.

The sample size of aircraft with mixed insulation types was too small to draw any definitive conclusions. There were however, two cases noted from the 747 and the first DC-9 of wires chafing against one with visible damage to wire insulation. In both cases, newer wire was chafing against older wire of a different type. The wires were not bundled together but crossed against one another where there was opportunity for relative motion between them. Some of the wire bundles from the DC-10 had mixed insulation types. The inspectors saw no visual indications of wear due to wire on wire abrasion in the bundles.

RSC Analysis

As discussed in Chapter 2 a Reportable Significant Condition (RSC) is a specific condition which, in the absence of information to the contrary, the working group could not confirm as having little or no safety impact for a broad fleet of revenue service aircraft. Seven specific findings were determined to be RSCs and were forwarded to the aircraft manufacturer and cognizant Aircraft Certification Office for resolution. Table 6-X summarizes these findings.

Aircraft	Location	Part	Finding	Possible cause
DC-9	wing tip	wire to tip lights	burnt wire	resistive heating
DC-9	tail cone stair	wire in spiral wrap	burnt wire	chafing
DC-9	near cabin fluorescent lights	wire ties	severe embrittlement	ultraviolet light
DC-9	tail cone	power feeder in conduit	breached and possibly burnt wire	chaffing
747	forward cargo bay	power feeder cables	wire-to-wire chafing	mis-installation of cables.
A300	aircraft bilge area just forward of electronics-bay	large bundle on left side.	delaminated wire	contamination
11011	cockpit	overhead circuit breaker panel wires	traumatic damage to wires	proximity to closure point.

In slightly more detail, the Seven RSCs were:

1. DC-9 Wing Tip Wire: Inspectors noticed the blackening and severe embrittlement of wire leading to wing tip strobe lights. The blackening extended over a length of several

inches on both sides of the aircraft. There was some speculation that this might be due to wing tip light modifications that resulted in higher electrical loads.

2. DC-9 Wire is Spiral Wrap: along vertical braces to either side of the aft stair there are small wire bundles protected by spiral wrap. Upon removal of the spiral wrap one inspector noticed that the several of the wires were burnt from apparent wire-to-wire arcing. (The exterior of the spiral wrap was not scorched.) The arcing may have been the result of chafing induced by the spiral wrap.
3. DC-9 Embrittled wire ties: An inspector noticed that most, if not all, of the wire ties in the vicinity of the interior fluorescent lights were so severely embrittled that they could be broken with very little force – pressure from a single finger. It is believed that the ultraviolet light from the fluorescent lights may have accelerated the aging of these ties.
4. DC-9 Power Feeder Cable in Conduit: Lectromec testing identified a breached power feeder cable within a conduit. The cable was not visually inspectable. Subsequent laboratory analysis found a charred area on the cable indicating electrical shorting or severe overheating.
5. 747 Power Feeder Cable Chaffing: An inspector noticed that one two power feeder cables crossing each other at a 60 degree angle was chaffed through to the core. The other power feeder cable did not appear damaged. The cables had no mechanical fastener at or near the point of crossing and contact. The chaffing was most probably caused by vibration and relative motion during operation of the aircraft.
6. A300 Polyimide Delamination: Apparent localized delamination of several wires was discovered during laboratory visual examination. Though there was no field indication on the specimen, other wires in the area were noted as being contaminated with toilet fluid. One of these wires was identified by Lectromec's field and subsequent lab testing as being breached to the conductor. Laboratory analysis of the bundle showed that several wires had partially delaminated and degraded polyimide insulation. (See Appendix 4.2.1)
7. L1011 Circuit Breaker Panel Wiring: An inspector noticed that two wires leading to circuit breakers had traumatic damage that probably resulted from the wire's being pinched between the swing-down panel and adjacent fixed panel. Over-length wire or improper routing is the most likely cause of the damage.

Because the intrusive inspection project was a focused (i.e. intensive but not extensive) look at six aircraft, it is inappropriate to assess the state of any of these aircraft on the number and nature of RSCs.



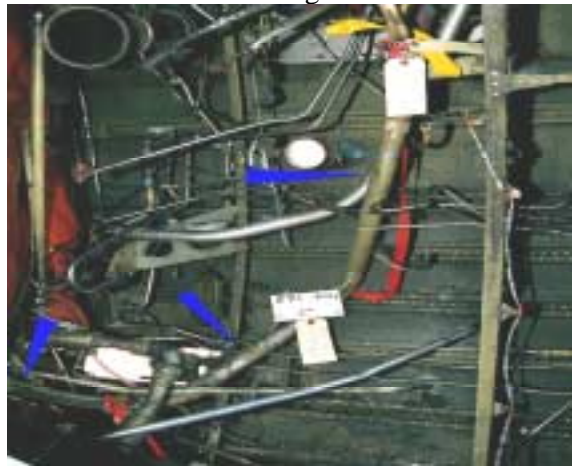
DC-9 Tail Cone Burnt Wires



747 Power feeder chaffing



L1011 Circuit Breaker Panel



DC-9 Tail Cone, Right Hand Side (blue arrows indicate conduit)



DC-9 Tail Cone Power Feeder removed from conduit



A300 EE Bay, LCL specimen where delamination was discovered

These six findings are to be examined by the appropriate airframe manufacturer in order to determine what – if any – fleet action is necessary. This determination is the prerogative of the manufacturer, subject to the appropriate regulatory oversight. The Intrusive Inspection Working Group has neither the expertise nor authority to pass judgment on the disposition of these issues.

Nevertheless, the airframe manufacturers have agreed to provide their assessment of these findings. **Their verbatim⁴ responses are included below without comment. The Intrusive Inspection Working Group neither endorses nor rejects the manufacturers analysis presented below.**

A300 delamination⁵

BACKGROUND: During the inspection of a decommissioned A300B carried out by the ATSRAC- Intrusive Inspection Sub-committee, qty 9 portions of bundles have been pre-selected through the aircraft for scheduled NDT testing and Laboratory analysis as per a defined Inspection protocol. One bundle section, (acronym code LCL), 2 meters length, made up of about 1200 wires, has been pre-selected on the left-hand side of the avionics bay (zone 121). It is assumed that the LCL bundle selection criteria were its large size, its location i.e. by side of a maintenance traffic passage and beneath the left fwd toilet area, and its dirty condition. The inspector performed no intrusion of the bundle at the time of the inspection

DESCRIPTION: During NDT testing of the bundle portion (application of a small voltage & measurement of a current leakage through a conductive fluid applied to the bundle), 8 wires were found with indication of breaches. Location along the bundle was not determined.

At laboratory, 7 out of the 8 wires were confirmed with true breaches when repeating the testing: 3 wires cut-off, 2 mechanical trauma, 1 split or cut of 12mm length in insulation, and 1 with tape looking as it is unravelling or delaminating. The region of the latter was about one foot long. Further investigation determined 3 breaches on two wires in this region.

Laboratory analysis of the atypical insulation condition of the wires of this localised portion confirmed a beginning of delamination (1/3) due to hydrolysis of the first layer of the outer polyimide tape (double-wrap insulation type, 50% overlap), the rest of the insulation remaining intact. Insulation resistance test of the other wire with same visual condition confirmed the integrity of the electrical characteristics of the wire. From these results, a delamination has not been demonstrated as the root cause for the breaches and other initial local condition could also be suspected (e.g. cut, mechanical trauma).

Though the exact contaminant was not evidenced anymore on the bundle (and this situation has stopped the hydrolysis phenomenon at some stage), laboratory analysis, and knowledge on polyimide material behaviour, suggests that polyimide hydrolysis was caused by the presence of a strong fluid base (pH>11) remaining enough time in the localised portion to initiate the degradation.

INVESTIGATION: The LCL specimen was reworked sometimes during the life of the aircraft as evidenced by the presence of modification and/or replacement wires inside the bundle, incorrect routing of a bundle from the LCL specimen to the rack connectors of the batteries of the Inertial Reference System, poor clamping of bundles in the area, and coaxial cable pressed against a structural round bar strengthening the battery rack structure.

On the aircraft, other wires in the area (e.g. coaxial cables) were noticed as being contaminated with toilet (also called blue fluid) from the fwd left toilet located above the area of the specimen.

⁴ Formatting changes have been made to make the documents consistent with this report. All references are specific to the section and do not correlate to items in other parts of this report.

⁵ Response provided by Jean-Luc Ballenghien and Dominique Mazzarino, Airbus representatives to the Intrusive Inspection Working Group

Sandia laboratory reported that main affected wires were located inside the bundle (i.e. not visible from outside) and that there was no visual indication of contamination outside of the specimen. However, the NDT technique consisting in applying water to the bundle and a clip probe with sponge along the bundle and wires could have diluted some remaining traces. Also, a rough external cleaning of the bundle at the time when the operator experienced the contamination cannot be excluded.

It is possible that a toilet fluid leakage (alkaline base) contaminated the bundle. However, whereas toilet fluid spillage may cause corrosion of the aircraft structure, the blue fluid is intrinsically not aggressive to wire insulation materials. Though the latest IRS batteries installed were not in place at the time of the inspection and a/c maintenance logs are not available to track previous report & maintenance action, the origin of the foreign fluid base can most conceivably be suspected from an IRS battery electrolyte spillage (K-OH Ph=14 + distilled water).

Since the laboratory analysis of the specimens was carried out several months after the inspection, and after storage in a dry and tempered loft, it is likely that any recent contamination would have dried up. Examination of the manufacturing dates of all the wires of the bundle could possibly have determined if latest modification or repair wires were damaged like the original fit wires. This information could help to possibly estimate a relatively "old" or relatively "recent" occurrence of the event. This information is not available yet from Sandia laboratory at the time of the issue of this report.

ACTION PLAN: The review of the Airbus In-service records has not revealed any other similar report of such a beginning of delamination on a polyimide wire. Also, similar contamination was never observed in the area of the batteries during Airbus Industrie Aging program, which has started back in 1992. Also, a mishandling during battery servicing or decommissioning activities cannot be excluded as well.

In order to collect more detailed data for a full assessment of the service condition of the area, Airbus has already enhanced its aging inspection procedure in the form of a specific inspection task to be carried out during the forthcoming Airbus aging in-service aircraft inspections, to be carried out during year 2001 campaign.

Further information on this subject will be conveyed as necessary to regulatory authorities through the established reporting channel.

In the interim, Airbus Industrie is planning the following actions to be completed by first quarter 2001:

A Service Information Letter (SIL) or an Operator Information Telex (OIT) will be released to the operators to reiterate the importance to comply to the following maintenance requirements:

As far as waste water system on in-service aircraft is concerned

- strict observance of procedures and precautions during servicing of toilet equipment and waste tanks and other equipment in order to reduce the possibility for fluid leakage and thus of its associated consequences (Ref. AMM 12-31-XX, and 38-32-XX, 38-35-XX etc),
- Compliance to cleaning and inspection requirements of existing scheduled maintenance tasks in order to prevent from the risk for structure corrosion and material degradation, and subsequent repair action (significant additional work). particularly in case of persistent leakage (Ref. .SRM 51-40-11),

- strict selection of the cleaning agents as recommended in the CML Section 14 and AMM 20-31-00, and their application as per AMM 38-31-00 (& 38-32-00 as applicable) to avoid aggressive contamination to structure and other aircraft material
- Airbus Industrie will also emphasises again on the various possibilities to reduce risk of leaks from servicing panels, waste holding tanks, drain pipes, cabin floor panel sealing and toilet floor-pan as documented in the existing publication material available at the operators (Ref. SIL 38-013, 38-020, 38-024, 38-028, 38-029, AMM 25-28-12, 25-40-XX, 38-32-00).

As far as battery installation, inspection/check and maintenance is concerned:

- Compliance to servicing, inspection and fluid spillage cleaning requirements as per the recommended AMM procedures (Ref. AMM 24-31-00, 34-25-XX) in order to prevent from any degradation to surrounding materials.

As far as cleaning of the wiring installation system on in-service aircraft is concerned:

- strict observance of Electrical Standard Practice procedures and precautions during inspection and cleaning of wiring and electrical hardware in order to reduce the possibility for damage from uncontrolled fluid leakage and/or unapproved fluid material (Refer to AWM 20-52-3X),
- Compliance to cleaning and inspection requirements of existing scheduled maintenance tasks in order to prevent from the possibility for degradation to wiring installation, and subsequent repair action (significant additional work), particularly in case of persistent leakage,
- Strict selection of the cleaning agents as recommended in the CML Section 11 and AWM 20-52-31, and their application as per AWM procedure to avoid aggressive contamination to aircraft material.

Airbus Industrie have also reviewed the existing maintenance documentation requirements and available at the operators to date. As far as wiring inspection & cleaning procedures of the Electrical Standard Practices Manual (AWM 20) are concerned, battery originated fluid will be specifically highlighted as an aggressive contaminant requiring increased awareness during inspection and cleaning procedure. The delamination degradation mode will be specifically documented in the damage assessment section and the repair process will be improved to highlight on this specificity (AWM 20-53-00).

747 Power Feeder Chaffing⁶

Because the configuration of the W1290 and W590 wire bundles on the Roswell 747 does not match that of our delivery records, we believe that the wire routing may have been changed at some point between initial delivery and the visual inspection of the intrusive wiring inspection protocol. In addition, we suspect that the post-manufacture change in wire routing coupled with a disregard for proper wire bundle separation outlined in our Standard Wiring Practices Manual was the probable cause of the bundle chafing. Therefore, because the wire routing is not per Boeing design requirements, because the rerouting was not accomplished in accordance with standard recommended practices, because in-service experience does reflect previous examples of chafing in this area, and because normal general visual inspections would have noted a

⁶ Response provided by Issa Ghoreishi, Boeing Representative to the Intrusive Inspection Working Group

discrepancy before system operational disruption, we do not believe that there exists a common fleet issue.

Boeing is aware that relative motion between wires with differing insulation abrasion characteristics will result in wear to one or both of the affected wires. For this reason Boeing recommends that relative motion between the wires be eliminated or, if that is not possible, installation of protection between the wires. In-service experience has indicated that wrapping of wire bundles and proper clamping at the wire bundle attachment points prevents relative wire motion between different wire specifications within the same wire bundle. In the case of two different wires or wire bundles crossing at an angle on the same plane, as in the case of the Roswell 747, Boeing specifies the installation of abrasion protection on one of the wire bundles and tying of the bundles together to protect against abrasion and to reduce relative motion. Boeing does not believe that the Roswell 747 exhibited the concern of insulation wear as a result of installing different wire specifications within the same wire bundle. We believe that the use of present installation practices as outlined in the SWPM would have prevented the noted chafing.

Finally, Boeing wire feeder installation practices results in separation of the individual feeder phases, but there are no special requirements for separation of individual power feeder wire bundles. Boeing applies similar best practices to all systems, regardless of the system power requirements, to prevent any arcing event. We do so because any arcing event on any system, regardless of the resultant damage to adjacent systems, is to be prevented.

Given our in-service experience, recommended wire bundle installation practices, proper maintenance of that installation, and the ability to identify a similar discrepancy through visual examination, we believe that a similar installation on other airplanes is unlikely. However, to ensure that operators are aware that this condition was noted on one airplane, and to alert them to the need to follow proper installation practices to prevent similar occurrences in the future, we will prepare an operator notification outlining the nature of the discovery which will include information concerning the age of the airplane, the systems involved, and details of our recommended wire installation practices. Release of this information will take the form of a Fleet Team Digest article and occur in the 1QTR 2001.

L1011 Switch Panel Wire Trauma⁷

This memo is in response to the FAA's Aging Transport Systems Rulemaking Advisory Committee's (ATSRAC) Intrusive Inspection Working Group's request for resolution to a Reportable Significant Condition (RSC), discovered during an inspection on a L-1011. The working group, due to lack of experience and/or expertise, could not disposition discrepancy, which is identified as "traumatic" damage to wires in the Overhead Circuit Breaker Panel.

After examination of the provided data, it is the position of Lockheed Martin that the following actions be analyzed to determine the best solution:

1. Service Bulletin 093-24-109 address's circuit breaker wiring that was reported to be chafing against a circuit breaker terminal. This SB can be revised to include the same solution for all wiring contained within circuit breaker panels, provide inspection criteria and instructions for repair and securing of the wiring.
2. Create a Service Bulletin that address's the specific discrepancy and provides a solution.

⁷ Response provided by Denis Kearny, L-1011 Systems/Avionics Engineering Lockheed Martin Aircraft Center

3. Create and release a Service Information Letter (SIL) or an All Operators Letter (AOL) addressing the RSC and that reiterates the importance of inspection and care of aging wiring, which is intended to bring the issue to the forefront of the minds of the operator's maintenance technicians.

Lockheed Martin will review the previously mentioned options and take the appropriate action necessary to ensure that each operator is aware of the RSC and its hazard potential.

RSCs for McDonnell Douglas DC-9 Aircraft⁸

INTRODUCTION: The FAA has formed a team with the aviation industry and others to evaluate aging aircraft systems. In late April 2000, an FAA representative and two employees of Lectromec removed sections of electrical wiring which had been in service aboard Northwest DC-9 Fus. 628 (FSN 47486). The wire was identified by Lectromec as having 'breached' insulation. The breach was identified and diagnosed through the use of a proprietary non-destructive process known as DelTest™. The DelTest™ was developed by engineers at Lectromec, a company that specializes in Non-Destructive testing. The removed sections of wire bundles identified as containing these breached wires were provided to Boeing in Albuquerque, NM, on November 15, 2000, for further analysis and to determine root causes.

SUMMARY: No data/photos were provided to Boeing showing the location/routing of the wires prior to removal. Therefore, the root causes for the conditions of Samples 1-4 (SRC #4) and 4-6 (SRC #2) could not be determined. During lab evaluation, Samples 3-4, 4-6, 8-1, and 8-9 were the only SRC⁹ items to fail a dielectric test of their insulation. Sample 1-4 had obvious physical damage to its insulation and was not subjected to a dielectric test. Samples 3-4, 8-1, and 8-9 had non-environmental splices/connections which were determined to be the causes for the excessive current leakage.

The returned wires and cables were tested for insulation integrity using industry standard wet dielectric testing per ASTM D3032 at 300 volts. Although many of the submitted wires showed signs of damage or degradation, only one wire (Sample 5-2, not a SRC item) failed wet dielectric testing due to excessive mechanical damage to its insulation. The cause for the Sample 4-6 dielectric failure could be attributed to exposure to excessive heat. The cause for Sample 1-4 excessive wear is attributed to chafing and exposure to excessive heat.

MATERIALS: N/A

TEST SPECIMEN DESCRIPTION: The test specimens consisted of 8 wire bundle sections from different areas of a DC-9 aircraft. The bundles were constituted of various gauges and configurations of wire insulated with a three layer PVC-Glass-Nylon construction. Two (Samples 1 & 3) of the 8 subject wire bundles submitted were routed through metallic conduit material as installed on the aircraft. Please see table 1 (Appendix) for sample descriptions.

The ASTRAC working group identified 4 Significant Reportable Conditions (SRC) for DC-9. For the purposes of this evaluation report, the SRC items are identified as follows:

SRC #1: Main cabin fluorescent lighting bundle ties (no part samples were provided to Boeing)

SRC #2: L.H. & R.H. wing tip lighting wiring (Samples 2,3,4, &6). (only Sample 4-6 had a breach, attributed to exposure to heat)

⁸ Information provided by Michael Monroe, Boeing Commercial Aviation Services

⁹ The Boeing notation SRC (Significant Reportable Condition) is equivalent to the term RSC (Reportable Significant Condition) used in the rest of this report.

SRC #3: Wiring from either side of aft ventral stair (Sample 8). (no breaches found)

SRC #4: Power feeder cable (Sample 1). (only Sample 1-4 had damage, attributed to chafing and/or excessive heat)

OBJECTIVE: Verify nature and cause of the identified wire insulation breaches.

PROCEDURE - Visual Inspection: Wire inspection found two general categories of wire damage:

1. Mechanical - bending and gouging
2. Heat/thermal damage

In several instances, the exterior insulation appeared to have been cracked after the wire had been physically bent sharply. An impromptu bend/flex test on a randomly selected wire, however, failed to produce similar cracking of the exterior insulation. The insulation of other wires appeared to have been gouged by contact with a semi-sharp object - in one case leading to complete breach of the wire insulation.

Many wires appeared to have suffered thermal damage. Some of this damage appears to have been inflicted by overheated adjacent wiring, however other thermal sources (hot air ducts, welding, etc) might possibly be responsible as well. No photos/data were provided to Boeing regarding the installations of the wire samples on the airplane to substantiate this.

PROCEDURE – TESTING: Dielectric testing was performed on all wire samples except Sample 1-1 through 1-4, Sample 2-6 thru 2-9, and Sample 6-8 and 6-9. While Sample 1 was not tested due to the size of the conductor, testing of the other samples was precluded by their extremely short length. Dielectric failure was defined as having a leakage current of 20 mA or more. All of the wires readily met this requirement except Samples 3-4, 4-6, 5-2, 8-1, and 8-9.

The wires that were furnished to Boeing were identified as possessing breaches in the insulation. The locations and the severity of the breaches were not identified by the Lectromec test team. The value of 300 volts was chosen because it would unquestionably identify a complete void in the insulation without inducing additional damage. It is also well over any voltage used on the DC-9 aircraft.

It should be noted that many wire samples appeared to have suffered thermal damage, which produced discoloration and cracking in the exterior insulation of the wire. This damage, though visually disturbing, rarely resulted in current leakage excessive enough to constitute a dielectric failure.

Sample 3-4 (SRC #2): Sample 3 consisted of four wires bound in a braided fabric insulation. Examination of the insulation found no evidence of any type of a breach. Although the insulation was not removed (and thus the individual wires were not inspected separately), it was noted that Sample 3-4 was the ground shield wire for the bundle, the connection of which was not watertight. Thus, the cause for the excessive current leakage was attributed to the unsealed crimp device.

Sample 1-4 (SRC #4): Sample 1 consisted of 3 aluminum power feeder cables routed through a metallic conduit. Visual inspection of Sample 1-4 suggested the damage observed was due to abrasion. Further inspection of Sample 1-4 found black deposits on the wire exterior. These marks, when aligned with correspondingly shaped marks in the conduit, placed the wire damage zone over a corresponding abraded area located on a bend inside the conduit. It was noted that the black deposits exhibited a gummy consistency rather than the powdery consistency expected of an aluminum oxide, and that the deposits only seemed to appear where the wire and conduit were in contact. The remainder of the tube remained relatively clean.

The outer braid layer was stripped from the wire. Inspection confirmed braid permeation by a gummy residue consistent with that found on the inside of the conduit. The insulation layer under the braid layer corresponding to the abraded zone was missing and black, gummy deposits were noted on the inner braid visible through this gap in the missing insulation. In the adjacent areas where the outer insulation was not completely worn, the corresponding remaining insulation had a slightly darker color and exhibited a soft, rubbery texture unlike the outer insulation observed away from the damaged area.

It can be deduced that the metallic tube was heated beyond the temperature rating of the cables. At the point where the cables were riding against the conduit, a condition, which began to degrade the cable's insulation occurred.



Figure 1: Sample 1-4

Sample 4-6 (SRC #2): Much of Sample 4-6 was discolored by what appeared to be thermal damage. While the exterior insulation had cracked and spalled in two separate locations, the underlying braid, which was badly discolored, appeared to be intact. Further investigation proved that the primary insulation layer (PVC) was damaged by the external heat source enough to prevent the sample from passing the established wet dielectric test.(Figure 2).



Figure 2: Sample 4-6

Sample 5-2 (not a SRC item): Sample 5 consisted of three wires tied in a bundle with a plastic strap. Inspection found that all three wires had suffered mechanical damage as shown in Figure 3: . Sample 5-2 was the only one of the three wires that displayed a breach to the bare conductor. Failure of the wire is attributed to this breach.



Figure 3: Sample 5-2 (L)

Sample 8-1 (SRC #3): Sample 8-1 wiring appeared undamaged, however the wire did contain the mechanical splice seen in Figure 4. Excessive current leakage was found at this unsealed splice.



Figure 4: Sample 8-1

Sample 8-9 (SRC #3): Sample 8-9 did exhibit some surface damage (Figure 5). Experience with the previous samples suggests that this damage was probably insufficient to cause excessive current leakage. Like Sample 8-1 this wire contained a mechanical splice similar to that in Figure 4. The splice was found to be the source of excessive current leakage.

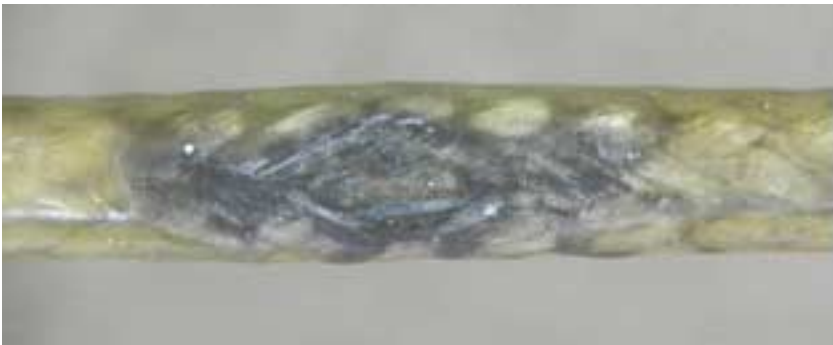


Figure 5: Sample 8-9

DISCUSSION: Boeing Engineering was not provided specific information about what constitutes a failure using Deltest™ procedures and equipment. The wires submitted exhibited signs of physical damage. One noted complete insulation failure (Sample 5-2) manifested in a high vibration area underneath a plastic mechanical strap. Current and historical process standards prohibit the use of plastic mechanical straps in high vibration areas. The other noted insulation compromised samples were damaged as a result of being subjected to higher temperatures than their rating.

Table 1: Sample Descriptions

Sample No	Sample Location	Wire ID	Dielectric Test ID	Dielectric Test Result (uA)	SRC
Sample 1-1	Conduit				4
Sample 1-2	Power feeder Cable	HV-2X2H0BAL			4
Sample 1-3	Power feeder Cable	HV-2X3H0CAL			4
Sample 1-4	Power feeder Cable	HV-2X1J0AAL			4
Sample 2-1	Right Wingtip Lights	L303B16N	2W	18	2
Sample 2-2	Right Wingtip Lights	L302G16	2V	21	2
Sample 2-3	Right Wingtip Lights	HV-L306G22	2X	47	2
Sample 2-4	Right Wingtip Lights	HV-L307G22	2U	42	2
Sample 2-5	Right Wingtip Lights	L352A22N	2T	14	2
Sample 2-6	Right Wingtip Lights	Cut	Not Done		2
Sample 2-7	Right Wingtip Lights	Cut	Not Done		2
Sample 2-8	Right Wingtip Lights	Cut	Not Done		2
Sample 2-9	Right Wingtip Lights	Cut	Not Done		2
Sample 3-1	Right Wing Flux vlv	2F4G24RD	2F4G24RD	42	2
Sample 3-2	Right Wing Flux vlv	2F5G24BL	2F5G24BL	42	2
Sample 3-3	Right Wing Flux vlv	2F6G24YE	2F6G24YE	44	2
Sample 3-4	Right Wing Flux vlv	GND SHLD	GND SHLD	>50,000	2
Sample 4-1	Right Wingtip Lights	L303B16N	6	38	2
Sample 4-2	Right Wingtip Lights	HV-L258K24	2	46	2
Sample 4-3	Right Wingtip Lights	HV-L354P24	1	49	2
Sample 4-4	Right Wingtip Lights	HV-L307G22	3	43	2
Sample 4-5	Right Wingtip Lights	L352A22N	4	30	2
Sample 4-6	Right Wingtip Lights	L259F24N	5	>50,000	2
Sample 5-1	Right Wheelwell Lighting	L414H16	1	100	Not SRC
Sample 5-2	Right Wheelwell Lighting	L414K16	2	>50,000	Not SRC
Sample 5-3	Right Wheelwell Lighting	L414J16	3	340	Not SRC
Sample 6-1	Left Wingtip Lighting	L358A22N	T	110	2
Sample 6-2	Left Wingtip Lighting	HV-L258L24	S	3300	2
Sample 6-3	Left Wingtip Lighting	HV-L342G16	V	120	2
Sample 6-4	Left Wingtip Lighting	L304B16N	W	2500	2
Sample 6-5	Left Wingtip Lighting	HV-L348G22	X	80	2
Sample 6-6	Left Wingtip Lighting	HV-L264Q24	R	120	2

Table 1: Sample Descriptions					
Sample 6-7	Left Wingtip Lighting	HV-L349G22	U	14	2
Sample 6-8	Left Wingtip Lighting	L267H24N	Not Done		2
Sample 6-9	Left Wingtip Lighting	Cut	Not Done		2
Sample 7-1	Misc.	C812B22BL	Blue	12	Not SRC
Sample 7-2	Misc.	C811B22RD	Red	12	Not SRC
Sample 8-1	Leftside Tailcone	H904A22N	C2C	>50,000	3
Sample 8-2	Leftside Tailcone	H903B22	C2B	15	3
Sample 8-3	Leftside Tailcone	1H310A20N	C1B	50	3
Sample 8-4	Leftside Tailcone	1H304K20	C1A	15	3
Sample 8-5	Leftside Tailcone	L795P18	5	20	3
Sample 8-6	Leftside Tailcone	HV-L103D22	2	51	3
Sample 8-7	Leftside Tailcone	L1035A22N	4	58	3
Sample 8-8	Leftside Tailcone	L1034A22N	1	60	3
Sample 8-9	Leftside Tailcone	L795K18	3	>50,000	3

Other Analysis

Noting that the Lectromec DC-9 results showed in one case relatively few breaches per thousand feet of wire and in the other the many, it is clear that there are variables effecting rate of wire installation deterioration to which our study was simply not sensitive. Nevertheless there are some qualitative comments we can make based upon our observations.

Hot Stamp Markings: A number of physical breaches of the insulation were determined to be at the location of hot stamps circuit identification marks. Seven of the forty-seven insulation breaches discovered during the DelTest were attributed to failure at hot stamp marks. Raytheon testing showed low insulation resistance values and wet dielectric failures at some hot stamp marks on some wires from the A300 and L1011 but not on the B-747. Subsequent visual inspection of the failures at hot stamp marks showed various degrees of hot stamp penetration, from superficial to fully penetrating. Controls on hot stamping processes and alternative surface marking methods (inkjet or UV laser marking) that are available today were not prevalent during installation of most of the wire examined during this study.

Cut-off Wire: Field and laboratory results showed that several bundles had wires terminated and stowed within the bundle. Without tracing the wire markings to a particular systems or knowing the service history of the bundle, it is impossible to know how these situations manifested themselves. There are, however, two possible hypotheses for this.

1. The aircraft manufacturer could have put the wires there as spare wires. If that was the case, the wires are usually marked with some kind of spare nomenclature. These wires would be terminated with an end caps, and the end cap termination would be situated at the periphery of the bundle.
2. As a result of repair or modification, the wire could have been deactivated and disconnected prior to retirement of the aircraft. While good practice calls for removal of the deactivated wire, economical circumstances often cause part of the wire run to be left in place. In any case, the remaining wire run should be terminated with an end cap.

In either case, the spare or deactivated wires are disconnected at each end. As long at the deactivated wire is neither hot nor grounded, it poses no threat to the other wires.

Flamability: Specimens of the four different wire insulations were burn tested to determine whether or not there were any indications of change in the wire's propensity to support

combustion. The sixty-degree flame tests showed that the wires all showed performance similar to new wire. In particular polyimide, XL-ETFE, and Poly-X showed no self-sustaining fire. Drippings did not flame and did not ignite facial tissue onto which they fell. PVC/Glass/Nylon – which was certified under different requirements – did exhibit some after burning. PVC/Glass/Nylon drippings did not flame and did not ignite the facial tissue.