Chapter 4: Laboratory Testing

Experimental Description

The working group selected 25 candidate laboratory tests to apply to aircraft wire specimens (see Appendix 1.2.7). These candidate tests were to be applied in accordance with Table 1.2.7-1 or Appendix 1.2.7. As laboratory results developed, the test plan was reduced to ensure an on time completion of the testing. Testing eliminated from the plan reduced somewhat the extent and statistical relevance of the results.

Certain wires were removed from the bundles of each section of the aircraft and brought to the laboratory for analysis. Typically this consisted of one wire from each bundle from each section. *The laboratory visual inspection is of the individual wire, and is not meant to be a statement representative of the whole bundle but only of the wire studied.*

Testing on randomly selected wire was performed at both Sandia National Labs and Raytheon. Sandia testing protocols were individually developed using the considerable expertise of it polymers group, while Raytheon testing used modified standard test methods in SAE AS4373.[1] Interpretation of the SAE-derivative test results in the same manner as these SAE certification tests is not appropriate: Some degradation of wire performance is to be expected with age. Tests methods applied are as follows.

Laboratory Visual Inspection Description (Sandia): Prior to other testing, lab personnel closely examined each specimen, often with the aid of magnification.

Mandrel Bend Test Description (Sandia): The wire (with conductor) is subjected to a series of bends around cylindrical mandrels of several different diameters (5, 2.5, 1, 0.5, 0.25, 0.125 inches) starting with the largest and proceeding to the smallest diameter. As the wire is bent around each it is carefully examined to see if this causes any cracking in the insulation or topcoat. It should be noted that for all specimens the mandrel bend testing seemed to produce cracks in on the outer layer and topcoat only: The conductor was not visible as it was still protected by the intact inner insulation layer.

Solvent Swelling Description (Sandia): The wire insulation is stripped to remove the conductor. The mass of the insulation is measured and then it is subjected to refluxing solvent. Afterwards the mass of the insulation along with the solvent retained is measured again. Finally the insulation is oven dried and the mass is again measured. Analysis leads to values for solvent swelling and the percent gel of the insulation, parameters which correlate to the amount of cross-linking in the polymer.[2] This usually holds true for elastomers but not necessarily for thermoplastics.

Modulus Profiling Description (Sandia): With the conductor removed, a very fine parabolically shaped indentor needle is used to probe the cross section of the wire insulation. Knowing the load on the indentor, its shape, and the distance it penetrates, the modulus (a measure of the toughness of the material) can then be calculated. This indicates not only the overall aging of the insulation

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[1] Some test had to be modified for various reasons, such as the short length of specimens and the tight timeframe to gather results.

[2] An aged polymer often tends to be either more or less crosslinked than newer ones.

but also the cross-sectional variation in this aging. In other words, one can determine whether the insulation has aged only at or near the surface (or conductor interface), or it has aged more uniformly through the entire depth of the insulation.

Density Description (Sandia): A common method for detecting certain polymer aging is measuring the density. As polymers age in air, they typically oxidize and this usually results in a density change. The conductor is removed from the insulation and the density of the insulator is calculated first by measuring its mass in air, and then by measuring its mass in a solvent of known density.

Tensile Elongation Description (Sandia): The conductor is removed from the wire insulation. The insulation is then grabbed on each end by pneumatically activated clamps and stretched to the breaking point.

Specimen Inspection (Raytheon): Specimens from each aircraft were visually inspected for signs of injury, degradation, and contamination. Magnification was used to help discern conditions or possible problems with the wire insulation. Observations are detailed in Appendix 4.2.1. Photographs of abnormal or interesting conditions are presented when appropriate. A variety of conditions were found in the specimens submitted from the subject aircraft.

Insulation Resistance (Raytheon): Insulation resistance is a measure of the electrical resistance that insulation imparts between the conductor and ground. Greater electrical resistance provides better insulating properties. The presence of shorts, weak areas, deterioration, or poor quality of the insulation material can lead to low values. Wire specimens were tested for this property first, since it imparts little stress on the wire. The test results can be variable, and long specimen lengths are necessary to accurately extrapolate values out to the standard 1000 feet units. Values are usually reported in megohms per thousand feet of wire. The requirement for the insulation resistance on new wire is specified by the respective wire specification, but generally ranges from 10,000 megohms (MΩ)/1000 feet for smaller gauge wire to 500 MΩ/1000 feet for larger gauge wire.

Wet Dielectric Withstand (Raytheon): The dielectric withstand test is an electrical test commonly used to determine the integrity of wire insulation. An electrical potential applied across the insulation will short if any area of the insulation is too weak to contain the electrical potential. An ammeter was used to measure the leakage current through the insulation between the conductor and the electrolyte solution.

All wire specimens were tested to verify the electrical integrity of the insulation before proceeding with other tests. Many of the failures had already been determined during the insulation resistance test. This test was also used in conjunction with other tests as a proof test for insulation integrity following mechanical or thermal stress. The results were listed with the applicable thermal or mechanical test, when performed as a post test.

High Voltage Wet Dielectric Withstand (Raytheon): The original intent of this test was to determine the voltage of insulation breakdown, but the maximum voltage available on the dielectric test equipment was 10,000 volts. Specimens were subjected to 10,000 volts for one minute to determine if the insulation would breakdown under the high electrical stress.

Conductor Resistance (Raytheon): The conductor from each wire specimen was tested to determine the resistance to an electrical current. The conductors were generally coated annealed copper or coated copper alloy. The coating was tin, nickel or silver. Each has different resistance properties. In addition, the resistance of the conductor can change due to other factors, including more or less mass (thick or thin areas), loss of the conductor coating, oxidation or other corrosion, or imperfections in the conductor material. Values for conductor resistance are typically reported as resistance per length (ohms/1000 feet) at a specific temperature. Values were reported for conductor resistance at 23°C (room temperature). Requirements are specified in the applicable wire specification.

Notch Propagation (Raytheon): This test measures the ability of a wire insulation to resist the propagation of a nick or cut through the insulation layers to the conductor. One of the major drawbacks of some of the more rigid insulation systems is the tendency for the materials to crack, and for the cracking to continue all of the way through to the conductor to create potential dielectric failure sites. There are several ways in which wire manufacturers have addressed this problem. One is to use materials that do not exhibit the tendency to propagate cracks. Another is to use more than one layer of material so that if one layer develops a crack or is nicked, another layer will retain its integrity.

Wrap (Raytheon): The wrap test evaluates the ability of wire to withstand thermal stress while under mechanical stress. The test uses a relatively short-term thermal conditioning, but the high mechanical stress during the thermal exposure can reveal weaknesses in the insulation and susceptibility of the insulation to cracking. The wrapback variant of the wrap test uses the wire itself as the mandrel, so that the bend is extremely small and tight.

Dynamic Cut-Through (Raytheon): This test is designed to measure the ability of a wire insulation to resist being cut by a sharp edge, such as the edge of a structure or a tool. This may lead to potential shorting due to exposed conductor. The force required to cut the insulation is dependent on several factors, including the modulus of the insulation material and the physical toughness. Hard materials tend to require more force than soft materials to cut through. The hardness of the conductor, wire gauge size, temperature, thickness of the insulation, and the edge used are all factors that affect the results. Cut through was performed at room temperature and at 85°C, roughly the highest temperature materials are normally specified to meet for service aboard aircraft, with the exception of specific high temperature areas.

Inherent Viscosity (Raytheon): The inherent viscosity is a measure of the viscosity of a solution of material at a known concentration. The polymeric chain length distribution will affect the viscosity of the solution. Higher average chain length polymers will exhibit higher inherent viscosity. Changes in polymer chain length also tend to change other physical properties of the bulk polymer, including tensile, elongation, and modulus. This test may not be used to compare different types of materials, since each will have specific viscosity to chain length relationships. This test is utilized by the polyimide tape manufacturers to characterize material from production lots. As a material ages, the molecular bonds may begin to break by various mechanisms, such as thermal ageing and hydrolysis, causing polymer chain length change and therefore inherent viscosity to decrease. The values less than 1.0 (100ml/gm) indicate some polyimide insulation degradation may have occurred (e.g. decrease of elongation).

Lamination Sealing (Raytheon): Wrapped wire insulation is to remain intact during its life, and should at no time unravel. The constructions generally incorporate an adhesive between the layers of insulating film to achieve this objective. Properly processed wire should resist separation of the layers during or following thermal exposure. The specimens were inspected for evidence of separation of the layers following thermal exposure.

Crosslink Proof/Accelerated Aging (Raytheon): The accelerated aging test is used to evaluate a wire's ability to withstand a high temperature under mechanical stress for a short period of time. Wire insulation is expected to survive short-term tests to temperatures above the temperature rating of the insulation. This assumes that the test temperatures are below the melt temperatures of the insulating materials for thermoplastic insulations. This test, sometimes called crosslink proof, is also used to determine if the insulation of a wire has been converted to a thermoset material by polymer crosslinking. For crosslink proof, a temperature above the melt point of the non-crosslinked material is selected. New wire is expected to pass the dielectric test following high temperature exposure. Insulation and conductor degradation is allowed provided the electrical integrity is maintained.

Lifecycle (Raytheon): The life cycle test is similar and complementary to the accelerated aging test. Specimens were exposed to elevated temperatures under mechanical stress, with temperatures lower than for accelerated aging, but for a longer exposure time. This test is used to determine the ability of a wire to withstand temperatures above the temperature rating of the insulation for an extended period of time. This test combined high heat with static stress by hanging the wire specimens with weights, and followed this with dynamic stress during the bend test. The specimens were then proof tested with a dielectric withstanding voltage to determine the integrity of the insulation. New wire would be expected to pass this test with no failures, legible marking, intact insulation, and without pitting of the conductor.

Dry Arc Track Resistance (Raytheon): Organic materials, such as those found in wire insulation, have the capability of breaking down under arcing conditions to form carbonized areas. The carbonization is highly conductive, and with less intact dielectric material present, the ability of the insulation to suppress arcs decreases, potentially leading to further arcing and carbonization. Conductive paths are formed that may lead to violent shorts, sometimes causing collateral damage to nearby wiring and other sensitive components. This cycle is termed arc track propagation, and certain materials have displayed more resistance to this phenomenon than others. The dry arc track propagation resistance test for wire insulation provides an assessment of the ability of an insulation to prevent damage in a dry electrical arc environment. The test also evaluates the ability of the insulation to prevent further arc propagation when electrical arcing is re-energized. Arcing is initiated by the cutting action of an aluminum blade which represents the possible chaffing action of a sharp piece of structural aircraft aluminum. Unacceptable arc propagation properties are defined by the length of wire insulation burned and by the damage of a certain number of collateral wires.

Wet Arc Track Resistance (Raytheon): This test is similar to the dry arc track propagation resistance test, except that it uses an electrolyte solution dripped across two neighboring wires with exposed conductor to initiate arcing. The electrolyte solution is 3% aqueous sodium chloride and represents the fluids that may be present in aircraft. The rate of arc propagation can vary based on the type of fluid and its conductivity. Unacceptable arc propagation properties are defined by the length of wire insulation burned and by the damage of a certain number of collateral wires.

Flammability (Raytheon): Aerospace wire is to be resistant to flammability by Federal Aviation Regulations (FAR part 25.1359). The sixty-degree test of the FAR Part 25, Appendix G, Chapter 1, Appendix A was utilized to determine the flammability of the wire specimens. In addition, a soft facial tissue was placed underneath the specimens to determine whether any flaming drips ignite the tissue. Smoke generation is not a requirement for this test, but was noted in relative terms.

Overview of Experiments

Data table 4-1 shows how many wires (not including repeated experiments of the same wire) were studied in the laboratory by Sandia broken down by aircraft and experiment. It should be noted that due to time constraints and logistics, certain aircraft (747, A300) were examined at Sandia in more detail than others.

Aircraft	Visual Inspection	Mandrel Bend	Solvent Swelling	Modulus Profiling	Density	Tensile	Infra-red Spectroscopy
A300	10%	14	10	10	10	0	2
DC-9 (1)	75%	26†	5	0	14	9	0
747	10%	68	18	8	30	38	0
DC-9 (2)	75%	10†	10	0	14	12	0
L1011	75%	12	0	0	0	0	0
DC-10	10%	15	0	0	0	25	0

Table 4-1: Number of specimens tested for each aircraft and each test.

† More wires were examined, but they were already cracked.

Data Table 4-2 is a similar table for the number of wires examined by Raytheon.

Aircraft	Visual	IR	Wet Dielectric	High Voltage Wet Dielectric	Conductor Resistance	Notch Propagation	Wrap	Dynamic Cut-Through	Inherent Viscosity	Lamination Sealing	Crosslink Proof/ Aging	Lifecycle	Flammability	Dry-Arc Track Resistance	Wet-Arc Track resistance
A300	10	10	10	5	10	6	5	5	2	4	N/A	5	2	0	0
DC-9 (1)	1	1	1	0	1	0	0	0	N/A	N/A	N/A	0	0	0	0
747	16	9	16	5	13	13	9	8	N/A	0	7	9	3	0	2
DC-9 (2)	20	20	20	6	18	0	6	6	N/A	N/A	N/A	6	3	0	0
L1011	60	60	60	14	57	11	11	14	12	10	N/A	8	4	0	0
DC-10	47	43	50	13	48	12	15	13	1	1	18	13	9	0	0

Table 4-2: Number of specimens tested for each aircraft and each test for Raytheon.

N/A- Not applicable

Raytheon also examined wires in order to validate findings with the Eclypse test system. The data in Table 4-2 does not include wires selected for these tests. Data for all Raytheon testing is compiled in separate tables for each aircraft in Appendix 4.2.1. The details of the test methods used by Raytheon are listed in Appendix 4.2.2

Airbus A300

The Wire Insulation: The wires studied had the coding 'AKB FA R --,' and 'AK DB M --' where '--' refers to the gauge size, either 20 or 24. The wire insulation studied consisted of a fluorinated ethylene-propylene polymer (FEP) coating, followed by two layers of a polyimide tape (Kapton®) on either a silver copper (AK) or nickel copper conductor (AKB).[3]

Laboratory Visual Inspection: Wires from nine sections of the aircraft were brought to the laboratories and studied. Eight sections appeared to be visually in the same condition. One section, the LCL-Midspan had a region that was atypical. This region was noticed because of the Lectromec DelTest™ which detected a breech in the insulation in this area (Figure 4-1).

[3] Ballenghien, J.-L., personal communication, Aerospatiale Matra, Airbus.

Figure 4-1: A300 LCL Midspan (FEP, polyimide insulation) bundle with breached wire as found from DelTest™.

Closer investigation showed that clearly an event occurred in a localized section (ca. 30 cm of a ca. 2 meter bundle) of the bundle that affected many wires (Figure 4-2).

Figure 4-2: Picture of A300 LCL Midspan (FEP, polyimide) bundle in region where the topcoat is cracked and has unknown flakes on numerous wires.

Closer examination under a microscope showed a dramatic difference between a typical piece of wire and the LCL Midspan area. It can be clearly seen that a typical section (Figure 4-3, upper), and the LCL Midspan region under investigation (Figure 4-3, middle and lower), are very different.

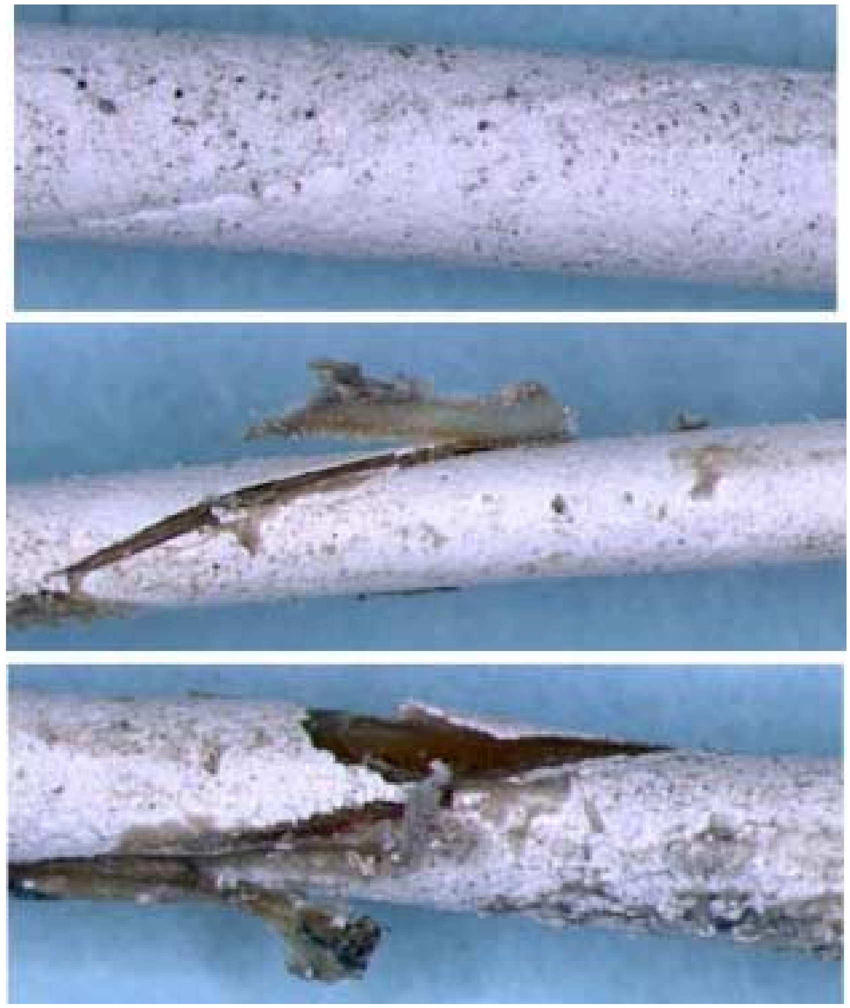

Figure 4-3: Pictures of A300 wire insulation (FEP, polyimide); a typical section (top), and two areas in the LCL Midspan where the insulation is atypical (middle and bottom).

A cross section of these wires was also examined under a microscope (Figure 4-4).

Figure 4-4: Cross section of A300 wires (FEP, polyimide) with conductor removed, from a is a typical section (left), and the atypical LCL Midspan (middle, right).

The typical section has the FEP coating still attached to the Kapton® (Figure 4-4, left). The atypical LCL Midspan section has the FEP completely detached from the Kapton®, and the Kapton® tape appears to be starting to unravel (Figure 4-4, middle and right).
Sandia's full analysis of this finding is attached as Appendix 4.1.1.
Mandrel Bend Results: One wire (or two for certain sections) was removed at random from a number of sections of the aircraft. Fourteen wires were examined and showed no cracking, aside from the LCL Midspan, which already had the inner layer exposed. Also an older non-aircraft wire (provided by Airbus) showed slight cracks on the surface.
Solvent Swelling, Modulus Profiling, Density Results: The results of these tests for this aircraft are the same as those described for the 747 aircraft later in this section.
Tensile Elongation Results: Due to the difficulty in stripping the insulation from the wire, tensile tests were not performed on all the sections.
Infrared Spectroscopy Description: This is a non-destructive technique that exposes the specimen to infra-red light. Information is obtained by measuring both the wavelengths of light absorbed, and the intensity, which can then be correlated to chemical structure.
Infrared Spectroscopy: Infrared (IR) spectroscopy yielded some interesting results for this aircraft. When the IR spectrum of a typical cross section of insulation (with the conductor removed) was compared to the LCL-Midspan Middle, dramatic differences in the outer layers were observed (Figure 4-5).

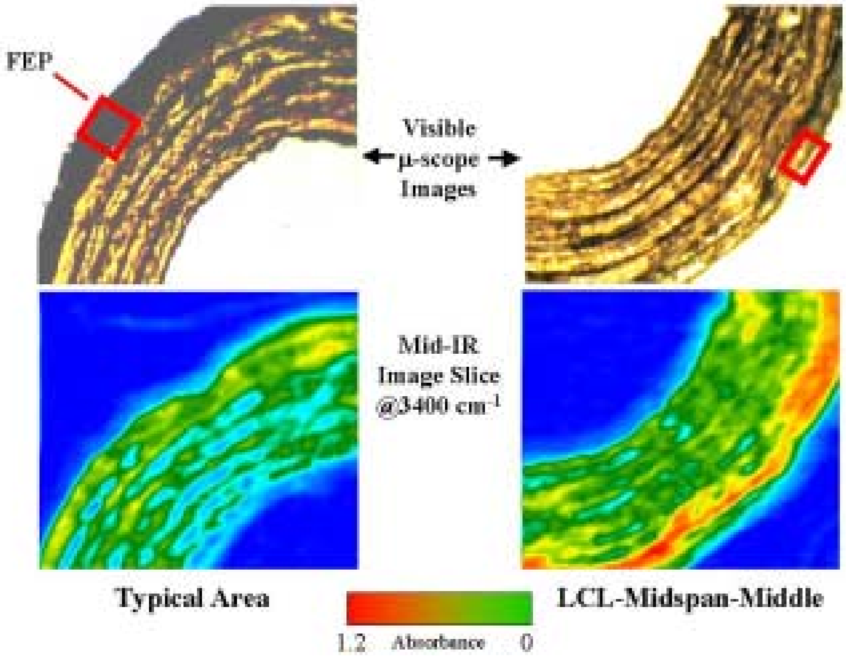

Figure 4-5: IR spectra of the cross section of A300 (FEP, polyimide) wires. The top set is the visible images, and the bottom the IR spectra at 3400 cm^{-1}.

The IR spectrum also shows that while the outer layers of the insulation appear to be different, the inner layers have the same spectra (Figure 4-6).

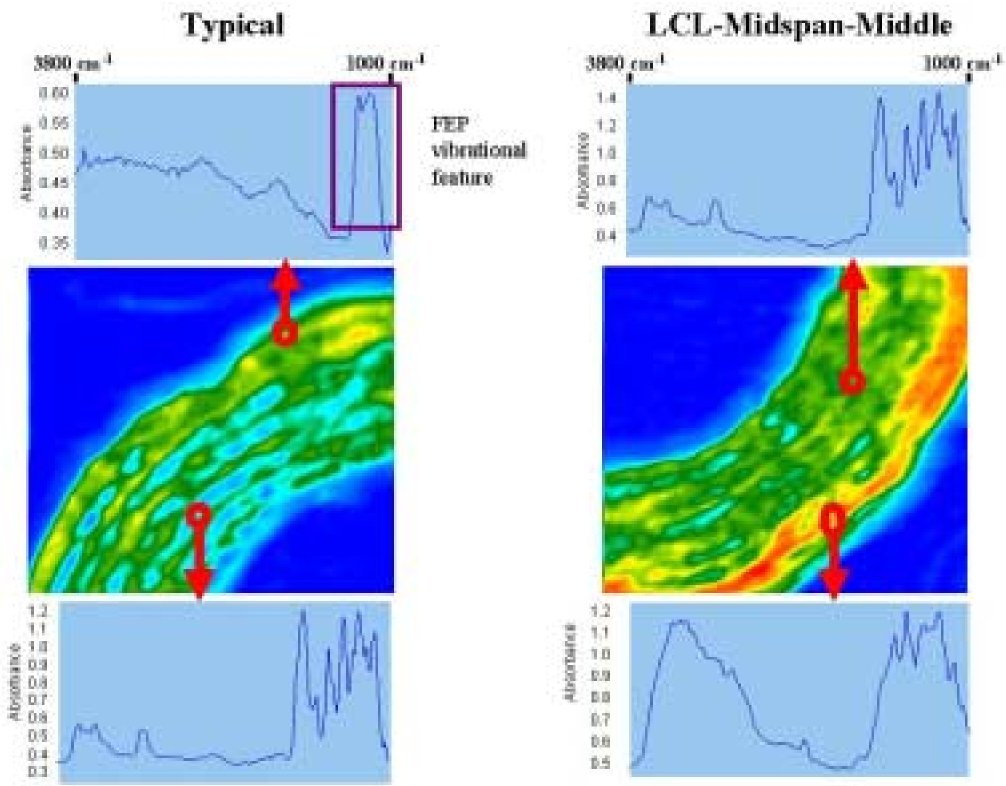

Figure 4-6: IR spectrum showing the difference between the outer layers, and the similarity of the inner for a typical insulation (FEP, polyimide) and the A300 LCL-Midspan-Middle (FEP, polyimide).

The IR spectrum of the flakes observed on the wire, of FEP, of Kapton®, and of a typical corrosion inhibitor compound are shown for comparison (Figure 4-7). It is important to note that the flakes appear not to be just a foreign compound or chemically changed insulation, but small particles of FEP (Figure 4-7, Spectrum A) are evident within the flakes.

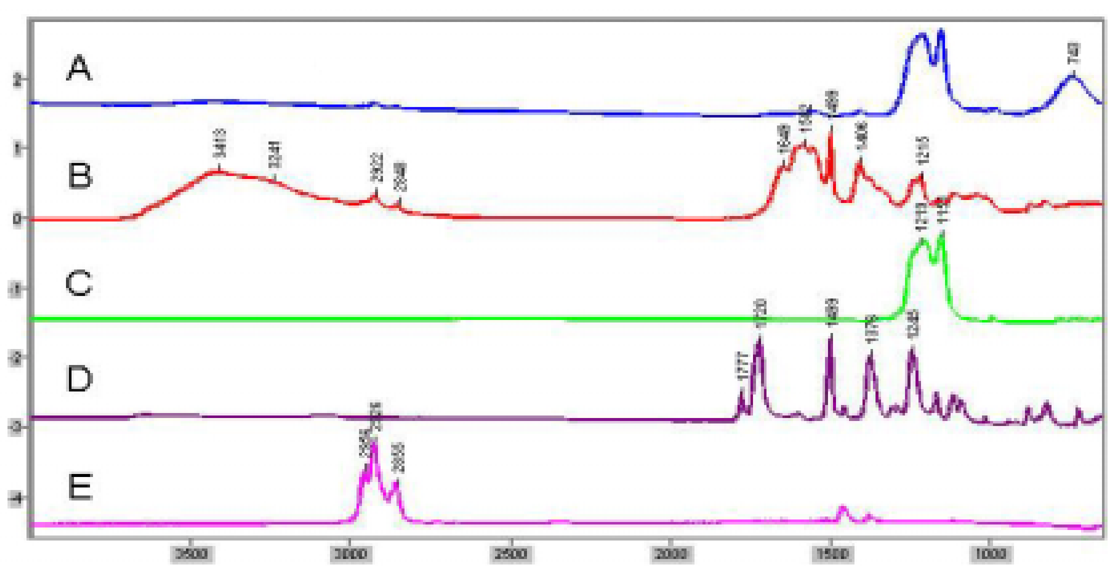

Figure 4-7: IR spectra of the unknown flakes (spectra A and B), FEP (C), Kapton® (D), and a corrosion inhibitor compound (E).

Raytheon Specimen Inspection: Only a few lengths of specimen were submitted for the A300 aircraft. Most of the wire was relatively clean, except for a black sticky substance on several of the specimens (ENS-2 C and D). All of the wire specimens exhibited abrasion of the outer coating, but none appeared to breach the inner layers of insulation, Figure 4-8. Some hot stamp marks protruded through the outer coating but did not appear to break the inner layers (CPT I and K, PSU-7 E and F), Figure 4-9. Later dielectric withstand proof testing confirmed dielectric failures on the marks of PSU-7 E specimen.

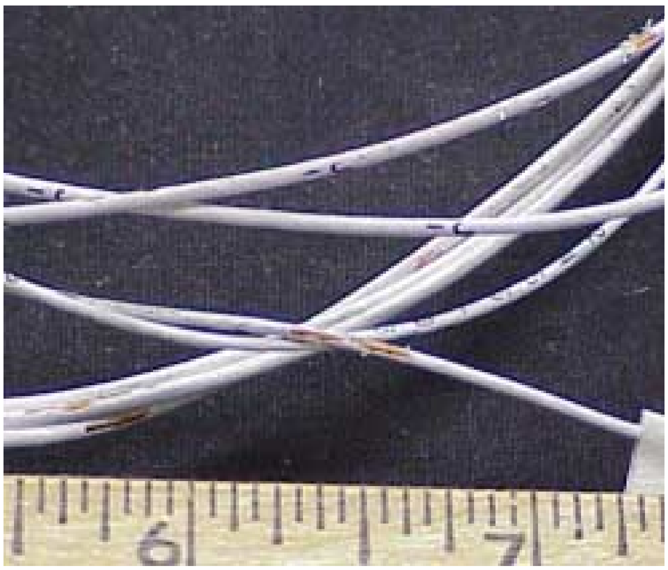

Figure 4-8: A-300, CPT I, PSU-6, PSU-7, (FEP, polyimide) abraded topcoat.

Figure 4-9: A-300, PSU-7 E, (FEP, polyimide) deep hot stamp marks along wire.

Insulation Resistance: All wire specimens were above 8000 MΩ/1000 feet with the exception of (PSU-7 E) which experienced immediate dielectric failure. The results were fairly consistent between specimens on a given specimen. Specification requirement is 760 MΩ/km at 20°C (approximately 2500 MΩ/1000 feet.) All specimens were above the requirement except one.

Wet Dielectric Withstand: Wire specimens tested to 2500 volts. One specimen failed the dielectric withstand proof test (PSU-7 E). This specimen failed by arcing through the insulation at one of the hot stamp marks after holding several hundred volts. This failure location was pulled out of the solution, and the specimen was rerun. Again, the specimen held several hundred volts, then failed at another hot stamp mark. This was repeated a third time with similar results. All other wire specimens passed the dielectric withstand test.

High Voltage Wet Dielectric Withstand: One specimen failed at 10,000 volts after 50 seconds (PSU-7). This failure occurred at a deep hot stamp mark.

Conductor Resistance: Conductor resistance of the wire specimens appeared to be within the specification requirements for each of the conductor sizes and types.

Notch Propagation: Wire specimens were notched with a 0.05 mm (.002 inch) blade as required by the wire specification. No notch propagation occurred following 10 cycles of bending flex around a mandrel with a diameter 6 times the diameter of the wire specimen tested. All specimens passed the wet dielectric withstand proof test following the bend test.

Wrap: Wire specimens were wrapped twice around a .125 inch mandrel. No oven conditioning took place. The outer coating on two specimens cracked (UCL and PSU-7), but all specimens passed the dielectric withstand proof test. This test is not required in the original wire specification.

Dynamic Cut-Through: . Greater than 80 pounds of force were required to cut through to the conductor at room temperature on all wires except CPT-I (56 lbs), and 56 to 100 pounds of force were required to cut through at 85°C for all wires tested.

Inherent Viscosity: Data was taken on two polyimide samples. Values measured from 0.61 to 0.72 (100ml solvent/gm polyimide).

Lamination Sealing: No separation of the layers was apparent following the thermal aging for any of the specimens.

Crosslink Proof (Accelerated Aging): This test was not performed on the polyimide wrapped wire type submitted from this aircraft as it is not applicable to this insulated wire type.

Lifecycle: Wire specimens were conditioned for 168 hours at 230°C, then subjected to the bend and dielectric withstand proof test. No specimens cracked following the bend test, and all specimens passed the dielectric withstand proof test.

Dry Arc Track Resistance: Unfortunately, this test requires a large quantity of wire that was not available for this test program on this aircraft. No specimens were tested on the wire from this aircraft.

Wet Arc Track Resistance: Unfortunately, this test requires a large quantity of wire that was not available for this test program on this aircraft. No specimens were tested on the wire from this aircraft.

Flammability: Specimens (UCL and ENS-2) all exhibited no after flame, no flaming drips, and no ignition of the facial tissue. Average total length of burn was 1.5 inches. Very little smoke generated.

DC-9 (1)

The Wire Insulation: There were two different wire types that were studied on this aircraft. The first was coded 7616964 B 24 90484 and consisted of a transparent nylon layer, a fiberglass layer, and then a poly-vinyl chloride (PVC) layer above the conductor. The second wire type studied had no coding and was a cable with a green transparent nylon outer layer with a steel shielding underneath, followed by a fiberglass layer and finally a PVC layer above the conductor.[4]

Visual Inspection: The wires from this aircraft were for the most part not that different from section to section. The only notable sections were ENS-1 which had some burn marks, and the ENL-1 sections that were cracked in numerous places. Some sections of wires had parts that were very dirty and had patches of a glue-like substance.

Mandrel Bend Results: Twenty-six wires were removed at random from numerous sections of the aircraft. Four different wires examined from section ENL-1, and one from LH Wheel Well, were cracked before the test. Section ENS-1 cracked at the 0.25" diameter level, section CPT-3 cracked at the at the 0.5" diameter level, section ECD-2 cracked at the at the 1" diameter level

Solvent Swelling, Density, Tensile Elongation Results: The results of these tests for this aircraft are the same as those described previously for the DC-9 (2) aircraft.

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[4] Fialcowitz, P. personal communication, A.E.Petsche.

DC-9(1) Supplemental Visual Inspection Summary[5]: A supplemental inspection of the DC-9(1) wire identified several additional findings on several specimens. Appendix 4.1.2 documents these findings in detail. Table 4-3 summarizes these findings by specimen type. Note that greater than three-quarters of the findings were on three specimens all in harsh environments outside the pressure vessel.

Bundle	LHWW	CPT-2	CPT-4	LCL-1	UCL-1/UCL-2	ECD-1	IPF	CTP-3	CTM-1	ENL-1	CPT-6	ENS-1	CDT-1	ECD-2	LCS-1	CDT-2
Events	12	0	0	1	3	0†	0	0	0	>13	1	2	1	>9	2	0

Table 4-3: Summary of Sandia Supplemental Inspection of the DC-9(2) Subject Aircraft.

† Specimen sent to Beoing

B747-100

The Wire Insulation: Wire coded 'W42B', corresponds to Raychem part number '88A', which consists of a conductor with one or two extruded layers of alkene-imide polymer, and a topcoat consisting of layers of aromatic polyimide with layers of aliphatic polyimide to provide color.[6] This wire also corresponds to Boeing Spec. designation 'BMS 13-42B,' which is crosslinked alkene-imide polymer insulator on a copper conductor.[7] This also corresponds to Military Specifications (Mil. Specs.) Mil-W-81044/16.[8] All wire discussed for the 747 will be of this type unless otherwise noted.

Laboratory Visual Inspection Results: Inspection of the wires after removal from the bundle showed no dramatic difference in the wires from section to section. Certain wires were covered in dirt and or grease, while others had patches of a brown encrusted or sticky substance (suspected, but not confirmed, to be corrosion inhibitor compounds).

Mandrel Bend Results: One or two wires were removed at random from numerous sections of the aircraft (a total of 32 specimens). Most specimens showed no cracking, however, one section, ECH-2 Zone 10, cracked at the 2.5" diameter level (Figure 4-10, left); a second wire from the same bundle did not crack when tested all the way down to the 0.125" diameter.

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5 Supplemental inspection and testing was performed at the request of ATSRAC after their first review of this report. The focus of this inspection and testing was on extending the body of data available for analysis and ensuring a balanced look at the several subject wire types. Sandia's contribution was a close visual inspection (with magnification) of wire from three aircraft: The two DC-9s and the DC-10.

6 Enault, N., personal communication, Wire and Cable Consulting.

7 Ghoreishi, I. S., personal communication, Boeing.

8 Kurek, J. "Aging Aircraft Wire, Testing Project Number 50-01-142, "Raytheon Systems Company, 1999.

Figure 4-10: 747 wire from section ECH-2 Zone 10 (alkene-imide polymer) showing cracked insulation from mandrel bend (left); non-aircraft wire (alkene-imide polymer) that also cracked (right).

It should also be noted that a similar wire manufactured in 1976 (provided by Raychem) and kept in a warehouse showed cracking at the 0.125" diameter level Figure 4-10, right).

Wire coded 'W42A' corresponds to Raychem number 88A0131. It also corresponds to Boeing Spec. designation BMS 13-42A which is crosslinked alkene-imide polymer insulator on a tin coated copper conductor. This wire type was also examined via the mandrel bend technique. Of the 18 wires examined cracking was observed in section ENS-1 Zone 9 at the 0.5" diameter level, and ENL-1 Zone 8 at the 0.25" diameter level (Figure 4-11).

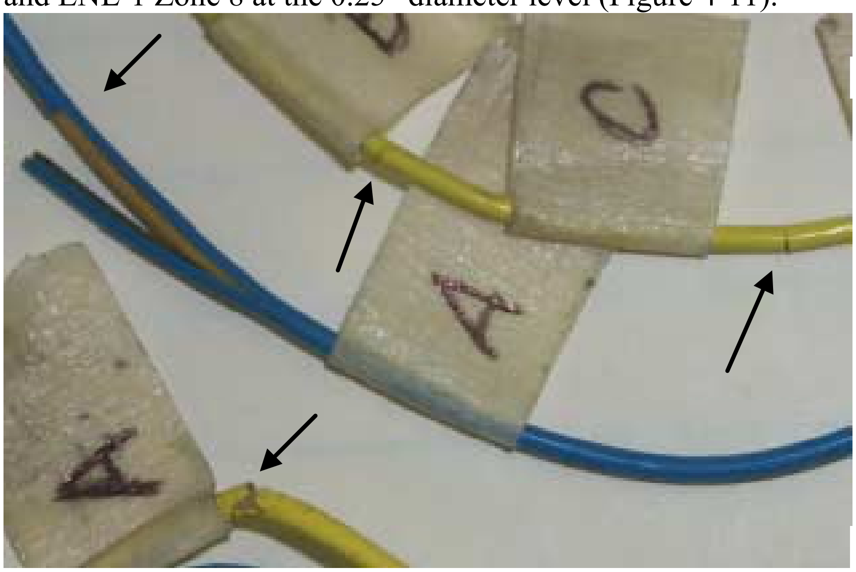

Figure 4-11: Boeing 747, ENS-1 Zone 9 (alkene-imide),top three arrows; and ENL-1 Zone 8 (alkene-imide) bottom arrow.

Wire coded W42B/8/2 corresponds to Raychem number 88A0821. This also corresponds to Boeing Spec. designation BMS 13-42B which is two (insulation colors red and blue) spirally laid wires with crosslinked alkene-imide polymer insulated tin coated copper conductor. This wire type was also examined via the mandrel bend technique. Of the 18 wires examined only one section, ICH-2 Zone 1 cracked at the 0.25" diameter level.

Solvent Swelling Results: Results from the nine sections studied agree within their error bars. A few hypothesis can come from this result, the first that this technique is not a useful means for following aging for this insulation type, and/or a more suitable solvent needs to be found. A second possible hypothesis is that aging has not occurred for any of the sections or that the aging of all nine sections is similar. Further tests would be necessary to draw any conclusions.

Modulus Profiling Results: The insulation material was too hard to get any kind of accurate reading. Therefore, this technique was found to be not applicable and yielded scattered data that was not reproducible. However, a newer instrument based on an Interfacial Force Microscope (IFM) is near completion and could prove useful in the future to determine similar information.

Density Results: Initial density results looked promising, but when this test was performed on a second set of wires there was too much scatter in the values to make any distinction between the sections. This test leads to similar hypothesis as the solvent swelling. It could be that either important aging has not occurred or that aging of this polymer does not result in a change in density. A further complication is the fact that the insulation has two layers, which often have very different densities. Thus density values for the two layers together will depend on their relative percentages which will undoubtedly vary from specimen to specimen. Methods do exist to look at very small specimens, and might be applicable if the layers can be separated.

Tensile Elongation Results: This insulation is constructed of two parts, referred to as outer and inner. During the tensile test it was noted that in many cases the outer and inner layers broke at different times, thus they were analyzed as separate entities. Preliminary results indicate that the outer insulation in the section CPT-4 (rear) Zone 7 elongated farther than the other sections examined.

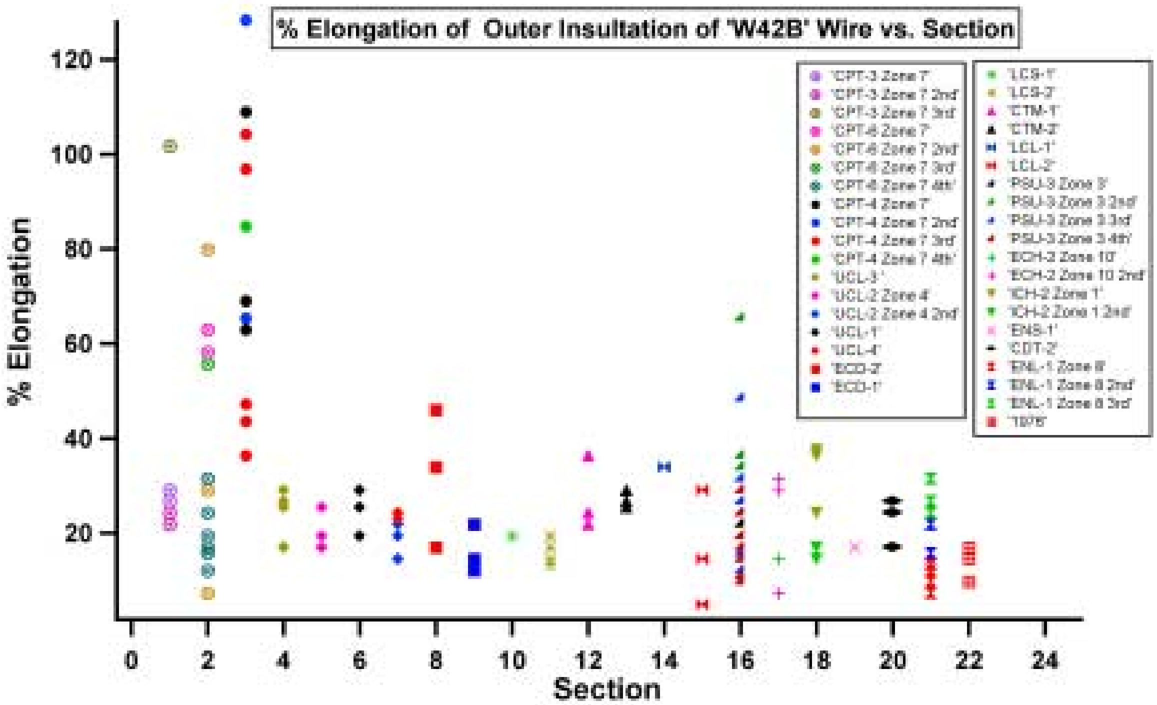

Figure 4-12: Elongation of the outer layer of wire W42B (alkene-imide) vs. section.

This hypothesis was supported by removing additional wires from a number of sections, including CPT-4 (rear) Zone 7, and repeating the experiment. The wires exhibited similar behavior (Figure 4-12). While there is scatter in the data, clearly one section (CPT-4) stands out. In general, the inner insulation either broke at the same time as the outer, or elongated much farther than the outer sections and did not display any noticeable difference from section to section due to the scatter.

Raytheon Specimen Inspection: Wire specimens from several areas appeared relatively clean, while others were very dirty (ENS-1 Zone 9), or exhibited yellowish sticky residue (UCL-3 Zone 3, LCL-1 Zone 1, PSU-3 Zone 3), black sticky residue (ENL-1 Zone 8), or red sticky residue (ICH-1 Zone 2 and ICH-2 Zone 1). Small metal particles were found on several wire specimens (LCL-1 Zone 1, LCS-1 Zone 1). Additional physical damage found on the submitted wire specimens included light abrasions (CPT-4 Zone 7, LCS-1 Zone 1, and ICH-2 Zone 1), a deep gouge (ENL-1 Zone 8), nicks (ICH-1 Zone 2 and ICH-2 Zone 1), some of which are fairly deep, and tight kinks (ICH-2 Zone 1 and PSU-3 Zone 3). Several specimens exhibited short parallel tractor marks at regular intervals (ICH-1 Zone 2 and ICH-2 Zone 1), such as those left by marking machines in wiring assembly shops. Most hot stamp marks did not appear to penetrate the surface. One wire specimen was in particularly poor condition, with cracks in the insulation and exposed conductor, and evidence of carbonization (ENS-1, Zone 9), Figure 4-13 and Figure 4-14. A non-environmental splice was included as a part of one wire specimen (LCS-1 Zone 1.)

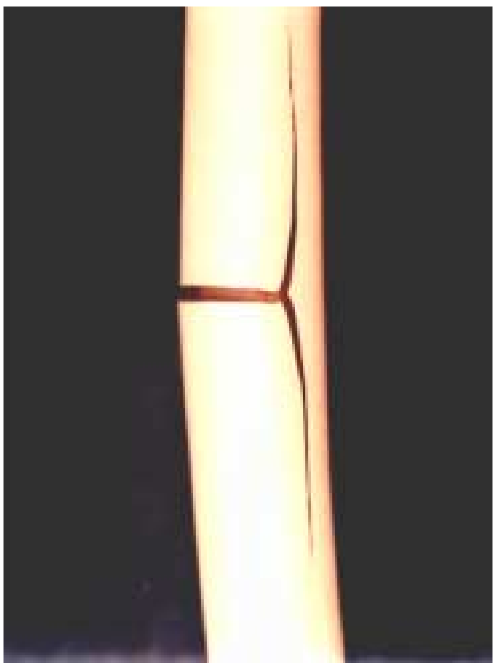

Figure 4-13: 747, ENS-1 Zone 9 (alkene-imide), cracked insulation

Figure 4-14: 747, ENS-1 Zone 9 (alkene-imide), exposed conductor.

Insulation Resistance: Wire specimens measured between 1000 and 8000 MΩ/1000 feet. These values arein the same range as the specification requirements, although some are slightly below. The results were highly variable. Several wire specimens measured near 0 MΩ/1000 feet (CPT-3, CPT-6 Zone 7), and two other specimens could not be measured due to dielectric failures (CPT-4 Zone 7, ENS-1 Zone9) when conductor was exposed or the insulation was in some way not able to fully protect the conductor.

Wet Dielectric Withstand: Two wire specimens failed the dielectric withstand proof test (CPT-4 Zone 7, ENS-1 Zone 9). The ENS-1 wire specimen was determined to have exposed conductor during visual inspection. All other specimens passed.

High Voltage Wet Dielectric Withstand: All tested specimens held 10,000 volts for 1 minute. The specimens which failed the 2500 volt dielectric test were not tested.

Conductor Resistance: The conductors of the wire specimens from this aircraft all exhibited resistances equal to or lower than the maximum allowed resistances of the wire specification.

Notch Propagation: No notch propagation occurred. The outer insulation of one specimen from ENS-1 Zone 9 cracked completely during the bend cycling, but all specimens passed the wet dielectric withstand proof test.
Wrap: Wrap back procedure used with oven aging at 200°C for 6 hours. Two specimens cracked as they were wrapped (ENL-1 Zone 8 (1 of 2), ENS-1 Zone 9 (1 of 2)), but only one of those cracked specimens (ENS-1 Zone 9) tested failed the dielectric withstand proof test.
Dynamic Cut-Through: Similar results from the areas tested at room temperature with 47 to 73 pounds force required to cut through to the conductor. One specimen (CPT-4 Zone 7) appeared to be somewhat lower than the others. At elevated temperature, 36 to 53 pounds of force were required. Three of the specimens appeared lower than the others (LCL-1 Zone 1, ENL-1 Zone 8, and ENS-1 Zone 9).
Inherent Viscosity: This test was not performed on the insulation from this aircraft. It is not known if the inherent viscosity test is applicable to this form of polyimide.
Lamination Sealing: This test was not performed on the wire from this aircraft. This test is designed for wrapped insulation constructions.
Crosslink Proof (Accelerated Aging): One wire specimen failed the dielectric withstand proof test following 7 hours of accelerated heat aging at 250°C and bend testing (ENS-1 Zone 9). All others passed.
Lifecycle: Wire specimens were conditioned for 168 hours at 200°C, then subjected to the bend and dielectric withstand proof test. A large number of specimens failed the lifecycle test by cracking during the bend test, and not maintaining electrical integrity during the dielectric withstand proof test. Four specimens passed this test out of 16 specimens tested (CPT-4 Zone 7 (1 of 1), ICH-1 Zone 2 (1 of 1), ENS-1 Zone 9 (1 of 2), and LCL-1 Zone 2 (1 of 2)). All other specimens failed this test.
Dry Arc Track Resistance: Unfortunately, this test requires a large quantity of wire that was not available for this test program on this aircraft. No samples have been tested on the wire from this aircraft.
Wet Arc Track Resistance: Due to the sample limitations, only minimal testing was performed on this aircraft. Two bundles of wire from the 747 samples were tested. Each bundle contains 7 wires. The top two were initially cut to expose the conductor, and 5 were used to determine the extent of collateral damage from the arcing. Each bundle tested developed large arcs which caused the loss of continuity on the pre-damaged wires, although the test continued for the full 8 hours. All 5 wires from each of the two bundles were collaterally damaged and failed the wet dielectric voltage withstand post test.
Flammability: Specimens run (ENL-1, PSU-3, LCL-1) all exhibited no after flame, no flaming drips, and no ignition of the facial tissue. Average total length of burn was 1.7 inches. Slight amount of smoke generated.

DC-9 (2)

The Wire Insulation: The wire insulation was the same as those described previously for the DC-9 (1).
Sandia Visual Inspection: The overall condition of the wires from this aircraft was far worse than any of the others examined in this study.

Figure 4-15: Burnt DC-9 (EPF) wire found by the DelTest™, that was inside a steel conduit and visually impossible to detect.

Figure 4-16: Wire from DC-9 (2) Zone 13 LWT (Nylon/Glass/ PVC) that clearly demonstrates the range of conditions observed.

The wires from sections LH tail cone, RH tail cone, Zone 13 LWT, TH tail cone, and ENL showed signs of damage and/or degradation (Figure 4-17).

Figure 4-17: Multiple pictures (all at 3.5X) of the same DC-9 (2) wire from section ENL (Nylon/Glass/PVC) illustrating the range of conditions observed.

These sections had regions that were charred/burnt, cracked, and embrittled; in some instances parts of the outer insulation were missing (Figure 4-18). Numerous events where found that appeared at first glace to be thermal events. Upon closer examination it was realized that many events that appeared to be thermal could be breached nylon with contaminants fiberglass (and or nylon/PVC). Due to this fact the reader is cautioned not to draw any conclusions about the causes of events based on a visual examination as they can be misleading.

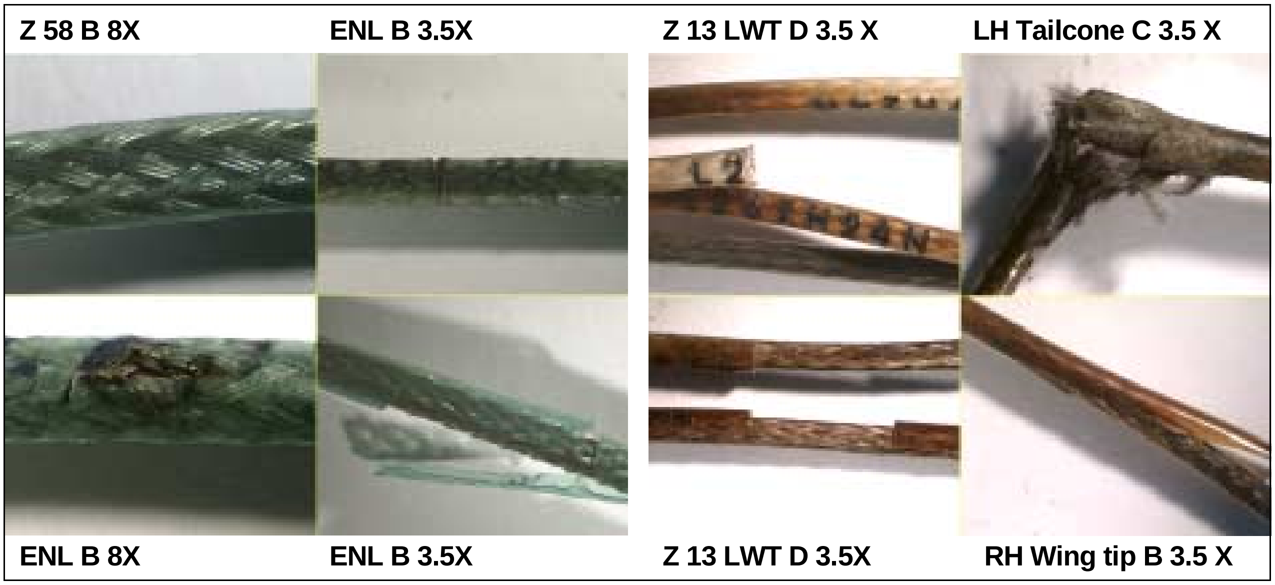

Figure 4-18: Variety of wires in various conditions all from the DC-9 (2) (Nylon/Glass/PVC).

The wires from sections Z 14 RH WT, and LCS had similar anomalies but not to the magnitude of the others. Many of these wires were in such condition that they could not be analyzed by the laboratory studies.

In follow-on laboratory analysis, several previously-unidentified instances of exposed conductor were found visually. Some appeared to be the result of thermal damage, while others appeared to be the result of chemical attack or other degradation mechanism. (See Appendix 4.1.2) Though laboratory analysis could have ascertained the nature of each of these flaws, there was insufficient time to complete this work.

In numerous instances the PVC insulation underneath the fiberglass and nylon layers was discolored (normally white, now yellow/green or brown). This discoloration maybe the result of aging or permeating contamination. The discoloration of the PVC did not always correlate with the discoloration and condition of the fiberglass and nylon.

Several blue stained wire segments were assumed to be contaminated with lavatory fluid. It was discovered that the discoloration of the wire was not limited to the outer nylon, but appeared to enter the different layers via regions where the nylon was breached. While the outer nylon and fiberglass layers were blue the corresponding PVC beneath this blue stained area was a dull yellow seen in other unstained PVC. This leads to the hypothesis that the lavatory fluid could have affected the chemical and mechanical properties of PVC.

From Table X it is apparent that the events where not uniformly distributed throughout the bundles. Though the data should not be considered indicative of the absolute or relative performance of specific specimens, certain bundles had many more events than others.

DC-9(2) Supplemental Visual Inspection Summary: A supplemental inspection of the DC-9(2) wire identified several additional findings on several specimens. Appendix 4.1.2 documents these findings in detail. Table 4-4 summarizes these findings by specimen type. Note that the great majority of findings were in harsh environments outside the pressure vessel (Specimen designations beginning with “E”).

Bundle	Tailcone, Left Side F61-7†	EPF†	Left Wing Tip Zone 13†	Right Wing Tip†	ENL Zone 61	CTM Zone 51	ENL 2 Tailcone	IPF	UCL Zone 58	ECH-1-2	Zone 58 S-8, S-5	LCL Zone 58	Unlabeled Bundle	F-27	ECD	Tailcone	LCS Zone 57	ECH-1	RH Tailcone F61-7	ENS External	ICH 1 and 2
Events	>3	1	>4	>5	>19	>6	2	0	5	1	0	1	0	0	6	>9	0	>3	>18	0	>5

Table 4-4: Summary of Sandia Supplemental Inspection of the DC-9(2) Subject Aircraft

† Bundles sent to Boeing

Mandrel Bend Results: A total of ten wires were removed at random from sections of the aircraft. One section, ENL was cracked before the test, and another section Zone 14 RH WT failed the test at the 0.125” diameter level. The section LCS showed signs of possible cracking.

Solvent Swelling Results: At this point in time, not enough data has been collected to make any statements except that as a technique for studying these wires, solvent swelling shows potential, and warrants further investigation.

Density Results: An attempt was made to measure the density of the nylon jacket but because the fiberglass was bonded to it this proved impossible. The density results for this aircraft presented the same problems as the 747 aircraft.

Tensile Elongation Results: Tensile results display too much scatter for the force at break, and the percent elongation is not useful as most insulations broke immediately.

Raytheon Specimen Inspection: Most wire specimens were fairly clean although a few were contaminated with a dark grey to black greasy residue which discolored the glass braid significantly when the nylon top coat was damaged (ISTA, ECD-2 RH Wheel well, RH and LF tailcone samples). Bubbles were found along the outer surface of several of the specimens, sometimes small (Zone-14 F and Zone-58 G) and sometimes larger (CDT-E and CDT-F) which made the surface feel very rough, Figure 4-19. In some areas, the normally clear, outer insulation was opaque and the glass fibers underneath could not be distinguished (Zone-14 F and G). One specimen was kinked in two places (UCL-G), Figure 4-20, while another was badly pinched with black discoloration (Zone-14 F), Figure 4-21. Small nicks were present in the outer insulation (Zone-58 H, CTM-P and Q). Bluish-green spots on the insulation of one specimen (CTM-Q) that was nicked, coloring the glass braid underneath. Small abrasion and crack in the outer insulation of one specimen (UCL-H). A number of wires were badly damaged with yellowed and cracked outer nylon coating (RHWT-C, LH and RH tailcone, ISTA) and exposed conductor (LH and RH tailcone, ISTA).

Figure 4-19: DC-9-2, CDT-E (Nylon/Glass/PVC) bubbles in outer insulation

Figure 4-20: DC-9-2, UCL-G (Nylon/Glass/PVC) kink in wire specimen.

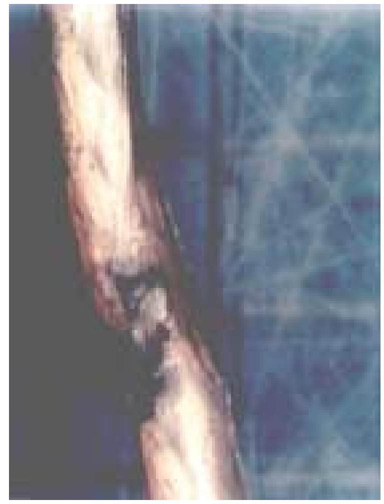

Figure 4-21: DC-9-2, Zone-14 F, (Nylon/Glass/PVC) pinched wire specimen.

Insulation Resistance: The insulation resistance values of the PVC/glass braid/nylon construction from the DC-9 (2) were generally lower than the other insulation types evaluated from the other aircraft. The values ranged from 1 to 330 MΩ/1000 feet. Some of this may be due to the tendency for the glass braid to wick up the electrolyte near the conductor. The results were quite variable. Dielectric failure occurred on a number of specimens (LH and RH tailcone, ISTA), especially when conductor was exposed or the insulation was in some way not able to fully protect the conductor. Specification requirements for new wire to this specification are in the 500MΩ/1000 feet range.

Wet Dielectric Withstand: A number of specimens failed the dielectric withstand proof test at 2500 volts. All failed samples exhibited cracked outer insulation or exposed conductor.

High Voltage Wet Dielectric Withstand: The wire specimens of this construction type are difficult to test to high voltages by this method due to the tendency for the braid to wick electrolyte solution up to the ends of the specimen. Several specimens maintained dielectric at 10,000 volts. Two specimens failed (Zone 58 H at 9600 volts, and CDT-F at 10000 volts after 35 seconds), while two additional specimens failed by arcing inside the insulation to the wet glass braid at 8400 (CTM-Q) and 9000 volts (Zone-14 H).

Conductor Resistance: This wire was constructed with copper alloy conductor. The conductors of two wire specimens exhibited conductor resistance that was slightly higher than the specification requirements (CTM-Q and LCS-D).

Notch Propagation: This test was not performed on the wire type submitted from this aircraft as it is not required. Additionally, the glass braid is not expected to be notched by the blade, and therefore would likely cause no greater damage than experienced in the wrap test.

Wrap: Wrap back procedure was used with oven aging at 95°C for 24 hours. Two specimens exhibited cracking in the outer nylon insulation following arcing (UCL-H and Zone-14 F). All specimens passed the dielectric withstand proof test. Samples with exposed conductor were not tested since they were cracked and had already failed the dielectric withstand voltage proof test.

Dynamic Cut-Through: Specimens tested at room temperature required 77 to >90 pounds force to cut through to the conductor. At elevated temperature (85°C), the specimens required 27 to 44 pounds force for cut-through.

Inherent Viscosity: This test is not applicable to non-polyimide based insulation constructions.

Lamination Sealing: This test was not performed on the wire from this aircraft. This test is designed for wrapped insulation constructions.
Crosslink Proof (Accelerated Aging): This test was not performed on the wire from this aircraft. This test is not applicable to the wire type submitted from this aircraft.
Lifecycle: Wire specimens from each specimen were conditioned for 120 hours at 120°C, then subjected to the bend and dielectric withstand proof test. No specimens cracked following the bend test, and all specimens passed the dielectric withstand proof test. Samples with exposed conductor were not tested since they had already failed the dielectric withstand voltage proof test.
Dry Arc Track Resistance: Unfortunately, this test requires a large quantity of wire that was not available for this test program on this aircraft. No specimens have been tested on the wire from this aircraft.
Wet Arc Track Resistance: Unfortunately, this test requires a large quantity of wire that was not available for this test program on this aircraft. No specimens have been tested on the wire from this aircraft.
Flammability: Specimens run (LCS, UCL, RH WT Zone 14) exhibited greater burning than other wire types, but no flaming drip occurred nor ignition of the facial tissue. Average after flame was 25 seconds, average total length of burn 5.3 inches. The worst specimen was UCL for which the after flame lasted 58 seconds and total burn length was 9.8 inches. Much thick, dark smoke was generated.

L1011

The Wire Insulation: Wire consists of a conductor with a wrapped polyimide tape insulation and a polyimide outer coat.[9]
Sandia Visual Inspection: Visually most of these wires appeared to be in the same condition, with the topcoat intact. Some wires were less than ideal. The two worst were CTM-2, where the majority of topcoat was missing, and RW LE (Figure 4-22) which had only fragments of the topcoat remaining. It should be noted that a second wire from CTM-2 showed no visual sign of the topcoat coming off or cracking. It should be noted that the polyimide taped insulation was still intact and only the topcoat was damaged.

Figure 4-22: An L1011 wire from section RW LE (polyimide). The topcoat (yellow layer) is flaking off, cracked, and missing in places, exposing the taped insulation.
Mandrel Bend Results: Twelve wire were examined via mandrel bend, and seven of them had topcoat either already cracked, or that cracked during the test. Wire topcoat from sections RW LE, and CTM-2 were cracked before the test. Wire topcoat from sections ENL, and LCS, and a second wire from CTM-2 cracked at the 0.125" diameter level.
For all cracks in all wires it appears that they only occurred on the outer topcoat layer, and not in the taped insulation. In all cases the conductor was not visible as it was still protected by the intact taped insulation layer.

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[9] Crum, B. and Sykes, P., personal communication, Lockheed Martin

Tensile Elongation Results: Similar to the A300 wires, the wires in this aircraft could not be stripped and thus no tensile data was obtained.

Specimen Inspection: Various wire types were present: mainly polyimide tape wrapped constructions to Lockheed specifications, but also including small quantities of polyimide tape wrapped wire with Airbus markings (UCL), MIL-W-22759/16 ethylene-tetrafluoroethylene insulated wire, and possibly polytetrafluoroethylene insulated wire. One non-environmental splice was present (PSU D), and one environmentally sealed splice was found in-line of one power feeder cable (IPF B.) The splice connected 2 gauge copper conductor to 0 gauge aluminum conductor. Some wire specimens were extremely dirty and sticky from fluid contamination (ENL, EPF). Wires from one specimen were covered with a black tacky substance (CTM and CTM-2). Small metallic particles were found in the dirt between the members of a twisted triple (ICH). The insulation of one specimen was blistered and contained deep hot stamp marks (LCL), Figure 4-23 and Figure 4-24.

Figure 4-23: L-1011, LCL-L (polyimide) blister along wire.

Figure 4-24: L-1011, LCL-L (polyimide) deep hot stamp marks.

Insulation Resistance: Results varied from values above 10,000 MΩ/1000 feet to 0 MΩ/1000 feet due to exposed conductor. The jackets were measured by shield to ground and tended to have lower insulation resistance than the insulation measured conductor to ground or conductor to shield. The results were highly variable. Dielectric failure occurred on a number of specimens, especially when conductor was exposed or the insulation was in some way not able to fully protect the conductor.

Wet Dielectric Withstand: A number of dielectric failures were found with this test method. Failures occurred in single wire specimens (CTM-2, ICH, LCL, and UCL) as well as in wire specimens and shields of twisted pairs and triples (CTM, ICH (3), RWTE). Of the two splices present, the environmental splice (IPF) maintained integrity, while the non-environmental splice (PSU) failed the dielectric test.

High Voltage Wet Dielectric Withstand: A few of the wire specimens exhibited dielectric failures before or at 10,000 volts after having passed at 2500 volts in the previous test (CTM-2 at

4000 volts, UCL at 8000 volts, and LCL at 10,000 volts after 50 seconds.) The LCL specimen failure occurred on a hot stamp mark.

Conductor Resistance: The conductors were of silver and nickel copper and copper alloy construction. The results show the conductor resistances to be generally within the range of the specified values for this wire construction, except for two which were slightly high (LCS-B and UCL-B.)

Notch Propagation: No notch propagation occurred. All specimens passed the wet dielectric withstand proof test.

Wrap: Specimens bent twice around a 6x mandrel. No oven conditioning took place. Two specimens exhibited cracking in the outer tape (LCS and CDT), but all specimens passed the voltage withstand proof test.

Dynamic Cut-Through: All specimens exhibited greater than 100 pounds of force to cut through to the conductor at room temperature and greater than 90 or 100 pounds of force at elevated temperature (85°C). The limits of the equipment were set at 90 pounds, then raised to 100 pounds partially through the testing to see if the limit was being reached.

Inherent Viscosity: Inherent viscosity measurements were taken on 12 insulation or jacket specimens. The measured values ranged from 0.5 to 1.0 (100 ml solvent/gm polyimide). It was assumed the wire constructions CTM-F, and ICH-J were similar to the SS polyimide construction.

Lamination Sealing: No separation of the layers was apparent following the thermal aging of 48 hours at 230°C for any of the specimens.

Crosslink Proof (Accelerated Aging): This test is not applicable to the polyimide wrapped wire type submitted from this aircraft.

Lifecycle: Wire specimens were conditioned 500 hours at 230°C, then subjected to the bend and dielectric voltage withstand proof test. All samples passed except one (CDT B). The insulation type on this failed wire is an extruded thermoplastic that is not expected to survive this thermal aging exposure.

Dry Arc Track Resistance: Unfortunately, this test requires a large quantity of wire that was not available for this test program on this aircraft. No specimens have been tested on the wire from this aircraft.

Wet Arc Track Resistance: Unfortunately, this test requires a large quantity of wire that was not available for this test program on this aircraft. No specimens have been tested on the wire from this aircraft.

Flammability: Specimens did not exhibit after flame, flaming drips or ignition of the facial tissue. Average total length of burn was 1.5 inches. Very little smoke was generated.

DC-10

The Wire Insulation: Wire coded BXS 7008-20 06090 corresponds to Raychem number '55A0811-20', which consists of an outer white layer, and an inner blue layer, both cross linked ethylene-tetrafluoroethylene co-polymer (X-ETFE) using a tin-coated copper conductor. This is similar to Military Specification Mil-W-22759/34.[10]

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[10] Zingheim, S., personal communication, Raychem Corp.

Sandia Visual Inspection: Visually all of these wires appear to be in the same condition. Some sections were dirty but all appeared to be in the same state, devoid of nicks, cuts or anything out of the ordinary.

DC-10 Supplemental Visual Inspection Summary: A supplemental inspection of the DC-10 wire identified several additional findings on several specimens. Appendix 4.1.2 documents these findings in detail. Table 4-5 summarizes these findings by specimen type.

Bundle	EE Bay	EE Bay F-11 Zone 110	EE Bay F-12 Zone 110	FRW EE Bay G2 Zone 110	Tailcone	CDT-1 Zone 210	Rt. Wing Leading Edge ECH	UCL-1 Zone 290	UCL-2 Zone 290	LCS-1 Zone 110	CTM-2 Aft Cargo	F-4 Zone 110	ENS-2 Zone 140	LCL Zone 110	CTM-1 Zone 130	ECD-1 Rt. Wing Trailing Edge	ECH-2 Tailcone	NO ID TAG	ECH/ECD	ENS-1 Tailcone†
Events	0	0	0	0	0	0	3	0	0	2	0	0	0	2	0	0	0	1	1	>1†

Table 4-5: Summary of Sandia Supplemental Inspection of the DC-10 Subject Aircraft.

† Specimen sent to Beoing

Mandrel Bend Results: Fifteen wires were removed at random from numerous sections of the aircraft. All 15 wires did not crack when tested.

Raytheon Specimen Inspection: One tape wrapped polyimide construction was submitted (LCS-1 specimen L) along with the XLETFE specimens. Many of the specimens were fairly clean. A few specimens had a black or yellow crusty material on the surface (UCL-1 Zone 290), while others were fairly dirty (ECD-1 Zone 640), and some were covered with a greenish black-yellow crusty sticky substance (CTM-1, CTM-2, and FWD EE Bay #1). Some specimens exhibited a black and bluish residue (Zone 110 F-11). Hot stamp marks do not appear to penetrate the first layer of insulation. Several of the wire specimens were nicked (Zone 290 UCL-1), kinked significantly (CTM-2), or had exposed shields (Zone 110 F-12, Zone 210 CDT-1).

Insulation Resistance: Most specimens were well over 10,000 MΩ/1000 feet, but two specimens were much lower, with insulation resistance measurements around 1000 MΩ/1000 feet (Zone 110 LCL-E and LCL-G) and near zero (CTM-2-B). Specimens with exposed shields were not tested as these would not be able to hold an electrical potential.

Wet Dielectric Withstand: Two wire specimens failed the wet dielectric withstand proof test (CTM-2-B which was badly kinked, and FW EE#1-D for which no physical damage was observed, although it was quite dirty).

High Voltage Wet Dielectric Withstand: One specimen failed the high voltage test before or at 10,000 volts (CDT-1-D at 7000 volts, CDT-1-D at 5000 volts to shield .).

Conductor Resistance: Several of the specimens submitted exhibited high conductor resistance readings compared to the maximum allowable values of the specification (F-12 F, G-2 B, G-2 J, LCS-1 F, CTM-1 B and CTM-2 B).

Notch Propagation: No notch propagation occurred. All specimens passed the wet dielectric withstand proof test.
Wrap: Wrapback procedure was used with oven aging at 200°C for 2 hours. No specimen exhibited cracking of the insulation, and all specimens passed the dielectric withstand proof test.
Dynamic Cut-Through: Cut through force required for the blade to contact the conductor varied from 26 to 28 pounds of force for 24 gauge wire and from 50 to 80 pounds of force for 20 gauge wire at room temperature. At elevated temperature (85°C), 14 to 17 pounds of forces were required for 24 gauge wire and 24 to 60 pounds of force for 20 gauge wire. The 24 gauge wires exhibited lower cut through values at both room temperature and elevated temperature. The polyimide wire required greater than 90 pounds of force both at room and elevated temperatures.
Inherent Viscosity: This test is not applicable to non-polyimide based insulation constructions. The one polyimide insulated wire exhibited inherent viscosity of 0.46 (100ml solvent/gm polyimide).
Lamination Sealing: This test is not applicable to non-wrapped insulation types. The lone polyimide specimen was aged 48 hours at 230°C, and no delamination was observed.
Crosslink Proof (Accelerated Aging): All specimens passed the dielectric withstand proof test following 7 hours of heat aging at 300°C and bend testing.
Lifecycle: Wire specimens from each specimen were conditioned for 168 hours at 200°C, then subjected to the bend and dielectric withstand proof test. No specimens cracked following the bend test, and all specimens passed the dielectric withstand proof test.
Dry Arc Track Resistance: Unfortunately, this test requires a large quantity of wire that was not available for this test program on this aircraft. No specimens have been tested on the wire from this aircraft.
Wet Arc Track Resistance: Unfortunately, this test requires a large quantity of wire that was not available for this test program on this aircraft. No specimens have been tested on the wire from this aircraft.
Flammability: None of the specimens run exhibited after flame flaming drips or ignition of the facial tissue. Average total length of burn was 2.0 inches. Medium amount of smoke was generated.

Summary

Several of the laboratory tests proved to be valuable to evaluate the wire specimens submitted. Screening tests such as insulation resistance and wet dielectric voltage withstand were instrumental in validating the visual findings and NDT results. Thermal aging tests, such as lifecycle, crosslink proof, and wrap were able to make some differentiation between the samples of an aircraft. Some of the wire was found to no longer meet the original requirements of the specifications, and although this would be expected to some degree due to degradation over time, it does not imply the level of performance in an application. Many wires exhibited exposed conductors and shields. These wires do not have electrical integrity, and present potential performance shortfalls.