Chapter 3: Non-Destructive Testing

After completion of the detailed visual inspection by the working group, on-board nondestructive testing (NDT) was performed on-site on selected wiring harness of all six aircraft.[1] The NDT tests, Lectromec's Deltest and Eclpyse's Automatic Test Equipment (ATE) insulation resistance and 2- and 4-wire tests, were specified and performed in accordance with the working group's intrusive inspection protocol (Appendix 1.2).

All data and statistics presented in this chapter are derived from only six aircraft. Though the statistics may suggest the possible presence of a phenomenon, they should not be considered indicative typical wire performance in any absolute or relative sense. These statistics are a starting point for analysis not its conclusion. Consolidated statistics (totals) assume some similarity across aircraft or specimen types. These statistics are indicative only to the extent that this assumption is true.

Lectromec NDT Testing

The first method of non-destructive testing used was the Lectromechanical (Lectromec) Design Company's DelTest™. In this test, voltage is applied to one end of a wire and the length of the wire is locally sprayed with tap water to facilitate current flow. A collection electrode is then passed on the outside of the wire harness to induce and measure any leakage current. The presence of leakage current is indicative of breached wire insulation, which may include cuts, cracks, non-environmentally sealed splices, abrasions, or breach at hot stamp area, within a particular zone and is usually accurate to within an inch of the breach. Once a breach was detected, Lectromec personnel red-flagged and photographed the area of concern so that the specific insulation breach could be pinpointed after the wiring harness was removed from the aircraft and taken to the Airworthiness Nondestructive Inspection Validation Center (AANC) for a more detailed inspection. The DelTest was applied to all six aircraft in this study and the summary results given in Table 3.1.7-1 of Appendix 3.1.7 on NDT testing results.

Eclypse NDT Testing

Eclypse International Corporation performed the second type of on-site non-destructive testing, but only on the A300, 747, and both DC-9 aircraft and on the same wiring specimens as tested by Lectromec. Eclypse personnel photographed the preselected wiring specimens prior to any cutting of the specimen to allow for connection to Eclypse's circuit analyzer set. When connection of the circuit analyzer interface to the wiring specimen was completed, the Self-Program mode of the analyzer was executed. This mode determines values for isolation, insulation, continuity, and the number of paths of each wiring harness.

Following the determination of the configuration, the analyzer then determines the conductor resistance values at three different constant current levels, 0.1, 0.5, and 0.8 amperes, using Four Wire Kelvin measurements. In addition, subsequent conductor resistance measurements were made at current levels of 1.0, 2.0, and 2.5 amperes using the two-wire method. The purpose of these measurements was to isolate conductors that exhibited significant differences in resistance values at the various loads. The variation of measurements may be indicative of several types of faults including broken conductors, corrosion at terminals or in the conductor at insulation breaches, loose terminations, cold solder joints, and improper crimps. For the two-wire testing, two wiring specimens from the DC-9 (2) tested higher than the expected 3.0 ohms and both of

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[1] The inspection team also recorded ground resistance measurements for many of the grounds in the inspected zones. The working group did not have the time or resources to analyze these measurements for this report.

these specimens had electrical components attached thus affecting the results. The four wire testing resulted in 7 individual measurements at over 0.3 ohms, three in the DC-9 (1) ENL1 wire specimen and four in the DC-9 (2) ENL wire specimen. The coloring and location of these wires indicate that they are probably thermocouple leads whose characteristics are consistent with the high resistance measurements.

The Eclypse circuit analyzer set also determined the insulation resistance of the wiring by utilizing high voltage (28, 115, and 500 volts DC) to test the dielectric strength of a conductor's insulation. When the measured resistance is less than or equal to the programmed limit, the analyzer initiates a scan algorithm to identify all the affected wires. Of the 65 wiring specimens tested, 2 exhibited anomalies during the insulation resistance testing. These were ECH2 (Exterior Complex Harness 2 taken from the wheel well) of the 747 and ECD (Exterior Conduit taken from the inboard trailing edge) of the second DC-9 (located in Miami). The Eclypse Transport Aircraft Intrusive Inspection Program Report in provided in Appendix 3.2.

Follow-on NDT Testing at AANC

Following non-destructive field testing and removal of preselected aircraft wiring specimens from the six aircraft, the wiring specimens were individually packaged and shipped to the AANC. The specimens that had undergone field non-destructive testing were set aside for re-test, as appropriate, by both Lectromec on all aircraft and by Eclypse.

The re-testing at the AANC had two purposes: (1) to determine if any changes had occurred to the wiring specimens after being removed from the aircraft and shipped to the AANC and (2) to pinpoint the exact location of insulation faults (including cuts, cracks, splices, abrasions, improper hot stamping, etc.) within a complex wire harness. At the AANC, it was possible to carefully disassemble each wire harness and mark the individual wires that contained insulation faults making it easier to identify the root cause of the fault. Those individual wires with faults were set aside for in-depth lab analysis as described in Chapter 4. The results of lab examination of the 47 breach indications found by Lectromec during the NDT testing of the six aircraft are summarized in Table 3-1 and illustrated in Figures 3-1 and 3-2. Detailed descriptions of each breach are given in the summary Lectromec report in Appendix 3.1.7. It should be noted that 3 additional breaches were observed on wire adjacent to previous breach indications.

TYPE OF BREACH	**A300**	**747**	**DC-9 (1)**	**DC-9 (2)**	**DC10**	**L1011**	**Totals**
Physical Breach	9	7	2	7	2	13	40
Breach at Hot Stamp Area	1	4	0	0	0	2	7
Total Length Wire Tested (ft)	7974	6706	4001	1986	4588	3594	28847
Total Breaches/1000 ft	1.25	1.64	0.50	3.53	0.44	4.17	1.63

Table 3-1: Lectromec Detailed Lab Findings on Breaches

Table 3-2 summarizes both the splices and cut-off wires found on the pre-selected wire specimens. Note that this table is incomplete because splices noticed visually during the field testing were assumed to be non-environmental, were not tested, and are not represented in the data. The table includes only hidden non-environmental splices discovered after disassembly of the bundle. Because there is no record of the total number of splices in any specimen, and because the original specification of the splice (i.e. environmental or not) is unknown, it is impossible to draw quantitative conclusions about the degradation of splices.

TYPE OF FINDING	A300	747	DC-9 (1)	DC-9 (2)	DC10	L1011	Totals
Splices[2]	4	1	1	0	0	1	7
Wire Cut Off	3	2	1	0	4	0	10
Totals	7	3	2	0	4	1	17

Table 3-2: Lectromec Detailed Lab Findings on Splices and Cut-Off Wires

Figures 3-3 and 3-4 show the specimen-, and wire-type-specific findings per thousand feet of wire inspected.

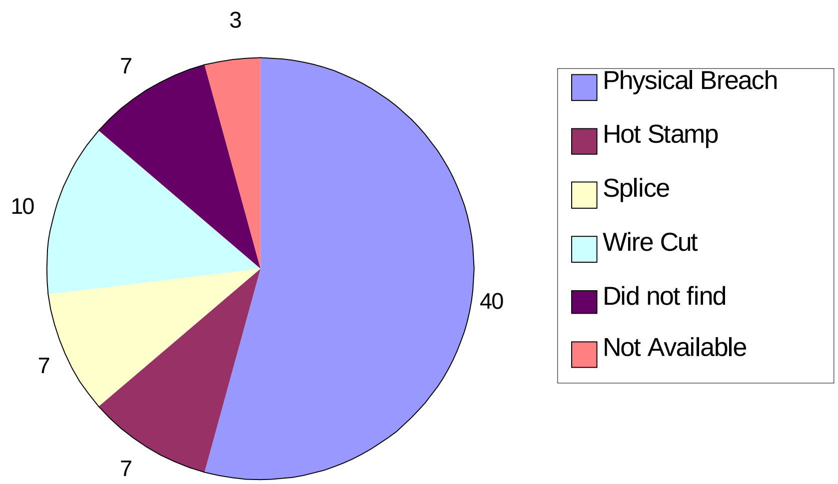

Figure 3-1: Deltest Results by Condition Category. Not all conditions identified here are faults.

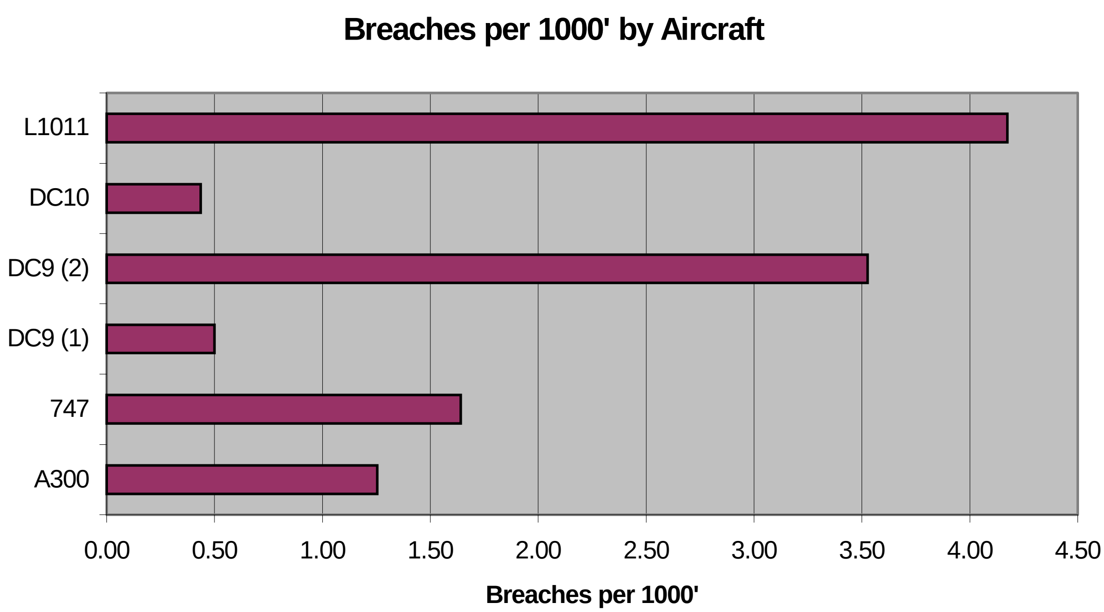

Figure 3-2: Aircraft Specific Findings per 1000 feet of wire

[2] Splice data is incomplete because wire bundles did not contain a uniform number of splices per foot and not all splices were tested.

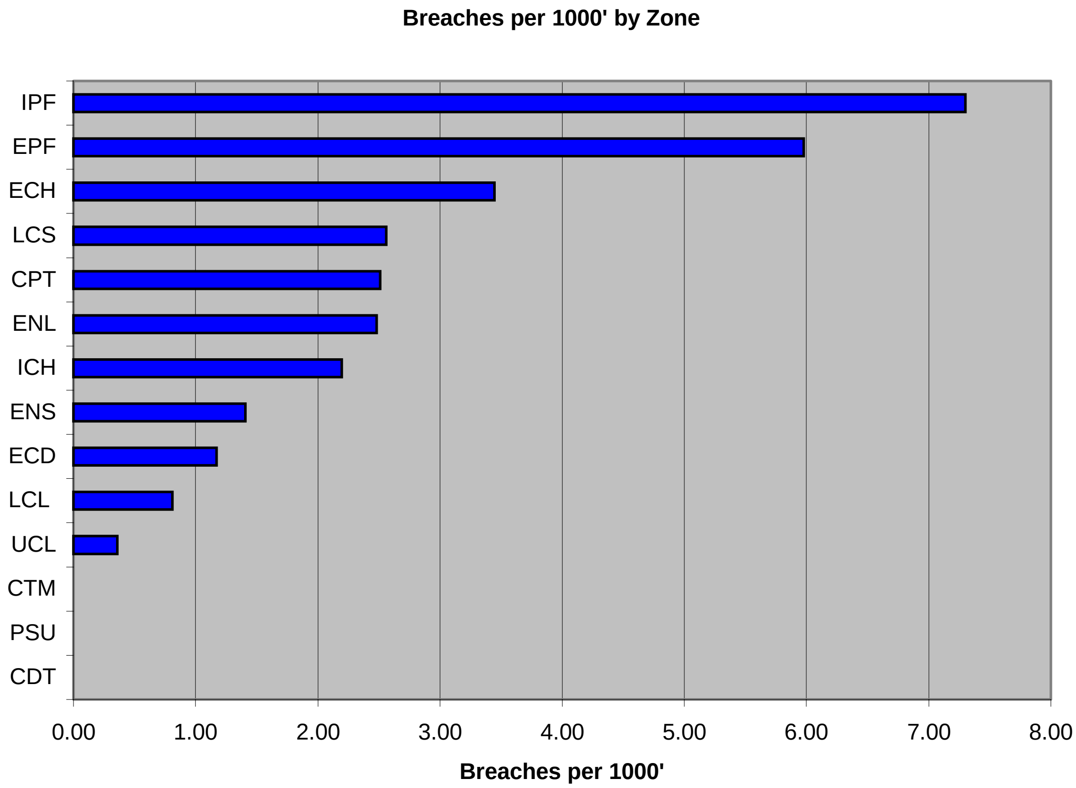

Figure 3-3: Specimen Specific Findings per 1000 feet of wire

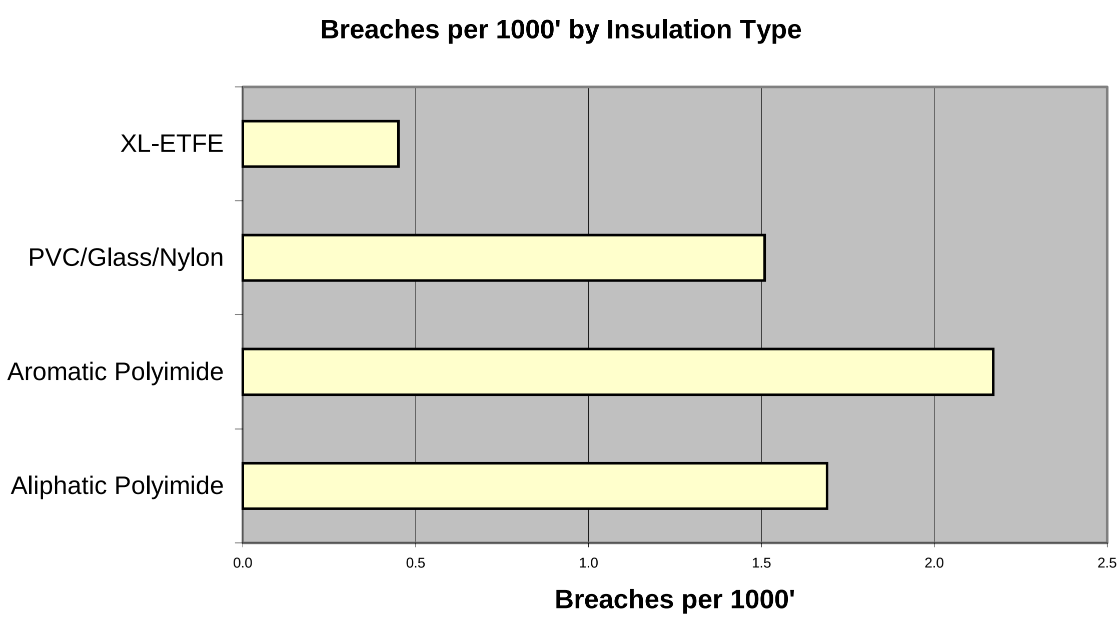

Figure 3-4: Wire-Type Specific Findings per 1000 feet of wire

Even though care was exercised to remove the wiring harness from each aircraft as they had been tested in-situ, in several instances there were configuration changes. Using the Eclypse Self-Program mode on its circuit analyzer set, there were 35 specimens from the A300, 747, and the two DC-9 aircraft that had a significant change in configuration between field testing and lab testing. The two primary causes of wiring harness configuration change were due to terminal blocks attached to the aircraft structure were not removed with the wiring harness or else the branches of a complex harness were cut at the field in order to remove the desired wiring harness from the aircraft. Because of these dramatic changes, it was impossible to replicate the results of some of Eclypse's testing between the field and the AANC sites.

Eclypse Flaw-finding test results are summarized in Table 3-3. These results are discussed more thoroughly in Appendix 3.2.

A/C	Damage†	Conductor Integrity‡		Insulation Resistance‡	Grounds‡		Mosture‡	
		2 Wire	4 Wire		Resistance To Ground	Isolation From Ground	Dry	Wet
A300	0/19	0/583	0/583	0/583	0/0	0/583	0/0	0/0
DC-9(1)	0/13	0/542	3/542	0/542	9/25	53/517	0/0	0/0
747	0/18	0/485	0/485	7/485	11/15	1/470	0/114	11/114
DC–9(2)	0/15	0/311	4/311	4/311	11/30	2/281	0/84	18/84
TOTAL	0/65	0/1921	7/1921	11/1921	31/70	56/1851	0/198	29/198

Figure 3-7 Eclypse Summary Results

†Number of Findings / Number of Specimens Tested

‡Number of Findings / Number of Wires Tested

The moisture testing consisted of re-installing the wire specimens on Eclypse's circuit analyzer set testing the dry samples and then spraying water onto the specimens. This was performed because of the variation of the results between the field and the re-test at the AANC. All six specimens passed when tested dry. Three specimens passed when first wet, that is, the insulation resistance was found to be within the limits of the wire. The specimens that passed were CTM from the DC-9 (2) and LCS and UCL2 from the 747. Three specimens failed when wet – ENL and ISTA from the DC-9 (2) and ECD1 from the 747. Note that both the ENL and ISTA specimens from the DC-9 (2) also had breaches found using the Lectromec DelTest™. The influence of moisture on the susceptible wire, and its dependence upon the ambient conditions is illustrated in Figure 3-5 below.

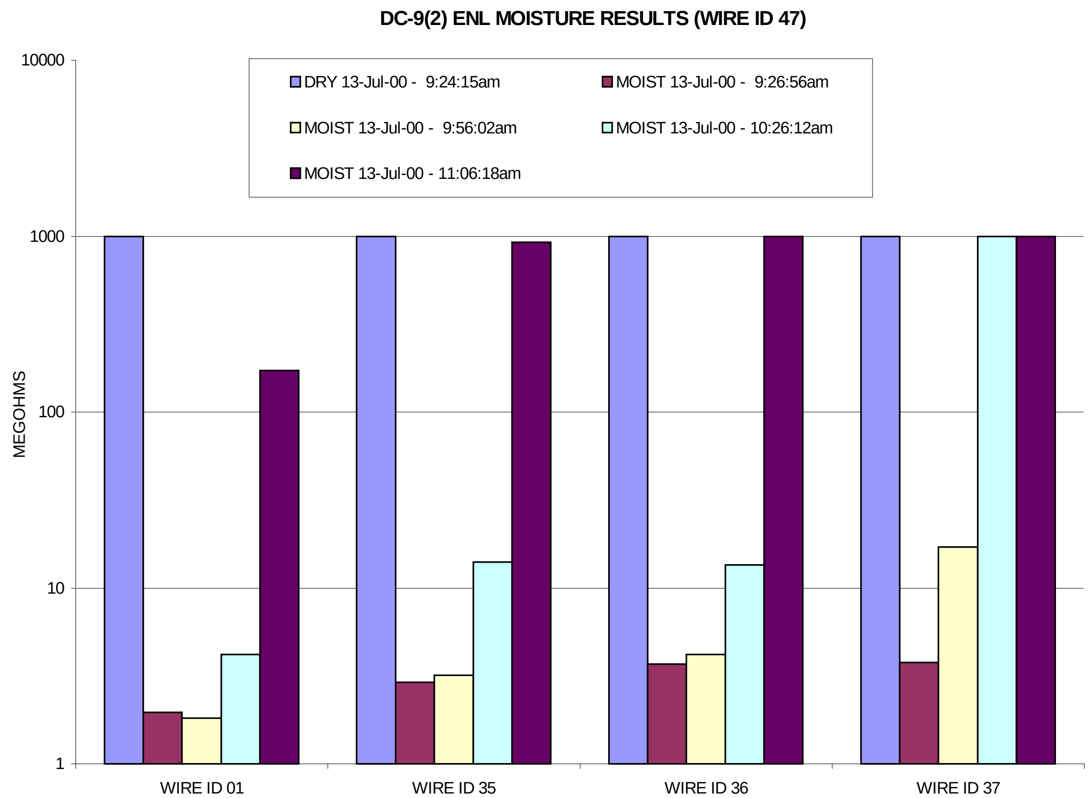

Figure 3-5: Insulation resistance dependence on dry-wet-dry cycling of wires.

Validation of NDT findings by Raytheon

Specimens of wiring that had insulation resistance anomalies discovered by the Insulation Resistance testing by Eclypse and the Lectromec Del Test, were selected and sent to Raytheon Indianapolis's test laboratory. The purpose was to validate the in situ insulation breaches or low insulation resistance readings with the well established laboratory insulation resistance and wet dielectric voltage withstand tests. The Raytheon laboratory testing largely validated the faults found by the NDT electrical tests (see Appendix 3.3).