

Appendix 3.2: Eclipse Final Report

Introduction

Eclipse International Corporation's Automated Test Equipment (ATE) utilizes DC circuit analysis techniques to characterize the insulation and conductor integrity of individual wires in cable assemblies found on aircraft. These testing techniques combined with the speed of ATE can quickly determine the overall condition of individual wires within a bundle. However, when a condition is identified as less than desired, DC testing is capable of discriminating the individual wire, but not the location(s) where the abnormal condition exists.

Eclipse International participated in the Intrusive Inspection Working Group approved Non-Destructive Test protocol on four aircraft. Specifically two DC-9's, one 747, and one A300 were tested *in situ* and retested in the laboratories at the FAA / AANC Validation Center in New Mexico. The specimens consisted of sixty-five partial cable assemblies identified by the working group inspection teams prior to NDT activities.

Summary of Findings

The 65 specimens produced a total of 1921 wires that were tested under *in-situ* conditions and in the laboratory after removal from the airframe. Table 3.2-1 presents the summary of tests conducted and the associated result.

A/C	Damage ¹	Conductor Integrity ²		Insulation Resistance ²	Grounds ²		Moisture ²	
		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

Table 3.2-1 Summary of Findings

¹ Number of Findings / Number of Specimens Tested

² Number of Findings / Number of Wires Tested

The primary findings are: 1) there was no evidence of damage to the specimens as a result of removal from the aircraft, 2) the overall integrity of the conductors was good, 3) the insulation resistance anomalies were primarily present in specimens located exterior to the pressure vessel, 4) moisture influence on external specimens was rapid and resulted in a high level of insulation resistance degradation.

Configuration

The measurement data indicates that the decommissioning of the specimens had no deleterious effect on the wire bundles or individual wires contained in the specimens collected. This observation is supported by the detailed measurements that demonstrate there was no significant change in conductor resistance values and insulation resistance values generally improved from the *in situ* to laboratory tests (see Section titled Moisture below). However, several specimens exhibited changes in configuration when they reached the laboratory that were the result one or more of the following items that do not affect test results.

- Additional conductors were cut during the specimen removal processes that eliminated continuity paths tested *in situ*.
- The weight of the test interface and the specimen occasionally caused test clips to become detached from specimen prior to test execution.
- The ID Tags for each individual wire could be accidentally lost in the removal, shipping, or other NDT activities, thereby making reconnection at the laboratory difficult to repeat.

Conductor Integrity Tests

Conductor integrity tests were performed using the constant current source and the measurement bridges within the Eclipse Model 501 Circuit Analyzer. In this test, leads were connected to each end of all the wires in a specimen and resistance measurements were taken using the methods described below.

Two-Wire Resistance Results: A two-wire resistance test refers to the use of the standard measurement bridge in the Eclipse analyzer that is primarily used to measure resistances above 1.0 ohm and less than 100 Kohm. This method requires a single connection being made to each end of a wire in a specimen. Two-wire tests were used during the NDT protocol to capture resistance measurements higher than the operational range of the four-wire method and to test wires at constant current stimulus levels higher than the four-wire measurement capabilities. The two-wire test provides higher current levels however it is not as accurate as a four-wire test and does not automatically compensate for resistances existing within the test interface and the internal components of the analyzer. Therefore, additional resistance allowances are made when analyzing data recorded with this method. The typical internal resistance of an Eclipse analyzer is between 1.2 to 1.4 ohms and the test interface cables add another 1.1 ohms. These resistances will add an average of 2.4 ohms to each two-wire resistance measurement. Conductors tested with this method per the NDT protocol were expected to be less than 3.0 ohms.

The two-wire test results indicate that the specimen's conductors are in good condition since only two (2) wires measured over 3.0 ohms of the 1921 wires tested both on the aircraft and in the laboratory. Subsequent evaluation of those two wires, (W47 and W61) of the DC-9(2) ECH1 specimen, determined that these values were the result of components to which they were connected.

Four-Wire Kelvin Resistance Results: A four-wire Kelvin resistance test refers to the use of the precision measurement bridge in the Eclipse analyzer that is primarily used to measure resistances between 0.01 to 9.99 ohms. This method requires two connections being made at each end of a wire in a specimen. With measurement accuracy within 1 percent and the ability to automatically compensate for resistances generated by the analyzer and test interface, measurements recorded with this method can be used to detect smaller flaws in conductors. NDT specimen testing was performed without prior knowledge of conductor type, length, or gauge. Therefore, analysis of data collected with this method was based largely on characteristics of the smallest gauge tested. Common wire specifications (MIL STDS, NBS Handbook 100, etc.) list 24 gauge, 19 strand copper wire as having as much as 19 milliohms per foot. A specimen of 10 feet in length could have 0.19 ohms of resistance. In addition to the raw conductor resistance, the connection made between the test lead and the specimen conductor and can be as high as 50 milliohms per side. Based on these values, conductors tested with this method under the NDT protocol should be less than 0.3 ohms.

The four-wire Kelvin measurement data corroborates the two-wire test results by indicating overall good conductor integrity. After initial review of the test data, there were 287 wires of the 1921 wires tested both on aircraft and in the laboratory that measured over 0.3 ohms. Additional investigation was performed on the wires that were still available in the laboratory to determine actual conductor gauge, length, and material type. Of the wires with greater than 0.3 ohms, 280 are categorized as within tolerance range based on actual gauge and length. The remaining seven (7) wires are

suspected to be thermocouple wiring, and when confirmed to be that type they would most likely be categorized as within normal tolerance range. Specifically these wires are from the DC-9(1) ENL1 (W44, W46, W50) and the DC-9(2) ENL (W24, W37, W51, W52).

Insulation Resistance Tests

Insulation integrity tests were performed using the high voltage power source of the Eclipse Model 501 Circuit Analyzer. Measurements were taken by connecting test leads to each end of all wires in a specimen then applying a fixed voltage stimulus and measuring the voltage resulting from the leakage current between a specific wire and adjacent wires using the methods described below.

Insulation Resistance Results: An insulation resistance test (also known as IR testing) refers to the use of the insulation measurement bridge in the Eclipse analyzer that is primarily used to measure resistances over 100,000 ohms. Several military standards and other specifications were reviewed to establish a threshold for identifying anomalies in the insulation of the specimens. The selected value of 100 Megohms was the lowest of the possible values from these standards thus providing the specimens with the most favorable opportunity to avoid exhibiting anomalies. Two specimens exhibited insulation resistance anomalies that were detected *in situ* and in the subsequent laboratory tests.

The 747 ECH2 specimen exhibited low insulation resistance in seven wires:

Specifically wire ID's 03,04, 05 and 08, 09, 10, 11 consistently fall below the 100-megohm threshold for isolation.

The DC-9(2) ECD specimen exhibited low insulation resistance in four wires:

Specifically wire ID's 08, 10, 14, and 39 consistently fall below the 100-megohm threshold for isolation.

The underlying causes of the low insulation resistance measurements include insulation breaches, cracks, abrasion, cuts, chemical degradation, and environmental exposure (thermal, moisture, etc.)

Note that both insulation anomalies 747 ECH2 and DC-9(2) occurred in external cable assemblies which are subject to exposure to the exterior environment conditions.

Additional insulation test results are presented in the section, *Insulation resistance to ground anomalies*. That section presents the test results for the integrity of the conductor isolation from ground.

Ground circuits

In accordance with the Eclipse *in situ* test protocol the aircraft structure was used as the point of connection for the reference ground clip. Subsequent to *in situ* testing, the specimens were removed from the structure for shipment to the laboratory and therefore the *in situ* data is the only data source available for the detection of anomalies to ground.

Each specimen consists of two categories of wire paths, those that are identified as connected to ground and those that are isolated from ground.

Conductor resistance to ground anomalies: The test results for conductors identified as connected to ground were examined to establish the integrity of the conductor and its connection to structure. Several specimens exhibited characteristics consistent with conductor breakage, loose connections, corrosion, poor termination, and poor bonding. Tables 3.2-2 through 3.2-4 present the summary of wires with high resistance to the aircraft structure.

Aircraft	Specimen	Ground ID	Wire ID's with high resistance to aircraft structure
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747	UCL4	W38	W13
747	ENS1	W128	W125
747	ENL1	W100	W87
747	ECD2	W34	W137, W145, W163, W167, W169, W179, W181, W257

Table 3.2-2, 747 Ground connection integrity

Aircraft	Specimen	Ground ID	Wire ID's with high resistance to aircraft structure
DC-9(1)	ICH1	W207	789
DC-9(1)	ECD2	W48	W28, W45
DC-9(1)	ENL1	W65	W377
DC-9(1)	ENS1	W18	W131, W155, W157, W163, W173

Table 3.2-3, DC-9(1) Ground connection integrity

Aircraft	Specimen	Ground ID	Wire ID's with high resistance to aircraft structure
DC-9(2)	ICH	W21	W11, W16, W82, W89, W107, W110
DC-9(2)	ENL	W54	W25, W75, W47
DC-9(2)	ECH1	W61	W104
DC-9(2)	ENS	W7	W3

Table 3.2-4, DC-9(2) Ground connection integrity

Insulation resistance to ground anomalies: The second category of wires consists of those not intended to be connected to ground. The test results for conductors identified as not connected to ground were examined to establish the integrity of the insulation in isolating the conductor from the aircraft structure. The less than 100M ohms criteria was applied to identify the individual wires exhibiting isolation anomalies. Table 3.2-5 presents the summary results.

Aircraft	Specimen	Ground Wire ID	Wire ID's with less than 100M-ohm isolation
DC-9(2)	ECH2	W07	W02 and W03
747	UCL4	W38	W02
DC-9(1)	ENL1	W65	W01, 02,03,04,06,07,08,09,10
DC-9(1)	ICH1	W207	W1 Thru W32 And W34 Thru W45

Table 3.2-5 Summary of Isolation from ground anomalies

Moisture

In the course of analyzing the measurements resulting from the Eclipse *in situ* and laboratory tests it was detected that the insulation resistance measurements generally tended to be lower in the field than in the laboratory. A review of the protocol data sheets that were completed to record the environmental conditions existing at the point of testing resulted in identifying the following conditions. Some specimens were noted as being wet, other tests were performed during rainy weather or after rain, and some of the Eclipse *in situ* tests occasionally followed the DelTest. However the data sheets do not provide sufficient information to conclude the environments noted caused the lower measurement results.

Eclipse selected six specimens that were available in the AANC laboratory and had not been subjected to any destructive laboratory testing. At the time of this selection all of the A300 and DC-9(1) specimens of interest were the subjects of destructive test at either Sandia or Raytheon. Therefore the 747 and DC-9(2) represented the available

specimen pool from which to select. The specimens selected were the 747 LCS, UCL2, ECD1 and the DC9-2 (Miami) CTM, ENL, and ISTA. These specimens were subjected to non-destructive tests to collect conclusive data related to the effect of moisture on their insulation resistance characteristics.

The specimens were initially tested dry to obtain a baseline then spray bottles were used to apply water and the items were retested several times over periods of time ranging from several minutes to overnight with no additional moisture applied.

Results of the testing of these six specimens was as follows:

- All specimens passed the dry testing with no anomalies measured.
- The DC-9(2) CTM, 747 LCS, and 747 UCL2 performed satisfactorily after the exposure to moisture
- The DC-9(2) ENL, DC9-32 ISTA, 747 ECD1 exhibited anomalies and the specific wires with anomalies are presented in Table 2.5-6.

Aircraft	Specimen	Wire ID's with Insulation resistance anomalies
DC-9(2)	ENL	W1, W4, W6, W7, W10, W11, W13, W19, W22, W26, W27, W33, W35, W36, W37, W47
747	ECD1	W1, W3, W7, W8, W10, W24, W43, W48, W51, W54, W57
DC-9(2)	ISTA	W5, W9

Table 3.2-6 Moisture Test Insulation Resistance anomalies

The three specimens in Table 3.2-1 exhibited rapid and large insulation resistance value changes when exposed to moisture. All three specimens exhibited the same basic pattern with respect to reaction time and insulation resistance value change. Figure 3.2-1 presents the insulation values measured and the time of measurement for the DC9-2 ENL specimen wire ID 47 when dry and moist. Wire ID 47 is a single conductor as are 35, 36, and 37 whereas 01 is a shield. The values are insulation resistance measurements made from wire ID 47 to each of the wire ID's of 01, 35, 36, 37. When the specimen was dry all measurements were at 1000 megohms, which is well above the 100-megohm minimum selected for anomalies. Upon the completion of the dry test run (9:24am) the moisture spray was applied and at 9:26am the initial moist specimen test run was completed, and subsequent test runs were completed at 9:56am, 10:26am and 11:06am without additional moisture applied. Referencing Figure 3.2-1 the very rapid and large decrease in insulation resistance is readily seen and also the slow recovery. The decrease in resistance occurred immediately while recovery to the 100-megohm level was over one hour for all of the subject wires.

It should also be noted that ALL anomalies identified were in external cable assemblies thus correlating with the findings of the insulation resistance tests described above.

Specific wires from each of these specimens were provided to Raytheon for destructive testing and subsequent correlation to the Eclipse test results.

Suspect Specimens: The results of the moisture tests precipitated a review of all *in-situ* measurement results that were very low compared to laboratory testing to determine the potential influence moisture may have had on these measurements. The *in-situ* data was examined to find measurement patterns that resemble the measurement patterns detected during moisture testing in the laboratory, that is, very low initial readings with a gradual increase in subsequent test runs (see Figure 3.2-1). After candidates were identified, the *in-situ* protocol checklists and pretest photographs were reviewed to find corroborating evidence of the presence of

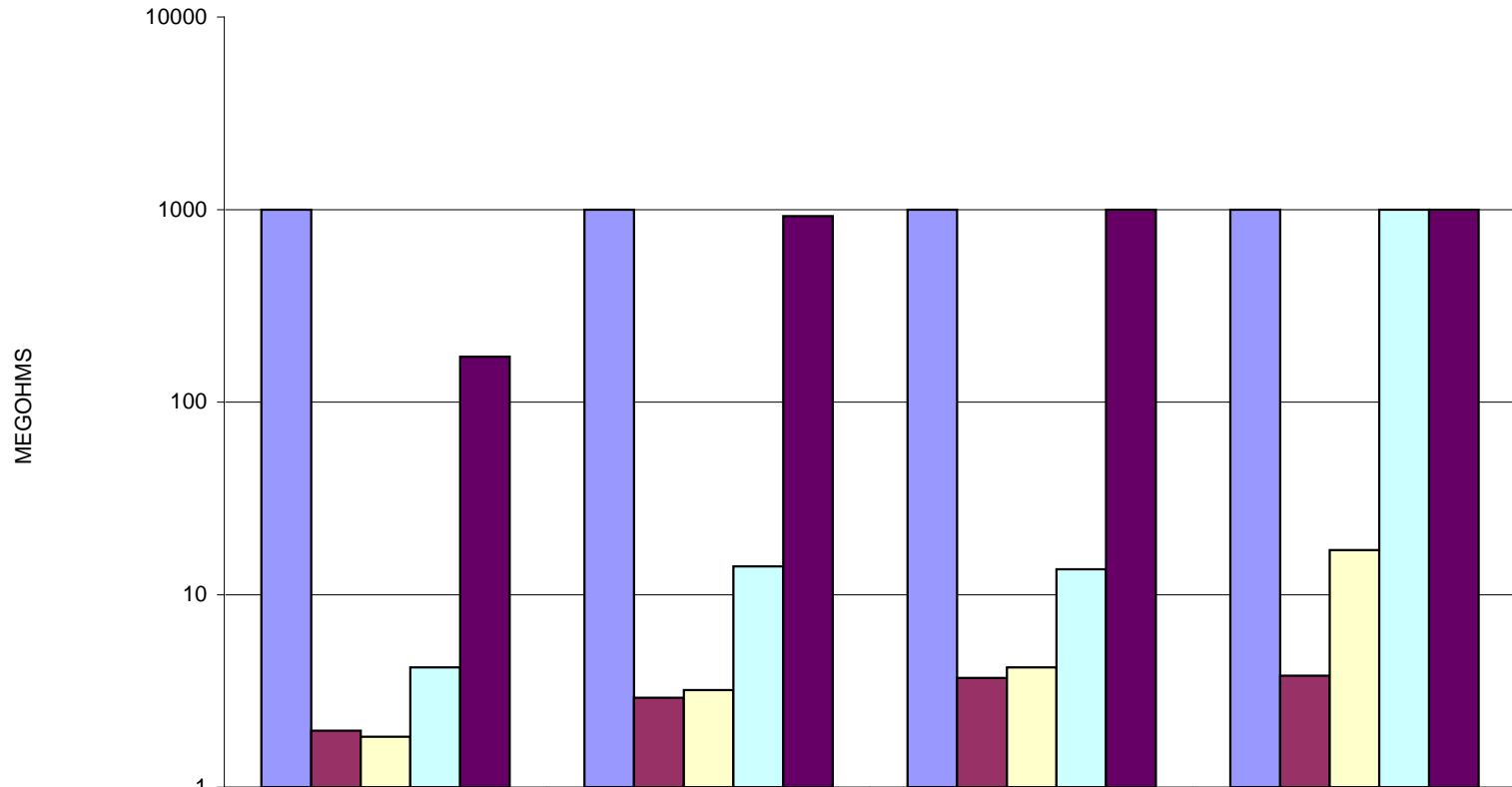
moisture. The result of the review indicates that the specimens presented in Table 3.2-7 may be susceptible to moisture.

Aircraft	Specimen	Wire ID's with Insulation resistance anomalies
A300	ECD2	W8, W10
DC-9(1)	ECD2	W1, W2, W18
DC-9(1)	CPT4	W1, W2, W3, W4
DC-9(2)	ECH1	W8, W15, W26, W31, W34, W35, W36, W47
DC-9(2)	ENS	W2, W3
DC-9(2)	EPF	W1, W2, W3

Table 3.2-7 Specimens indicating moisture susceptibility

The external bundles again contained most of the insulation resistance anomalies related to moisture and these are the bundles that are, in their normal aircraft installation, subjected to wet or moist environmental conditions.

DC-9(2) ENL MOISTURE RESULTS (WIRE ID 47)



	WIRE ID 01	WIRE ID 35	WIRE ID 36	WIRE ID 37
■ DRY 13-Jul-00 - 9:24:15am	1000	1000	1000	1000
■ MOIST 13-Jul-00 - 9:26:56am	1.962	2.916	3.684	3.787
■ MOIST 13-Jul-00 - 9:56:02am	1.826	3.188	4.185	17.06
■ MOIST 13-Jul-00 - 10:26:12am	4.196	14.02	13.53	1000
■ MOIST 13-Jul-00 - 11:06:18am	171.8	925.3	1000	1000

Figur

e 3.2-1 DC9-2 ENL Moisture Test Results for Wire ID