Handout 5

Intrusive Inspection Project
Report to ATSRAC

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Intrusive Inspection Working Group

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Eclypse	Alan Ferguson, Kevin Steidel
Wire Producers	Raychem, Alcatel, Tensolite
Airframers	Boeing (several), Airbus (several)
Operators	Northwest, United, FedEx, DHL, SwissAir
Government	FAA, NTSB, Transport Canada
ATSRAC	several

Premise and Objectives

Premise

- By their nature, ASTF's non-intrusive inspections were unable to collect certain data necessary to fully assess the state of wire in aged aircraft. In particular, a detailed assessment of wire-specific, degenerative flaws was beyond the scope of that project.

Objectives of the Intrusive Project

- To assess the state of wire in aged aircraft.
- To assess the adequacy of visual inspection.

Overview

- Rigorous protocol addressing 14 characteristic locations across several aircraft types. (Where possible locations correspond with non-intrusive inspection protocol.)
- Enhanced inspections to assess insulation electrical properties, insulation mechanical properties, other degradation related parameters.

Specimen Types

- Interior and Exterior of Pressure Vessel
- Bilge and Crown Areas
- High/Low Maintenance Locations and Installations
- Bundles Exposed and In Conduit
- Straight Runs and Complex Harnesses
- Small and Large Bundles
- Small Gage and Large Gage Wire (Power Feeders)

Aircraft Information

All six aircraft have been subject to the detailed visual inspection and on-aircraft nondestructive testing:

Aircraft	A300	DC-9	747	DC-9	L1011	MD-10
Inspection	9/99	11/99	1/00	5/22/00	6/12/00	6/25/00
Year Mfr	1978	1967	1973	1971	1972	1979
Hours	40,000	75,000	100,000	66,800	63,600	61,300
Retired	7/99	8/99	5/99	12/99	6/99	5/00*
Wire	PI	P/G/N	PolyX	P/G/N	PI	XL-ETFE

*** Aircraft temporarily decommissioned**

Visual Inspection Results

There were 4 finds that the group considered worthy of formal manufacturer follow-up:

- 747: White feeder cable worn to conductor and riding on copper feeder cable (in good condition).
- DC-9(2): Blackening and severe embrittlement of wires leading to wing tip lighting at both wing tips. There was some speculation that this might be due to wing-tip light modifications which resulted in higher electrical loads than design would tolerate.
- DC-9(2): Severe embrittlement and failure of plastic bundle ties in the vicinity of the internal fluorescent lighting. This failure was not noted in other locations on the aircraft.
- DC-9(2): Burnt wire beneath spiral wrap in aft tail cone on corresponding wire bundles on either side of the aft stair. (Inspectors generally characterized wire in this zone as "very tired", probably as a result of excessive and prolonged exposure to heat.) There was no evidence of the burn on the spiral wrap leading us to believe that failure was internally generated (e.g. an intermittent short between wires).

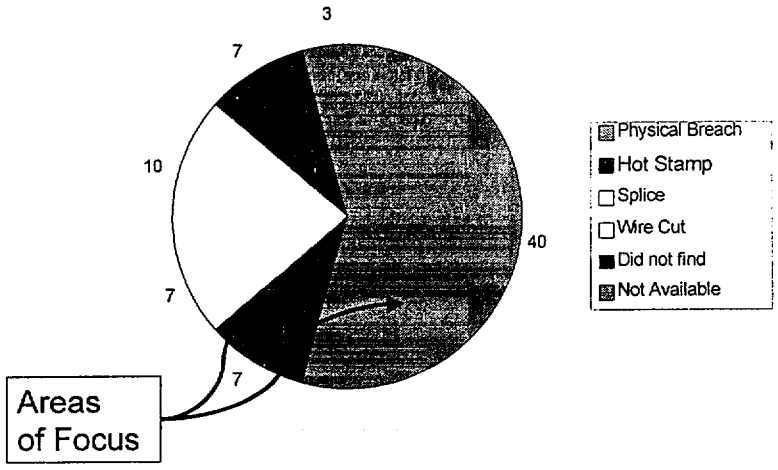
Intrusive/Non-Intrusive Comparison

Intrusive Inspection Finding Categories - Wire	Non-Intrusive Finding Categories - Wire
Inadequate Repair	Previous Repairs, Condition of
Degraded Repair	
Heat Damage	Heat/Vibration Damage
Vibration Damage	
Collateral Damage	Indirect Damage
Cracked Insulation	Cracked/Abraded Insulation
Non-traumatic Abrasion	
Traumatic Damage	
Broken Shield	Broken Shield/Conductor
Broken Conductor	
Exposed Shield	Exposed Shield/Conductor
Exposed Conductor	
Fluid or Chemical Contamination	Fluid or Chemical Contamination
Wire Corrosion	Wire Corrosion
Arcing	Other Wire Conditions
Other Wire Conditions	

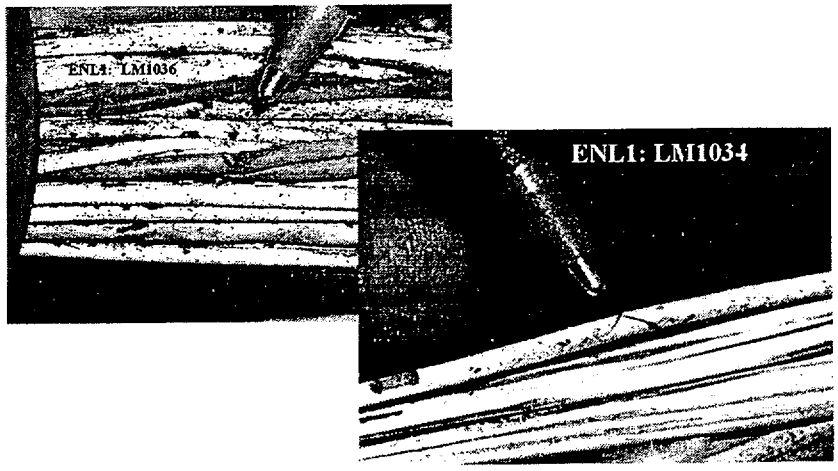
Visual Findings By Aircraft

	Inadequate Repair	Degraded Repair	Heat Damage	Arcing	Vibration Damage	Collateral Damage	Cracked Insulation	Abraded Insulation	Traumatic Damge	Broken Shield	Broken Conductor	Exposed Shield	Exposed Conductor	Fluid or Chemical Contamination	Wire Corrosion	Other Wire Condition
A300-1	4	0	0	0	0	0	1	3	1	0	1	0	1	10	0	7
DC-9-1	1	1	1	0	4	1	18	12	1	0	1	1	2	7	3	0
747-1	2	2	0	1	3	2	12	6	3	1	1	2	4	9	0	0
DC-9-2	5	0	14	1	4	2	26	18	4	0	2	0	9	4	0	4
DC-10	1	0	0	0	0	1	0	5	0	2	0	0	0	9	0	2
L1011	6	1	0	0	0	0	6	3	2	1	0	1	4	14	0	7
Totals	19	4	15	2	11	6	63	47	11	4	5	4	20	53	3	20
Significant	12	2	15	2	10	6	48	41	9	1	4	2	20	31	2	5
Totals Pre-selected	4	0	7	0	4	1	19	6	1	0	0	1	5	6	0	2
Pre-selected Significant	2	0	7	0	3	1	16	6	1	0	0	1	5	2	0	1

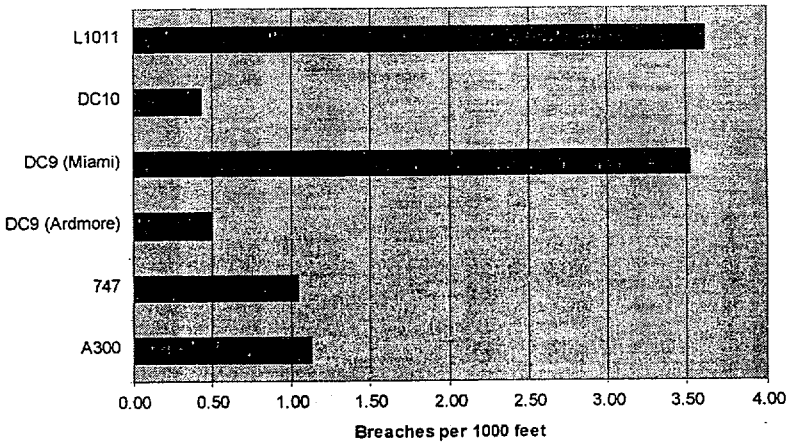
DelTest Results By Finding Type



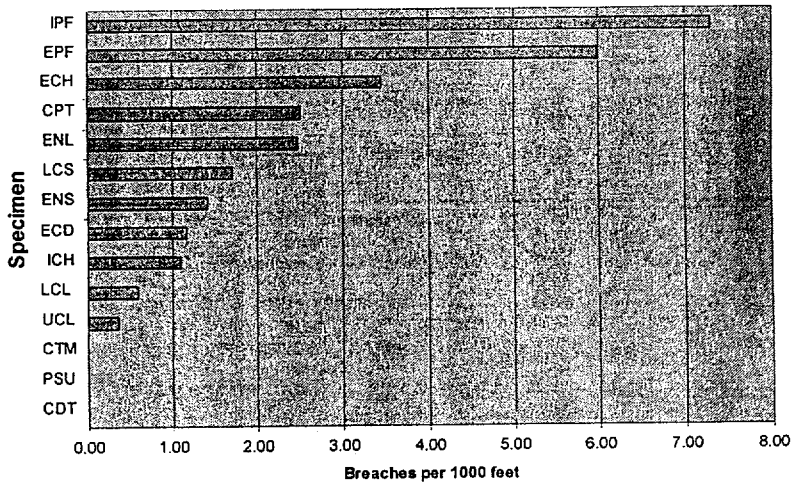
Typical Lectromec Findings



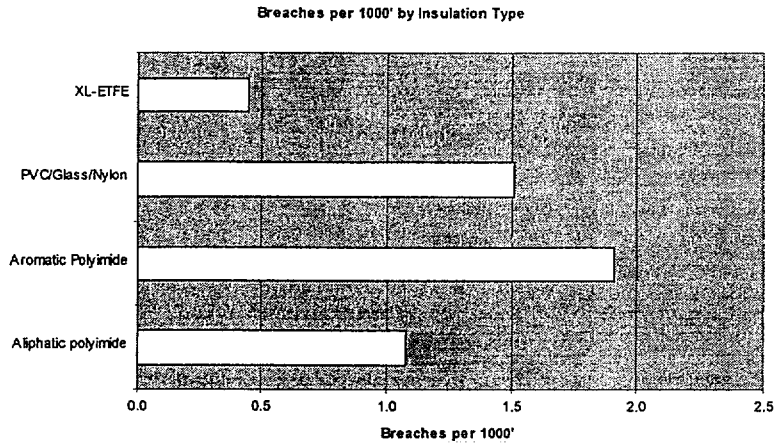
Deltest Results by Aircraft



Deltest Results by Specimen Type



Deltest Results by Wire Type



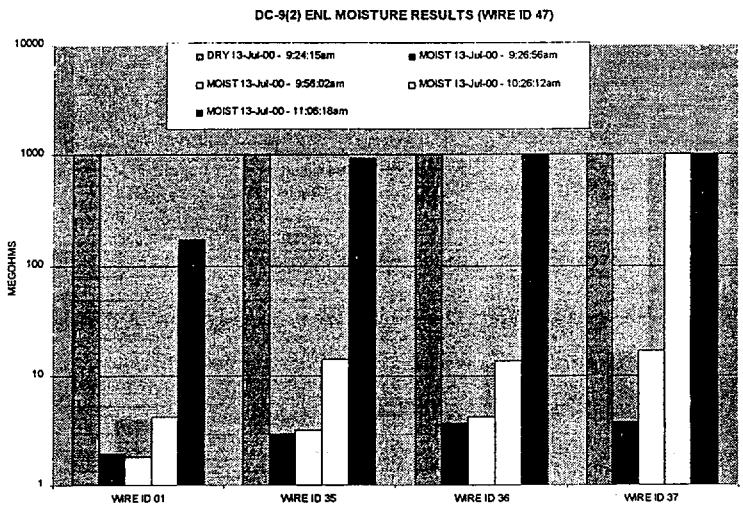
Eclype Results

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

†Number of Findings / Number of Specimens Tested

‡Number of Findings / Number of Wires Tested

Eclypse Moisture Test Results



NDT Observations

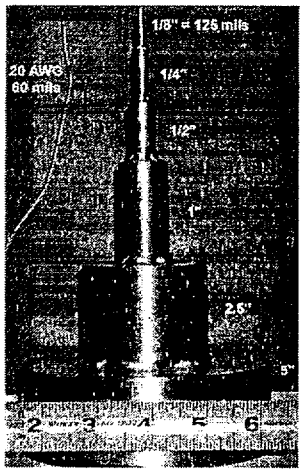
- Deltest is simple, objective, and accurate (but limited to breached insulation).
- Eclypse testing is subjective but potentially indicative of failure precursors.
- Eclypse testing requires
  - Detailed knowledge of installation
  - Baseline for comparison
  - Sophisticated interpretation of results

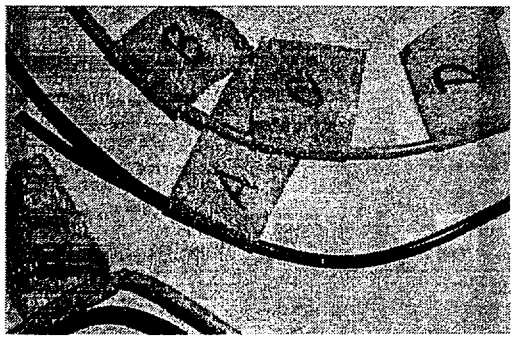
Laboratory Testing

Sandia National Labs	Raytheon
Optical Microscopy	Optical Inspection
Mandrel Bend screening	Wrap Test
Density Measurements	Wet Dielectric – Voltage Withstand
Modulus Profiling	Conductor Resistance
Insulation Tensile S And E	Insulation Resistance
Solvent Swelling	Inherent Viscosity Test
Infrared Spectroscopy	Dynamic Cut-Through, Notch Propagation
	Lamination Sealing
	Cross Link Proof Test, Life-cycle
	Dry/Wet Arc Tracking
	Flammability

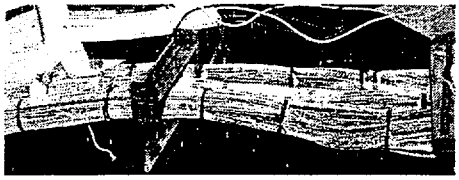
USAF Wright Labs will be doing some additional X-ray testing of connectors

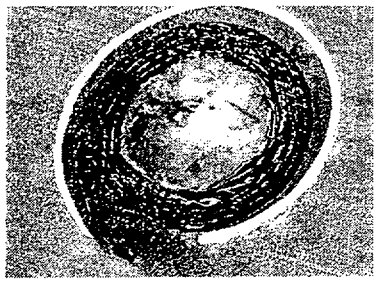
Mandrel Bend Testing



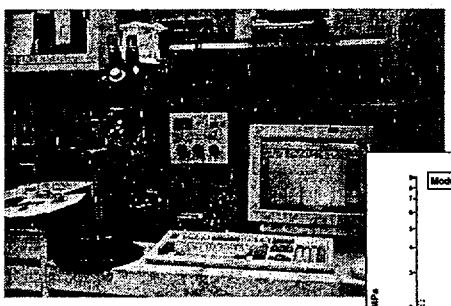


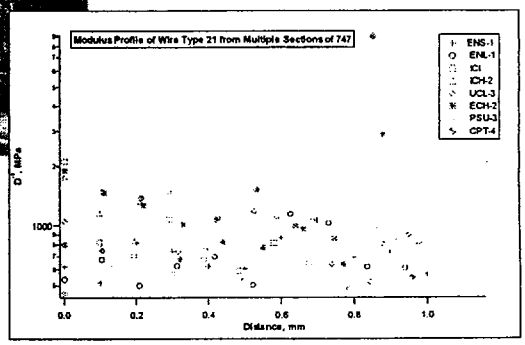
Directed Visual Examination



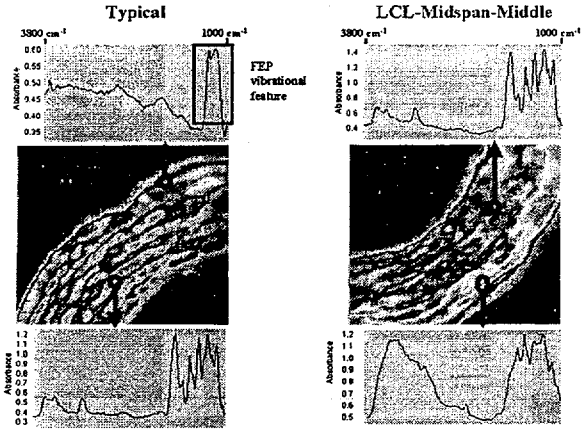


Modulus Profiling

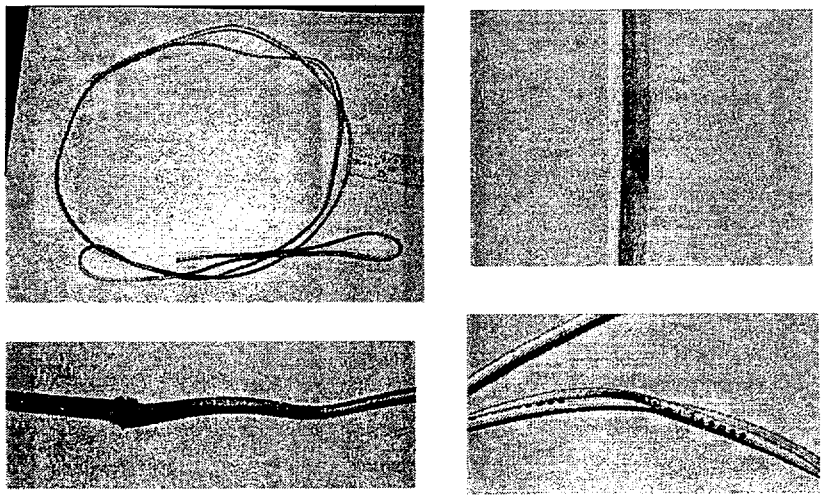




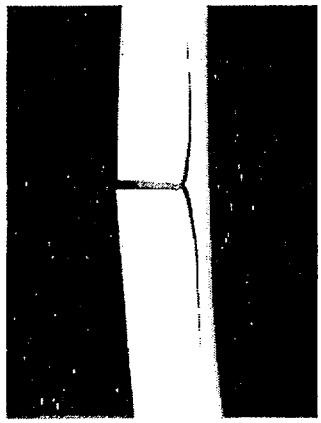
Infrared Spectroscopy



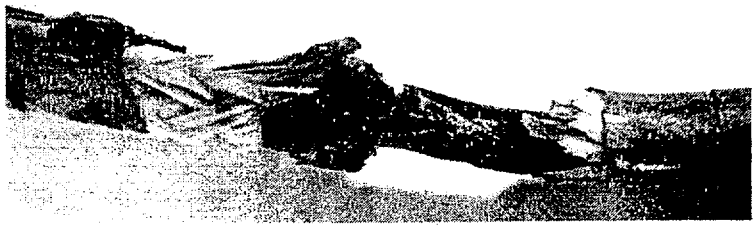
Typical Findings: DC-9 "Tired Wire"



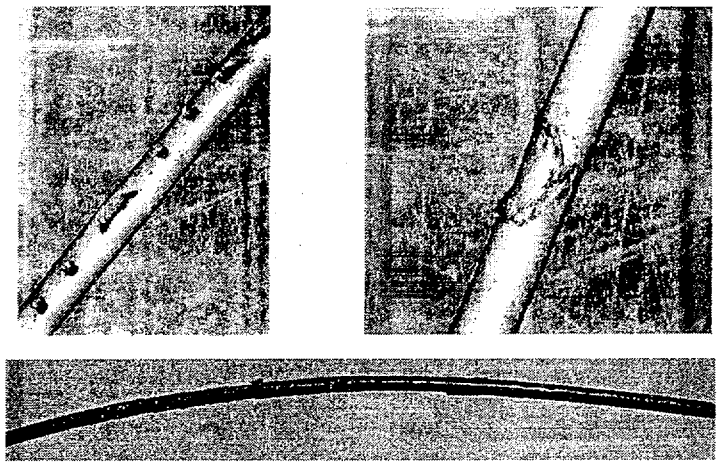
Typical Findings: 747



Typical Flaws: DC 9



Typical Findings: L1011



Wire Conditions

Wire Condition	Degenerative	Fire Hazard	Cmn Mode
Inadequate Repair		✓	
[redacted]			
Collateral Damage		✓	
Traumatic Damage		✓	
[redacted]			
Wire Corrosion	✓		
Broken Shield			
Broken Conductor			
Exposed Shield			
Exposed Conductor		✓	✓

Select Age-Related Conditions

Deteriorated Repair: A currently dysfunctional wire splice assumed to have met requirements when established (e.g. a splice originally established to be environmentally sealed but no longer so). Does not include inappropriate or unacceptable repair practice.

Heat Damage or burnt wire: Thermal damage to insulation resulting from the presence of elevated temperature over some extended period of time.

Vibration Damage/Chafing: Insulation wear (material loss) resulting from the repeated application of a force which if applied only once would not result in noticeable damage.

Cracked Insulation: A breach in the wire insulation resulting from internal stresses in excess of the local strength of the polymer. Does not include tearing resulting from the direct physical contact with other material (e.g. knife cut).

Arcing: Localized burnt spot on one or more wires indicating one or more instantaneous discharges of electrical energy.

Delamination: The unraveling of a tape-wrapped insulation. The separation of layers of insulation in a multilayered construction.

Data Summary

Wire Conditions	Findings			
	Significant Findings in All Zones	Significant Findings on Preselected	NDT Findings	Additional Lab Findings
Degraded Repair or Splice	2	0	≤7	0
Heat Damage or Burnt Wire	15	7	2	+
Vibration Damage/Chafing	46	8	2+	+
Cracked Insulation	48	16	12+	++
Arcing	2	0	2	0
Delamination	1	0	1	0

The working group collected an abundance of data, not all of which was analyzed for this report.

Data Synthesis

Wire Conditions	Found By		Frequency			Potential Options for Prevention or Mitigation of Consequent Failure
	Visual – All Wire	On-board NDT	Unique	Infrequent	Common	
Degraded Repair or Splice	S	F		✓		Staggering of splices, design modification, re-fabrication with environmental splice, periodic rework.
Heat Damage or Burnt Wire	F	S			✓	Visual inspection, periodic rework, design modification, installation of heat or fire shielding.
Vibration Damage/Chafing	F	S			✓	Visual inspection, AFCB, ATE, design modification, periodic rework.
Cracked Insulation	O	F			✓	AFCB, DelTest, periodic rework, wire segregation or separation
Arcing	O	A		✓		AFCB, design modification, wire segregation or separation, periodic rework.
Delamination	O	F		✓		AFCB, design modification, wire segregation or separation

State of Wire in Aged Aircraft

There were signs of characteristic degradation on all wire types:

- **Polyimide**: Instance of delamination were observed on the A300 and L1011.
- **PVC/Glass/Nylon**: Substantial degradation of wire on one the two DC-9 aircraft (cracking, thermal degradation).
- **Poly-X**: Characteristic radial cracking.
- **ETFE**: Relatively good condition, but with some signs of dielectric performance degradation.

State of Wire in Aged Aircraft

- **Mixed Wire Type**: At least one problem was observed in a mis-configured bundle. There was no physical evidence of chafing on properly configured bundles, but the data and analysis are insufficient to conclude.
- **Hot Stamp Markings**: Breaches were often co-located with hot stamp marks.
- **Cut-Off Wire**: Though not a wire degradation issues, this frequency of this finding is worth noting.
- **Flammability**: All wire types performed as expected – i.e. equivalent to new wire of the same type.

Adequacy of Visual Inspection

- Visual inspection is an effective tool in the management of wires subject to heat damage, burning, and chafing. In high-risk situations, visual inspection must be combined with other means of preventing or mitigating failure.
- Visual inspection is not adequate for the detection of degraded repair, cracking, arcing, or delamination. Where these conditions may occur, and where the consequence of wire failure is unacceptable, other means for prevention and mitigation must be used.
- Though some specific degenerative conditions cannot be directly observed, correlation of other findings with the existence of these conditions is, in some cases, possible. One cannot, however, rely exclusively upon this deductive assessment of wire condition.

Threat Assessment

- Flaws were categorized as unique, infrequent, or common. Each class handled separately.
- For all but unique flaws, the Working Group will use a formal threat assessment procedure **for plausible, hypothetical situations of interest to ATSRAC**.
- In judging the threat, consideration was given to:
  - Aggravating or contributory factors
  - Wire insulation type
  - Estimated probability of existence
- In making recommendations consideration was given to:
  - Visual detectability
  - Efficacy of other inspection or testing

Generic Factors

Benign Environment: Low humidity, nonflammable environment. Few or no critical system wires in bundle. Uncontaminated and secured well.

Explosive Environment: An environment where there is a reasonable expectation of the presence of an explosive combination of gases during some phase of operation.

Flammable Materials: Surrounding materials that can sustain combustion under normal operating conditions. Includes the wire insulation itself (e.g. PVC but not polyimide.).

Other Critical Systems: The wire in question is bundled with other wires, at least one of which supplies current to a systems required for safe flight.

Moisture: Normal relative humidity in excess of 90% during some phase of flight (landing, takeoff, climb, cruise, decent, approach, landing), resulting in enhanced likelihood of shorting.

Generic Factors (continued)

Vibration: Sufficient relative motion between wires or between wires and structure to cause or accentuate intermittent shorting.

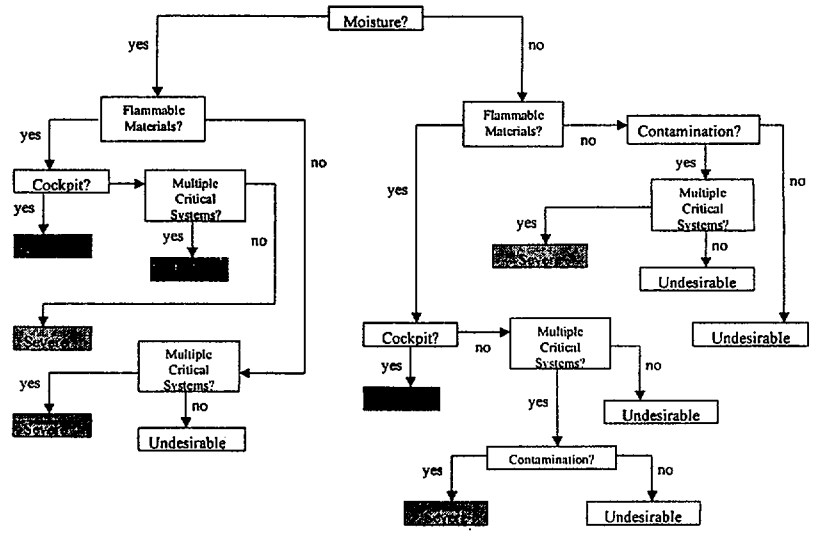
Contamination: Contamination as the result of normal operation or maintenance resulting in either enhanced flammability or likelihood of shorting.

Cockpit or Electronics Compartment: High consequence failure locations within the aircraft.

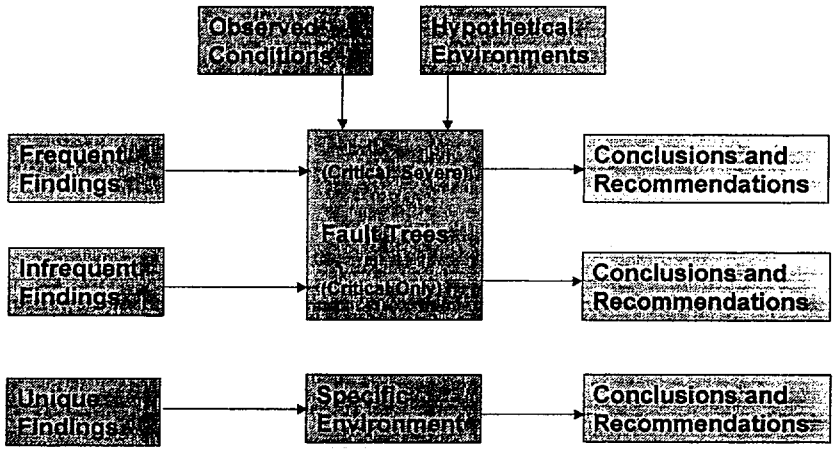
Arc Tracking Potential: The presence of Polyimide and other arc tracking materials in the bundle.

Potential for Excessive Resistance Heating: Wires with high current loads may fail as the result of excessive resistive heating at repair or splice locations. This failure can evolve into severely burnt, cracked, or melted insulation on the offending wire and its neighbors. With excessive heat and bare wire at these locations, the potential for fire is high.

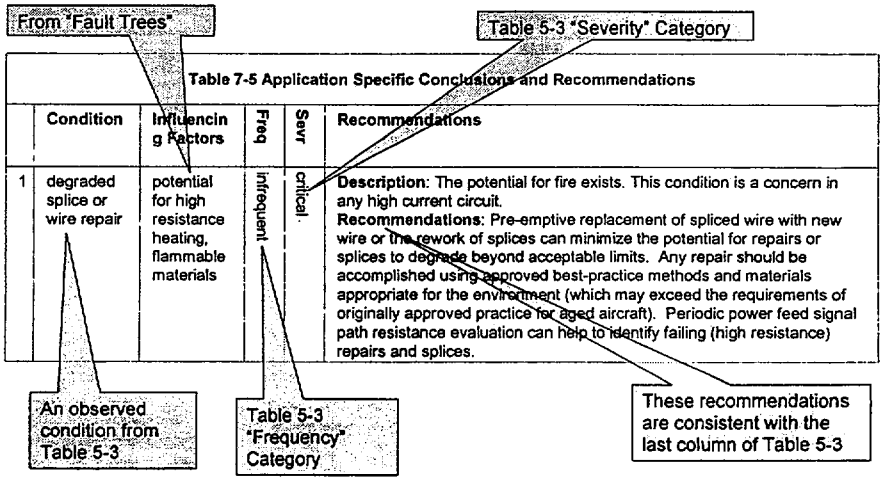
Delamination "Fault Tree"



Threat Assessment Summary



Recommendations Roadmap



Commentary

- The close visual examination of 6 retired aircraft and the collection of samples from these aircraft has resulted in a wealth of data, which has been only partially analyzed by this project.
- Though the working group is confident of its conclusions and recommendations, it also recommends the continued laboratory results of the wire specimens
  - to increase further our confidence in the findings
  - to explain in greater detail certain phenomenon.