Making the Connection for a Lifetime – Considerations for Maintaining a Reliable Aircraft Wiring System

October 2017

Presenter: Michael Traskos

Agenda

- History of EWIS
- Overview of wiring system
- Regulatory considerations
- EWIS maintainability/inspection
- Determining system health and fault detection/isolation
- Conclusion

What is EWIS?

Electrical

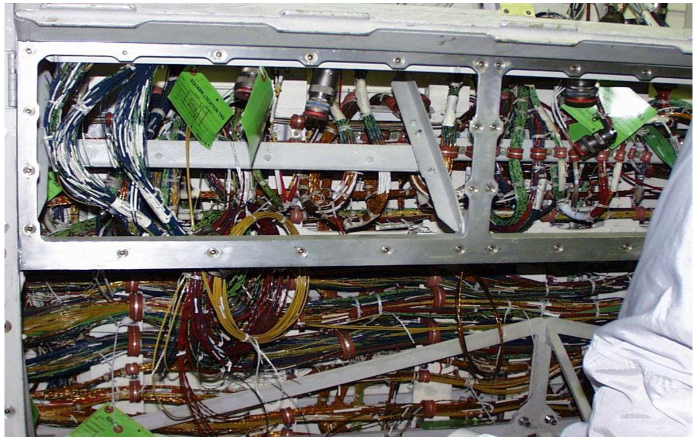
Wiring

Interconnection

System

What is EWIS?

- **Sec. 25.1701 — Definition: "**electrical wiring interconnection system (EWIS) means any wire, wiring device, or combination of these, including termination devices, installed in any area of the airplane for the purpose of transmitting electrical energy, including data and signals, between two or more intended termination points."



What is EWIS?

Lectromec

- Wires and cables
- Bus bars
- The termination point on electrical devices
- Connectors, including feed-through connectors
- Connector accessories
- Electrical grounding and bonding devices and their associated connections
- Electrical splices
- Materials used to provide additional protection for wires, including wire insulation, wire sleeving, and conduits that have electrical termination for the purpose of bonding
- Shields or braids
- Clamps and other devices used to route and support the wire bundle
- Cable tie devices
- Labels or other means of identification

History of EWIS - Guidance

Lectromec

- Guidance on wire and cable installation on aircraft dates back to 1954 with the MIL-W-5088 (now AS50881).
- Individual companies have developed their independent standards over time to capture best practices.
- ASTM F2799 for preventative maintenance.
- AC 43.13 is FAA guidance of wire system design and sustainment.

History of EWIS and Why it Matters

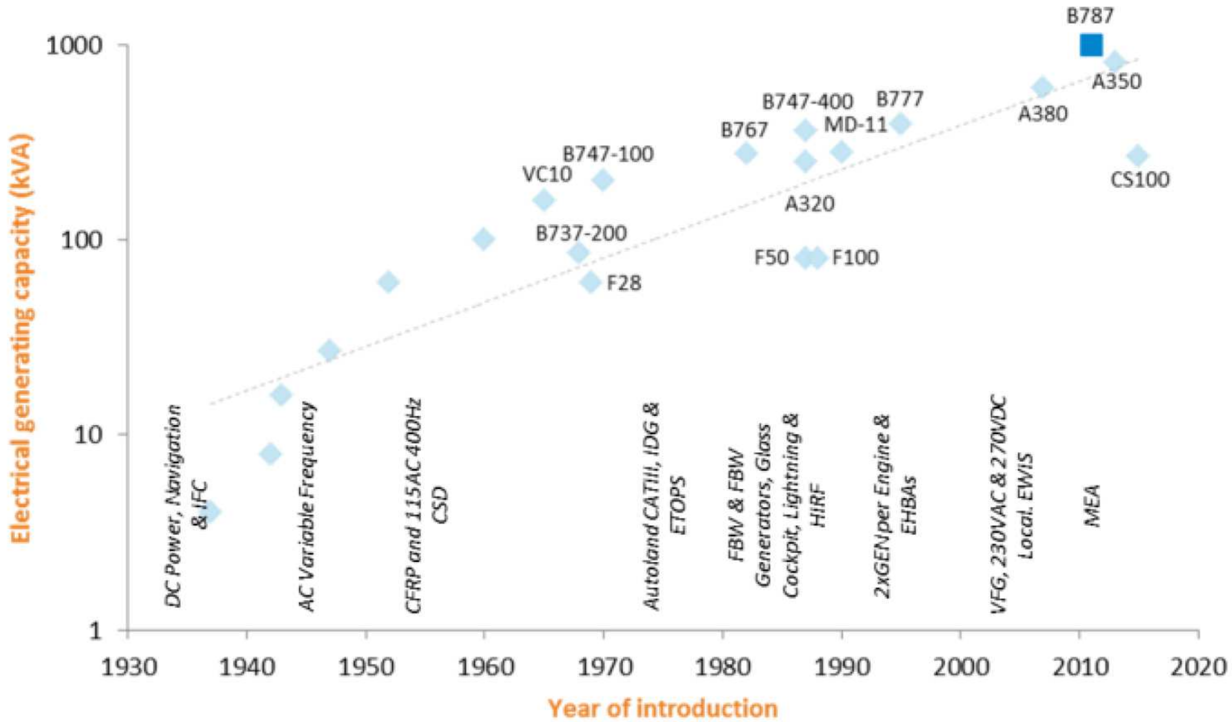
Lectromec

- **TWA 800**
  - Crash Date: July 17, 1996
  - Boeing 747 exploded off the coast of Long Island, NY.
  - Suspected cause: Arcing to Fuel Quantity Indicator System (FQIS) wires led to ignition of fuel tank.

- **Swiss Air 111**
  - Crash Date: September 2, 1998
  - McDonald Douglas MD-11
  - A rapid succession of electrical fires led to loss of control and crash.
  - “Aircraft certification standards for material flammability were inadequate in that they allowed the use of materials that could be ignited and sustain or propagate fire.”

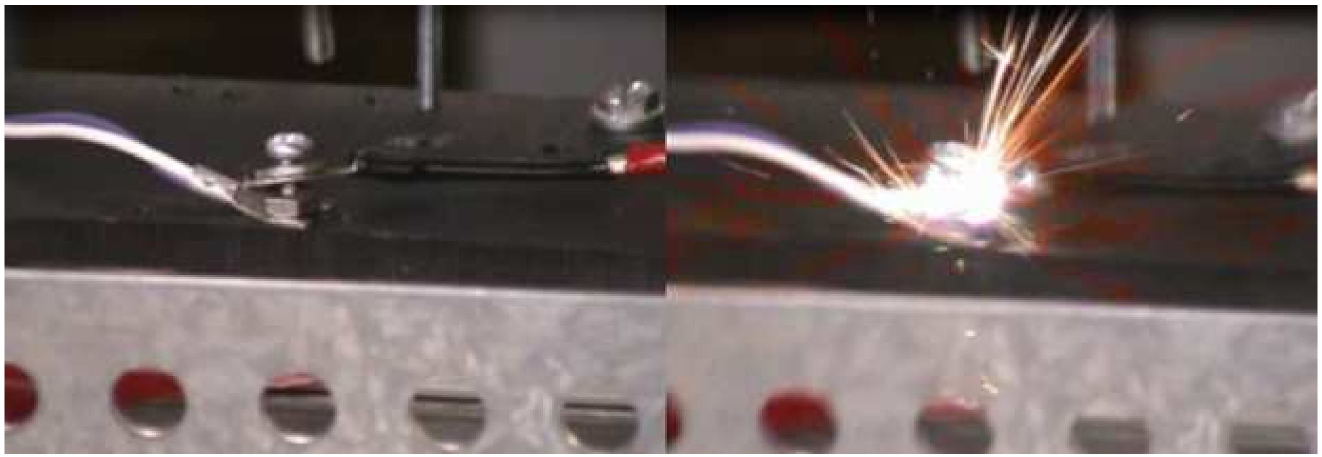
Growth of Electrical Power on Aircraft

- The electrical generating capacity of aircraft is only going to increasing.
- B787 has the electrical generating capacity of 1.25 MW... Enough electrical power to supply 1,000 homes.



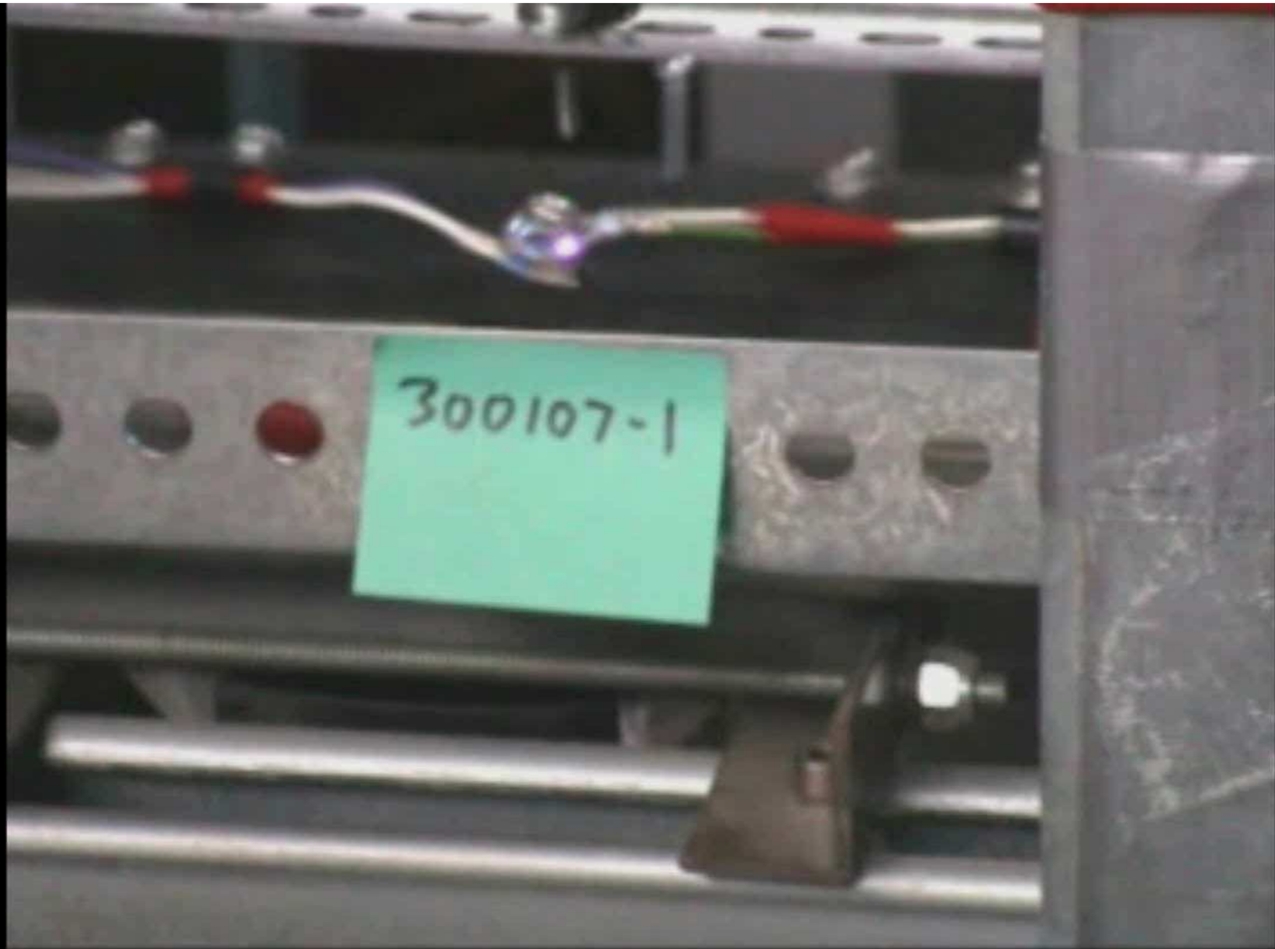
When EWIS Components Fail

- When electrical components fail, there is a lot of energy to go into the electrical arcing.
- Thermal circuit breakers are not designed to rapidly remove power from arcing events.



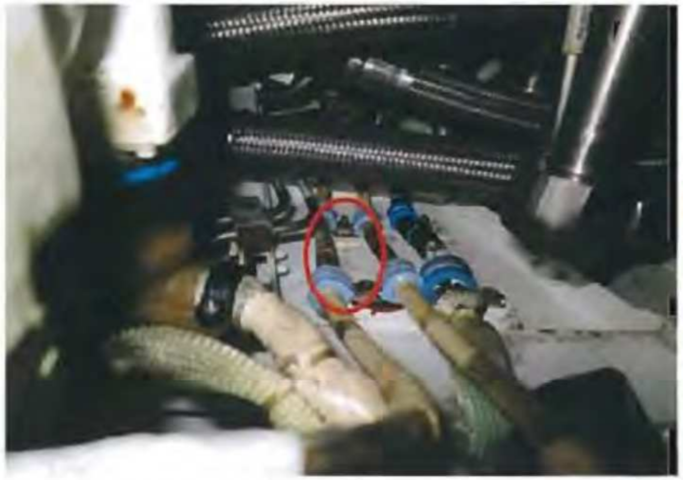
When EWIS Components Fail

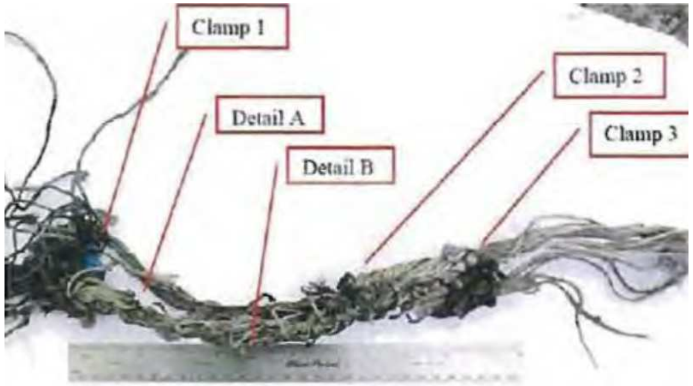
Lectromec



When EWIS Components Fail

- F-22 Crash November 2012.
- The primary mishap cause was a chafed 270VDC positive generator feeder wire that arced.
- Arc burned through adjacent hydraulic line.
- When the pilot attempted to restart the generator, the ensuing arc ignited the misting hydraulic fluid and started a fire in the aircraft.
- Circuit protection was designed to respond in less than 100ms.





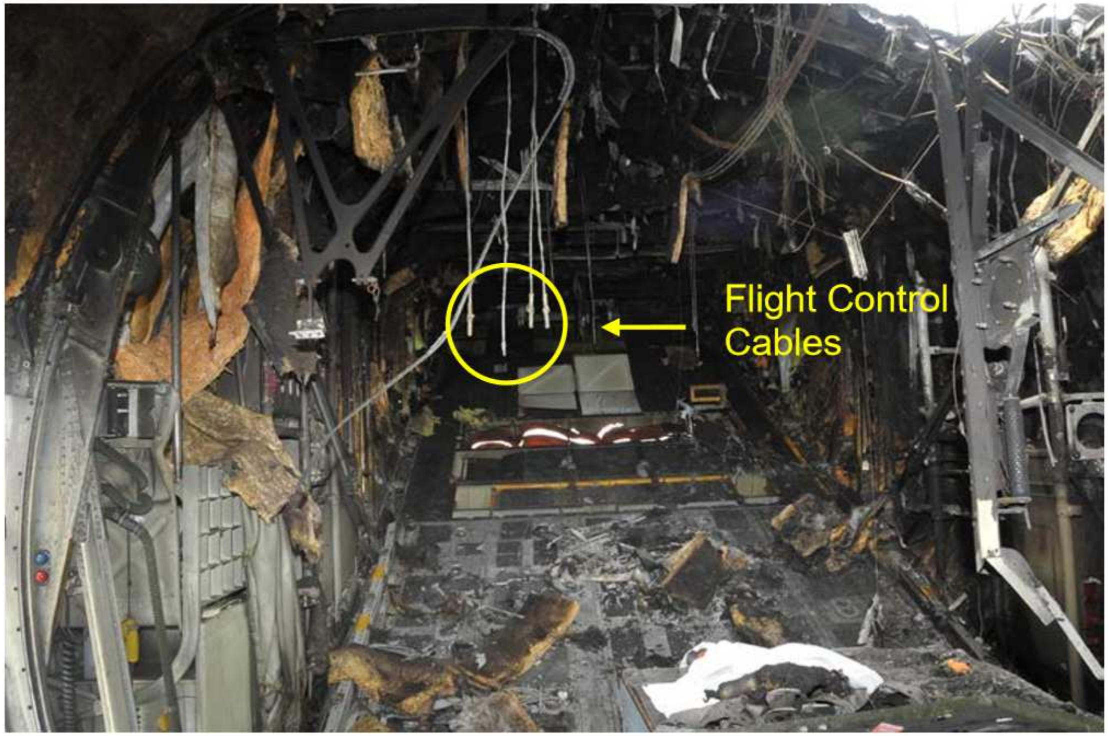
When EWIS Components Fail

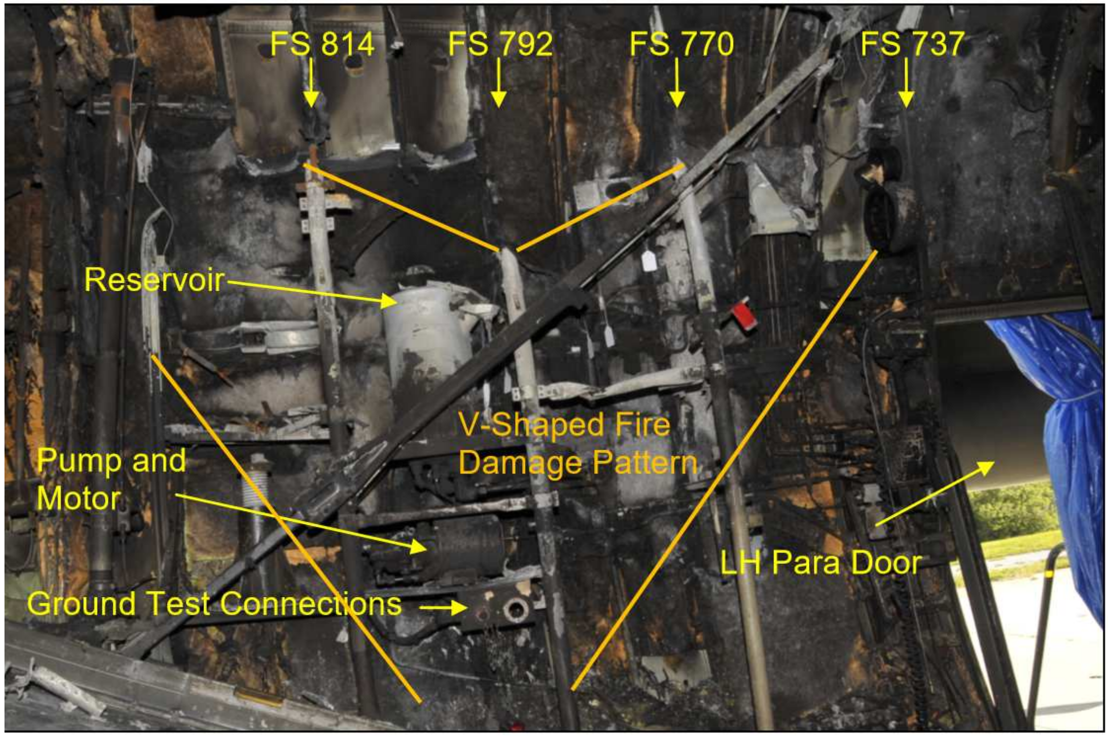
Lectromec

- C-130 Incident in 2012.
- The investigation determined chafing and arcing occurred between a hydraulic line and a power cable.
- The investigation determined a series of deficiencies in the modification and approval process, as well as its installation and in-service maintenance practices were directly causal to the fire.
- Had incident occurred during any other part of flight would have resulted in loss of aircraft.

When EWIS Components Fail

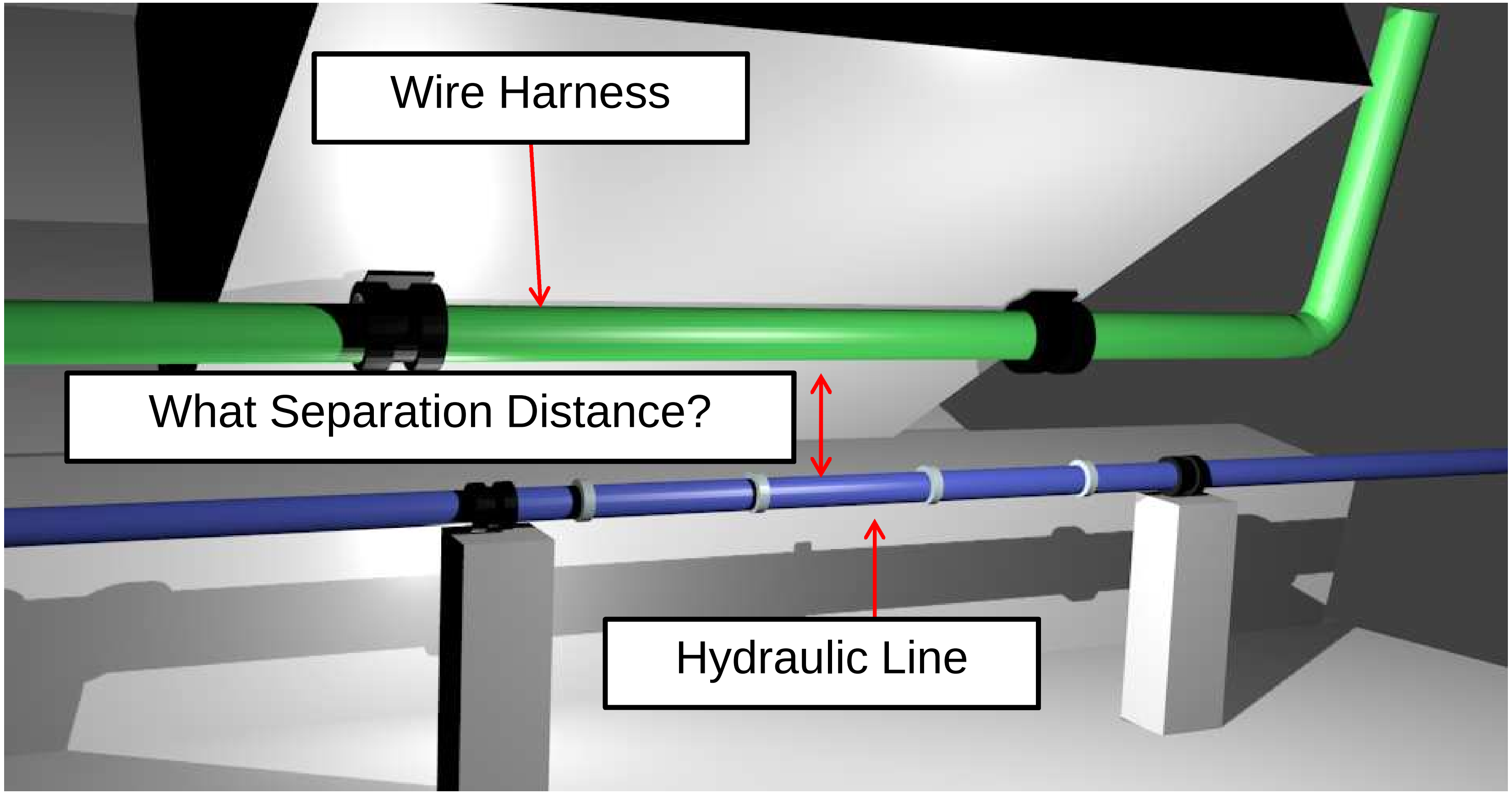
Lectromec





Canadian National Defense Report: 1010-CC130342 (DFS 2-5) December 2015

What Separation is Necessary?



https://www.lectromec.com/publications/

115VAC Two Phase Arcing Event

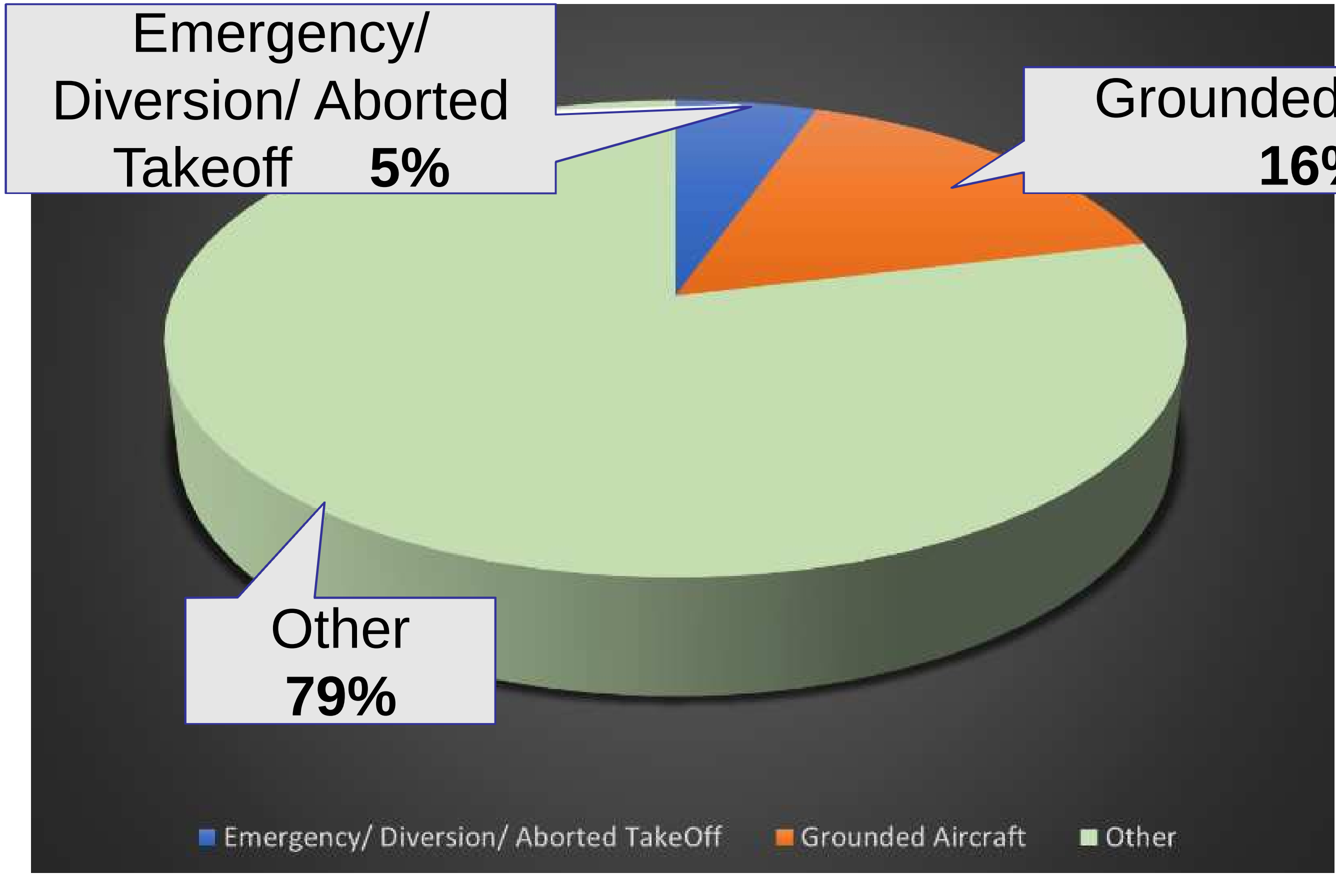
16 AWG Arc Track Resistant Wire Harness

1.0” Separation

Aluminum Hydraulic Line

Impact of EWIS Failures On Commercial Aircraft

Lectromec



https://www.lectromec.com/analysis-of-2016-ewis-failures/

Modifications

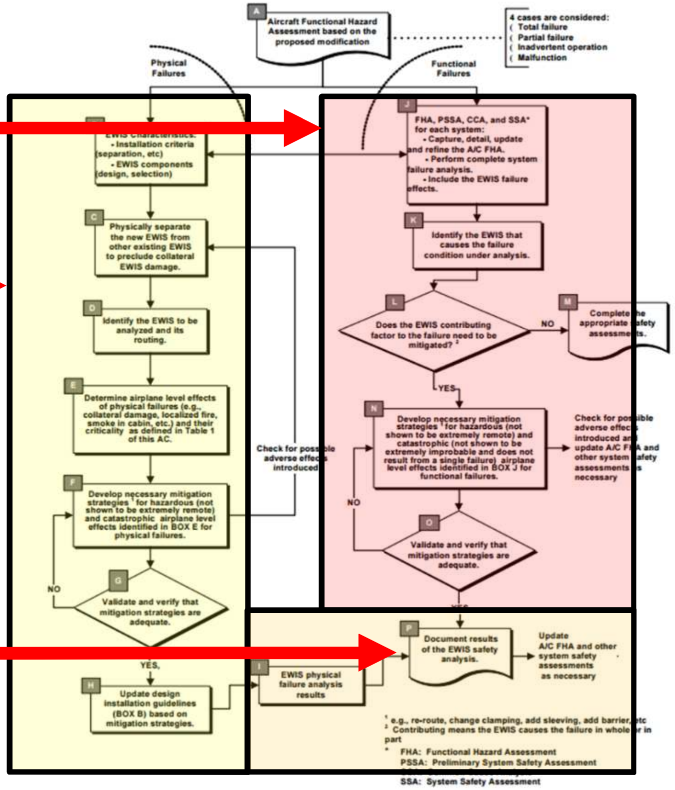
Lectromec

- Consider a new aircraft design: A lot of information is necessary for the development of a safe EWIS.
  - Form and function of all EWIS parts
  - Fire protection
  - Electrical bonding
  - EWIS risk assessment
  - System separation

EWIS Functional Failure Analysis

EWIS Physical Failure Analysis

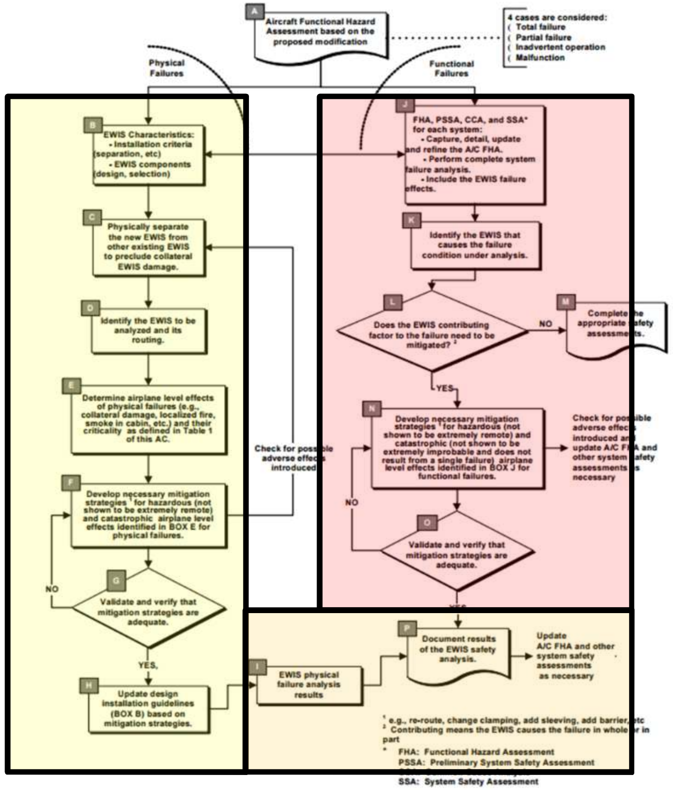
Comprehensive EWIS Failure Analysis



Mitigation as used in this flowchart means to eliminate the hazard entirely or minimize its severity and probability to an acceptable level. In the case of § 25.1709, the EWIS failure must be mitigated to a point where the probability of a hazardous failure is at least extremely remote and the probability of a catastrophic failure is at least extremely improbable

Modifications

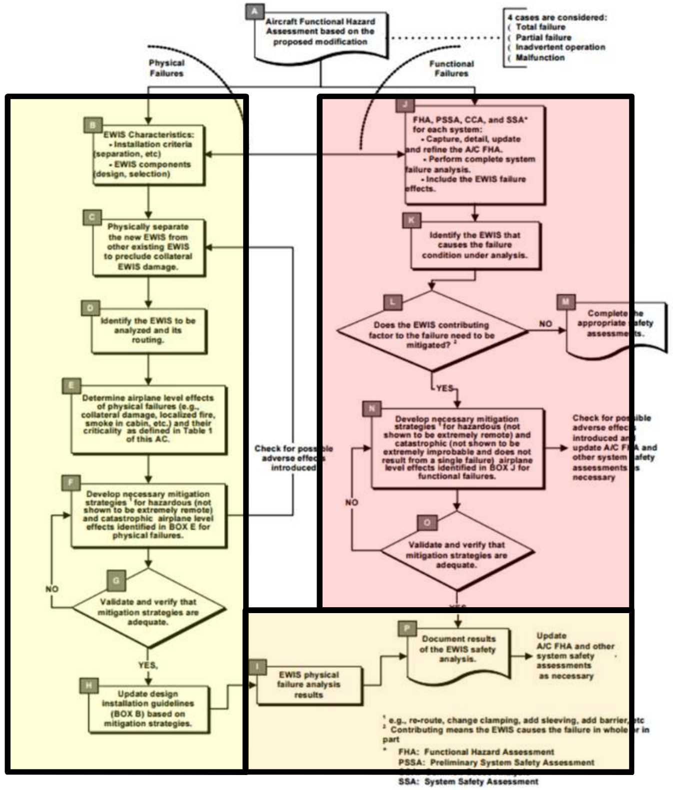
- When performing aftermarket modifications, is it possible to gather this information and not impact airworthiness?



Mitigation as used in this flowchart means to eliminate the hazard entirely or minimize its severity and probability to an acceptable level. In the case of § 25.1709, the EWIS failure must be mitigated to a point where the probability of a hazardous failure is at least extremely remote and the probability of a catastrophic failure is at least extremely improbable

Modifications

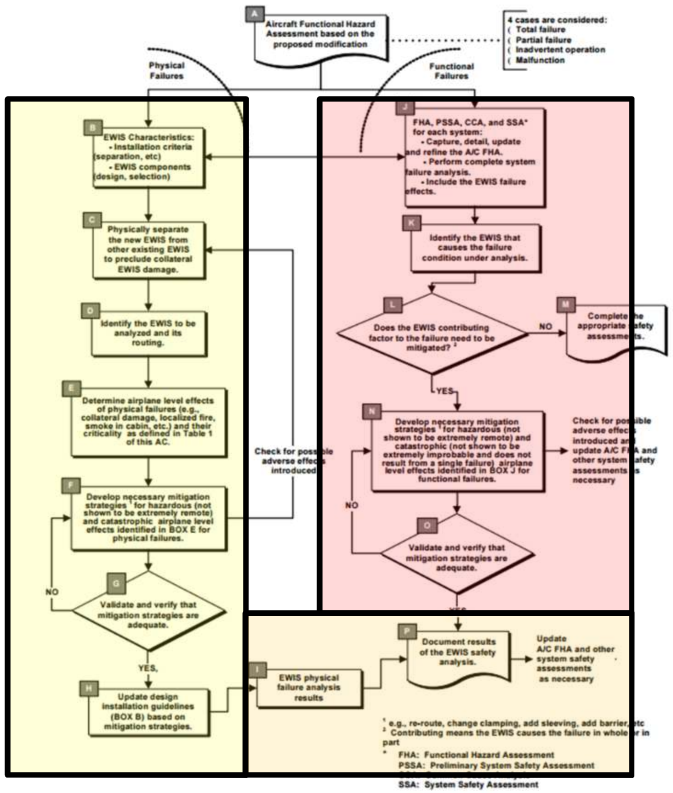
- AC 25.1701 provides guidance on how to handle certification compliance with the regulations for both new aircraft designs and aircraft modifications.
- In terms of the EWIS assessment portion (25.1709), the modification of EWIS requires special handling



Mitigation as used in this flowchart means to eliminate the hazard entirely or minimize its severity and probability to an acceptable level. In the case of § 25.1709, the EWIS failure must be mitigated to a point where the probability of a hazardous failure is at least extremely remote and the probability of a catastrophic failure is at least extremely improbable

Modifications

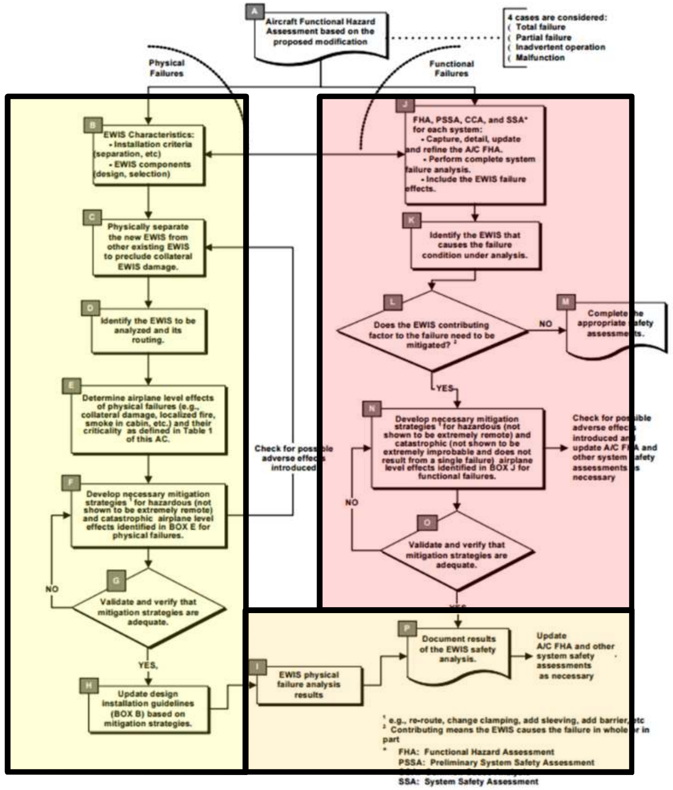
- AC: “Applicants for post-Type Certification modifications should use the analysis depicted … when the applicant cannot identify the systems or systems functions contained in existing aircraft EWIS that may be utilized as part of the modification.”



Mitigation as used in this flowchart means to eliminate the hazard entirely or minimize its severity and probability to an acceptable level. In the case of § 25.1709, the EWIS failure must be mitigated to a point where the probability of a hazardous failure is at least extremely remote and the probability of a catastrophic failure is at least extremely improbable

Modifications

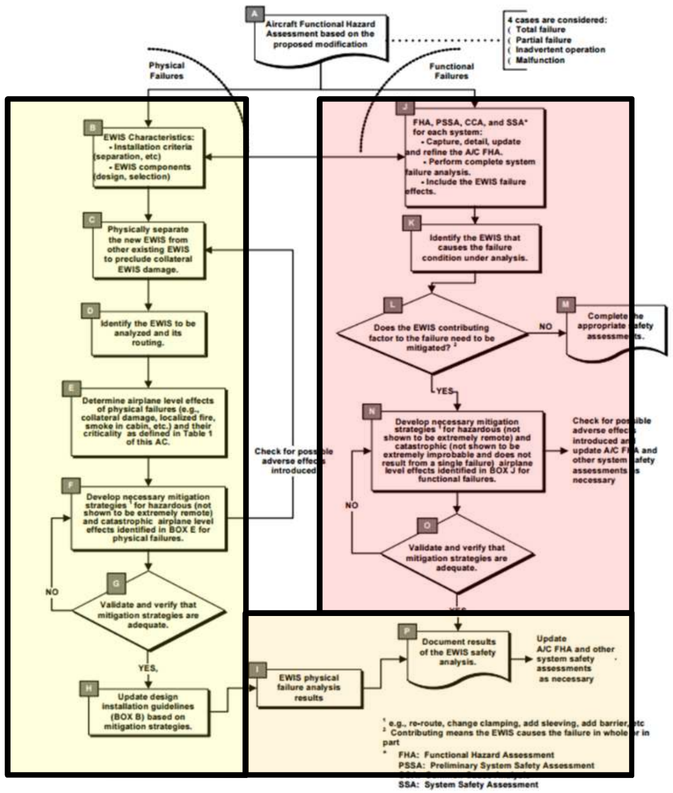
- **“An applicant should not add EWIS to an existing EWIS if the systems or systems functions contained in the existing EWIS are unknown**. To do so could introduce unacceptable hazards. For example, IFE power wires could inadvertently be routed with aircraft autoland EWIS.”



Mitigation as used in this flowchart means to eliminate the hazard entirely or minimize its severity and probability to an acceptable level. In the case of § 25.1709, the EWIS failure must be mitigated to a point where the probability of a hazardous failure is at least extremely remote and the probability of a catastrophic failure is at least extremely improbable

Modifications – Post TC

- What does that mean for a modifier who needs to run wires in the aircraft?
- Determine everything in the wire harness or run the wire harness separately.
- Separate runs can be a challenge when routing through lighting holes in structures where space is limited.
- Determining the course of action is a balance between the creation of additional feedthrough holes or joining the harnesses for the feedthrough then breakout afterwards.



Mitigation as used in this flowchart means to eliminate the hazard entirely or minimize its severity and probability to an acceptable level. In the case of § 25.1709, the EWIS failure must be mitigated to a point where the probability of a hazardous failure is at least extremely remote and the probability of a catastrophic failure is at least extremely improbable

Sustainment

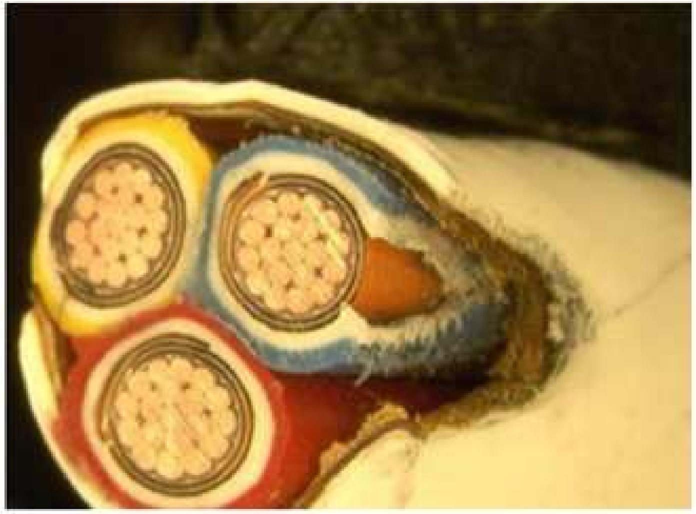
- What can happen to the EWIS over time and damage incurred by maintenance, environmental impact:
  – Fuel Tank Safety
  – High Intensity Radiated Fields (HIRF) protective systems
  – Lightning
  – Impact on Connectivity

Fuel Tank Safety

Lectromec

- SFAR88 and AC 25.981 provide the framework for fuel tank safety.
- Primary guidance is for the avoidance of fuel tank ignition sources.

Example of a frayed fuel pump wire,
representative of post-accident inspection findings
on commercial aircraft (not from TWA 800)



Example of chafed Wire in Wire Harness
representative of post-accident inspection
program(not from TWA 800)

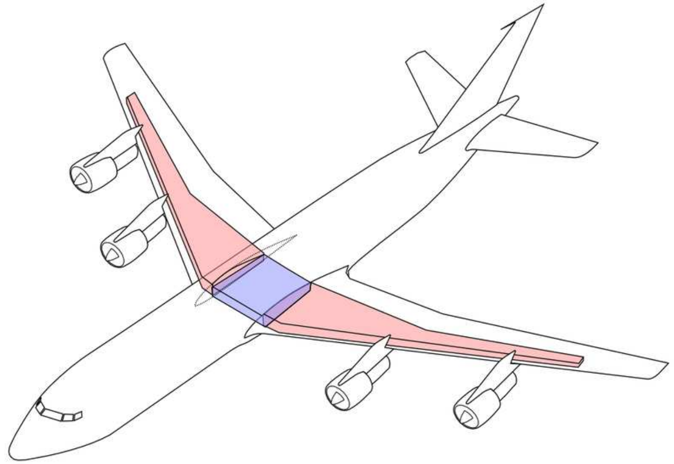
Fuel Tank Safety

- The FAA requirement 25.981 on fuel tank ignition prevention states, “No ignition source may be present at each point in the fuel tank or fuel tank system where catastrophic failure could occur due to ignition of fuel or vapors.”
- To aid in the analysis to achieve a certifiable design, the FAA has provided advisory circular (AC) 25.981-1C, “Fuel Tank Ignition Source Prevention Guidelines.”

Fuel Tank Safety

Lectromec

- How much energy is needed for fuel ignition?
  - "Laboratory testing has shown that the minimum ignition energy in an electrical spark required to ignite hydrocarbon fuel vapor is **200 microjoules**."
  - An electrical arc connected to a 115VAC system with a current draw of 100A would produce this threshold in less than 0.1microseconds.



Resources for Fuel Tank Safety

Lectromec

- SFAR-88: Fuel Tank System Fault Tolerance Evaluation Requirements
- AC 25.981-1C: Fuel Tank Ignition Source Prevention Guidelines
- AC 25.981-2A: Fuel Tank Flammability
- AC 25.1309-1A: System Design and Analysis
- AC 25.1701-1: Certification of Electrical Wiring Interconnection Systems on Transport Category Airplanes
- AC 25-8: Auxiliary Fuel Systems Installations
- AFRL/RXS 09-026: KC-135 Refueling Pressure Regulator Butterfly Valve Fracture
- ARP594: Fuel Pump Thermal Safety Design.
- ASTM D149: Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials

Resources for Fuel Tank Safety

Lectromec

- ASTM D3755: Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials under Direct-Voltage Stress
- DoD (JSSG)-2009: Air Vehicle Subsystems -- Appendix E
- ECA 186-4E: Passive Electronic Component Parts, Test Methods for; Method 4: Dielectric Test (Withstanding Voltage)
- FAA Report DOT/FAA/AR-98/26: A Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks (June 1998)
- FAA Report DOT/FAA/AR-00/19: The Cost of Implementing Ground-Based Fuel Tank Inerting in the Commercial Fleet. (May 2000)
- FAA Report DOT/FAA/AR-01/6:Inerting of a Vented Aircraft Fuel Tank Test Article with Nitrogen Enriched Air (December 2000)

Resources for Fuel Tank Safety

- FAA Document DOT/FAA/AR-TN02/79: Limiting Oxygen Concentrations Required to Inert Jet Fuel Vapors Existing at Reduced Fuel Tank Pressures (April 2003)
- FAA Document DOT/FAA/AR-07/30: Jet A Volatility Survey, (July 2007)
- FAA Document DOT/FAA/AR-05/8: Fuel Tank Flammability Assessment Method User's Manual (May 2008)
- FAA Document DOT/FAA/AR-98/26: Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks, June 1998.
- FAR 25.901: Powerplant - Installation
- FAR 25.981: Fuel Tank Ignition Source Prevention Guidelines
- FAR 25.1707: System separation: EWIS

Resources for Fuel Tank Safety

Lectromec

- FAR 25.863: Flammable fluid fire protection
- FAR 25.954: Fuel system lightning protection
- FAR Part 26, subpart D: Fuel Tank Flammability
- FAR 26.33: Holders of Type Certificates, Fuel tank safety
- FAR 26.5: Continued Airworthiness and Safety Improvements for Transport Category Airplanes
- MIL-B-5087B: Bonding, Electrical, and Lightning Protection, for Aerospace Systems
- MIL-B-83054: Baffle and Inerting Material, Aircraft Fuel Tank (March 1984);
- MIL-DTL-27422: Tanks, Fuel, Crash-Resistant, Ballistic-Tolerant, Aircraft
- MIL-DTL-5578: Tanks, Fuel, Aircraft, Self-Sealing

Resources for Fuel Tank Safety

Lectromec

- MIL-DTL-62011E Detailed Specification: Pump, Fuel, Electrically-operated: 24-Volt DC, In-Tank Type, General Specification for
- MIL-DTL-6396 Tanks, Fuel, Oil, Cooling Fluids, Internal, Removable Non-Self-Sealing
- MIL-F-17874B Fuel Systems: Aircraft, Installation and Test Of
- MIL-PRF-81975 Couplings, Regulated, Aerial Pressure Refueling Type MA-2, Type MA-3 and Type MA-4
- MIL-R-25988 (Fluorosilicone) Rubber, Fluorosilicone Elastomer, Oil-And Fuel-Resistant, Sheets, Strips, Molded Parts, And Extruded Shapes
- MIL-STD-810G Environmental Engineering Consideration and Laboratory Tests
- MIL-STD-1798C Mechanical Equipment and Subsystems Integrity Program

Resources for Fuel Tank Safety

Lectromec

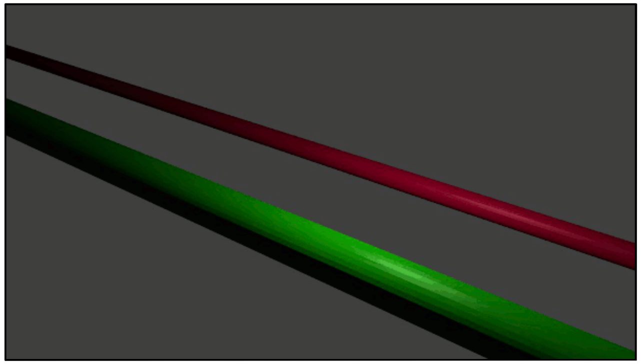
- MIL-HDBK-516C: Airworthiness Certification Criteria
- RTCA DO-160: Environmental Conditions and Test Procedures for Airborne Equipment
- SAE AIR 1662: Minimization of Electrostatic Hazards in Aircraft Fuel Systems (October 1984)
- SAE AIR 4170A: Reticulated Polyurethane Safety Foam Explosion Suppressant Material for Fuel Systems and Dry Bays (November 1998);
- SAE AIR 5128: Electrical Bonding of Aircraft Fuel System Plumbing Systems (January 1997);
- SAE ARP568B: Uniform Dash Numbering System for O-Rings
- SAE ARP594D: Fuel Pump Thermal Safety Design”
- SAE ARP6179: Evaluation of Gas Turbine Engine Lubricant Compatibility with Elastomer O-Rings

Resources for Fuel Tank Safety

- SAE ARP-8615: General Specification for Fuel System Components
- US Air Force Technical Report AFAPL-TR-70-65: Effects of Fuel Slosh and Vibration on the Flammability Hazards of Hydrocarbon Turbine Fuels Within Aircraft Fuel Tanks (November 1970), Edwin E. Ott;
- 14CFR Part 25 Appendix M: Fuel Tank System Flammability Reduction Means
- 14CFR Part 25 Appendix N: Fuel Tank Flammability Exposure and Reliability Analysis

HIRF

- HIRF (High Intensity Radiated Fields)
- Background: In 1986, the FAA sought a definition and thresholds for HIRF.
- The study found civil aircraft design were significantly underestimating HIRF by as much as 4 orders of magnitude.
- First standards were imposed in 1987



HIRF

Lectromec

HIRF REQUIREMENTS EXCERPTS FROM §§ 23.1308, 25.1317, 27.1317, AND 29.1317	FAILURE CONDITION	SYSTEM HIRF CERTIFICATION LEVEL
Each electrical and electronic system that performs a function whose failure would prevent the continued safe flight and landing of the rotorcraft/airplane	Catastrophic	A
Each electrical and electronic system that performs a function whose failure would significantly reduce the capability of the rotorcraft/airplane or the ability of the flightcrew to respond to an adverse operating condition	Hazardous	B
Each electrical and electronic system that performs a function whose failure would reduce the capability of the rotorcraft/airplane or the ability of the flightcrew to respond to an adverse operating condition	Major	C

Source: AC 20-158

How to Show HIRF Compliance

Lectromec

- Identify critical systems and evaluate the routing system wiring
- Develop pass/fail criteria
- Verify protection by test, analysis or similarity
- Submit HIRF compliance report
- Identify HIRF maintenance requirements

HIRF – Protecting EWIS

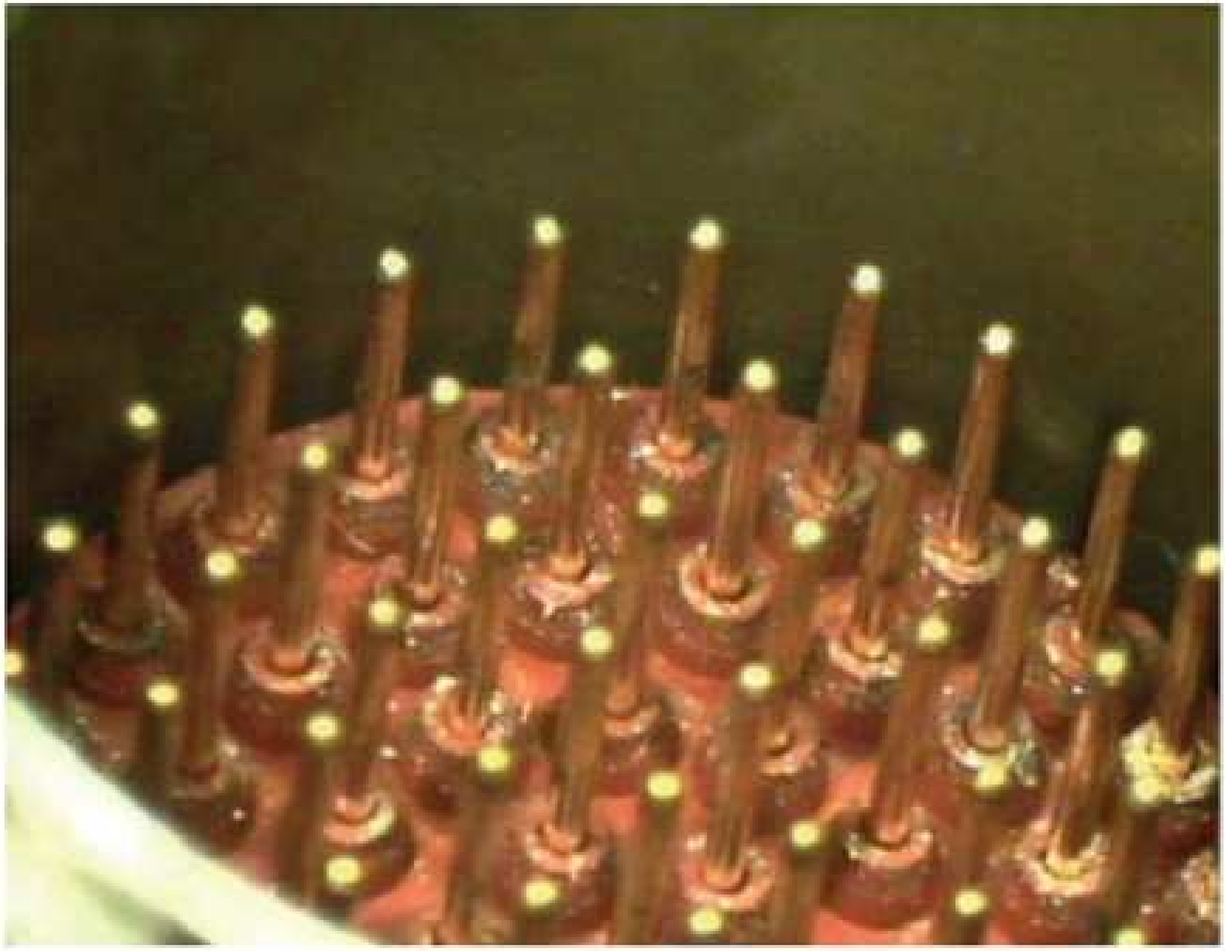
Lectromec

- When EMI/RFI protection is required, special attention must be given to the termination of individual and overall shields
- Backshell adapters designed for shield termination, connectors with conductive finishes, and EMC grounding fingers are available for this purpose
- Proper grounding of shielded cables and harnesses. Damage or corrosion at interfaces can reduce protection
- Trimming of shielding helps to reduce HIRF susceptibility

Sustainment – Aging System

Lectromec

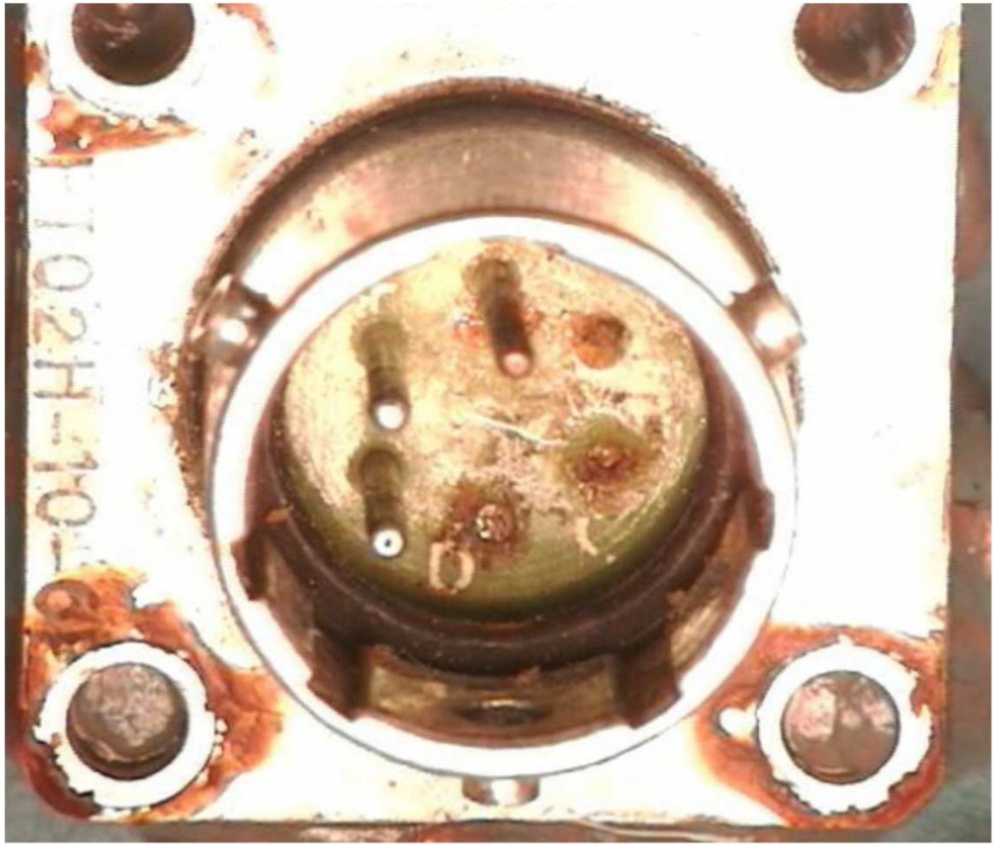
- Wear on connector contacts and flaking of plating materials
- Indication of too many mating/demating cycles, corrosion, or poor quality products
- Application of CPCs inside of connectors is not a good practice



Sustainment – Aging System

Lectromec

- The electrical leakage path between the normally isolated contact pins can impress sufficient voltage and current to cause the valve relay to activate and partially or completely close the value resulting in engine fuel starvation.
- Corrosion between the tin plated contacts and gold plated sockets.
- The extensive corrosion was accelerated by the presence of moisture and having tin plated pin contacts inserted into gold plated copper alloy sockets.

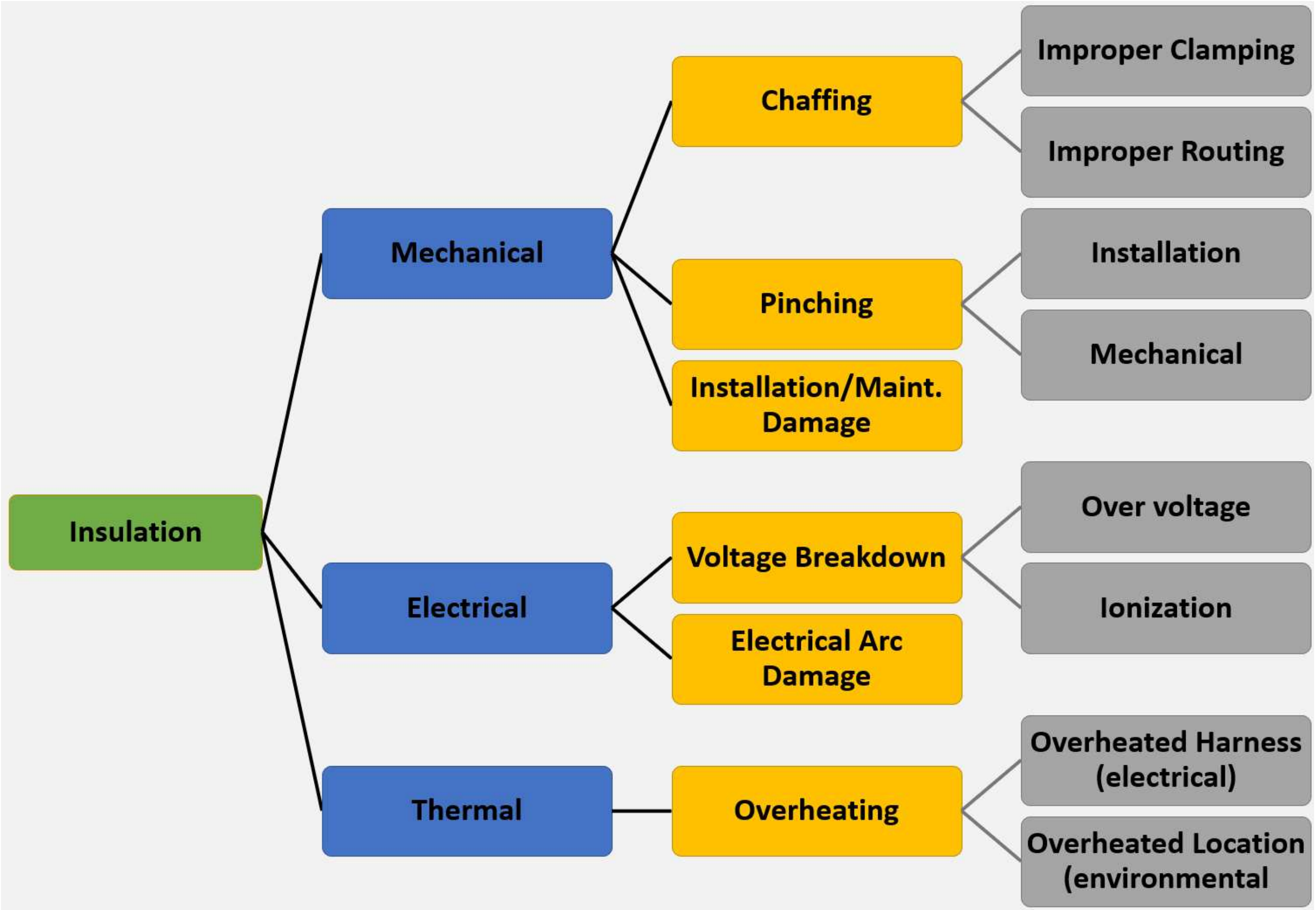


Sustainment – Aging System

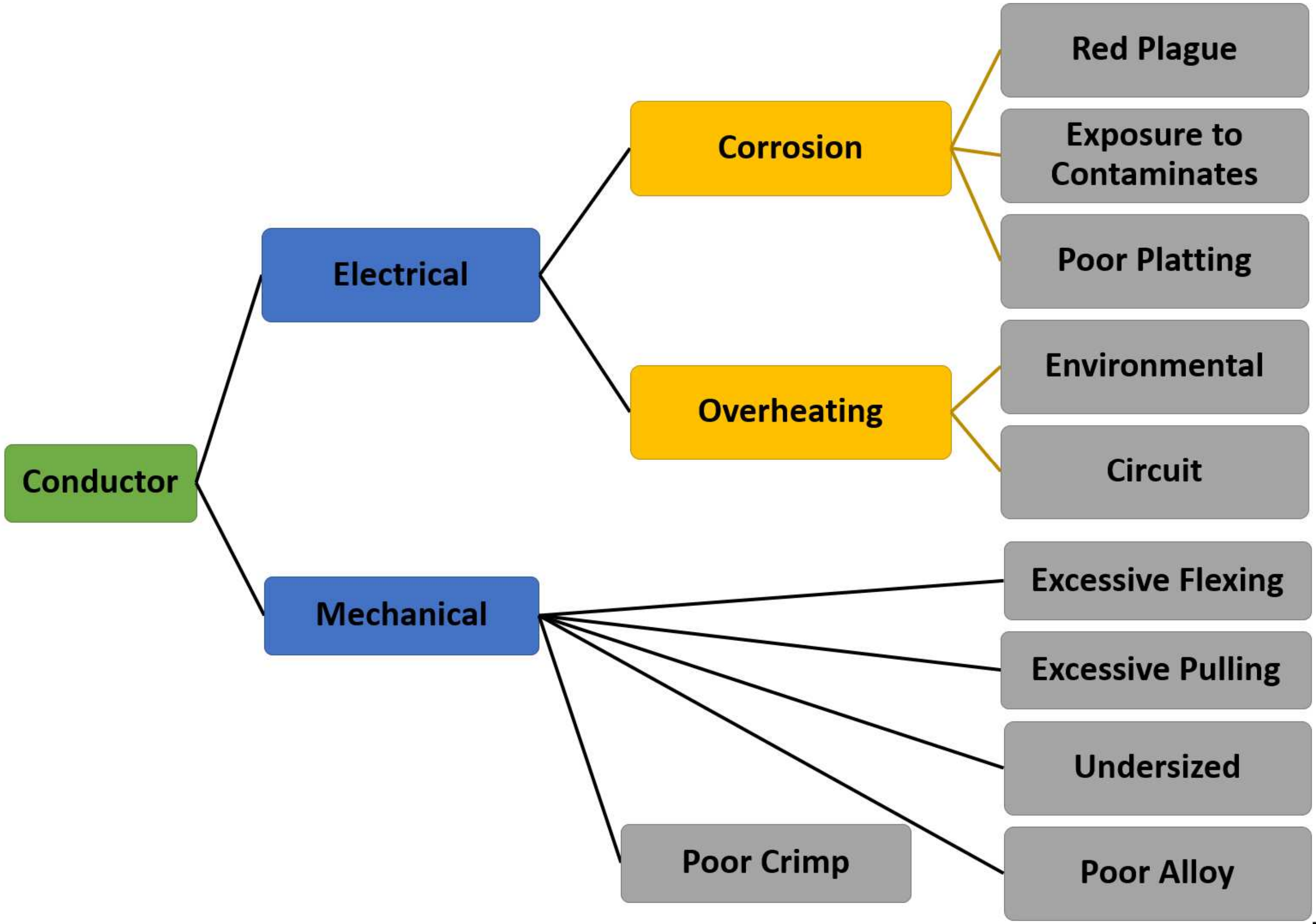


How Can Wires/Cables Fail

Lectromec



How Can Wires/Cables Fail



Wire System Sustainment

- Three ways to determine EWIS health
  - Visual inspection
  - Point to point testers
  - Degradation assessment

Sustainment – Visual Examination – The Good

Lectromec

- Requires little tooling
- A thorough inspection can find major problems
- Can be done with limited setup time
- FAA EWIS Job Aid provides a good starting point for visual inspection

Sustainment – Visual Examination – The Bad

- Trained inspectors can easily miss wire system problems.
  - Lectromec participated in a FAA retired aircraft inspection.
  - A visual inspection team inspected the same harnesses separately.
  - Using advanced tooling, Lectromec found approximately **60** instances of damaged wiring insulation.
  - The trained visual inspection team only detected **two**.

Sustainment – How to Evaluate

Lectromec

- Point to point testing equipment.
- Places a voltage or pulse (possible high voltage) on a circuit to look for shorts, breaks, impedance changes.
- Programs can be setup to specifically test a given harness and can be compared against past results.
- Technology has improved significantly in last decade.

Sustainment – How to Evaluate

Lectromec

- Effectiveness of automated wire system testing has been shown. Best data available from Navy Air Systems.

- Found with the used of automated wire system testing resulted in fewer EWIS related maintenance issues.

AWTS Tested Aircraft	Pre PMI	Post PMI
Total # of Aircraft Repair Actions	592	356
Total Flight Hours	858.5	1,043.3

Sustainment – How to Evaluate

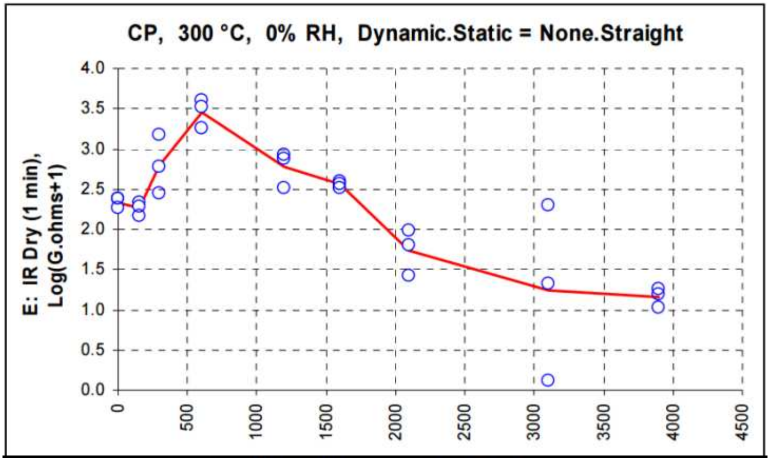
Lectromec

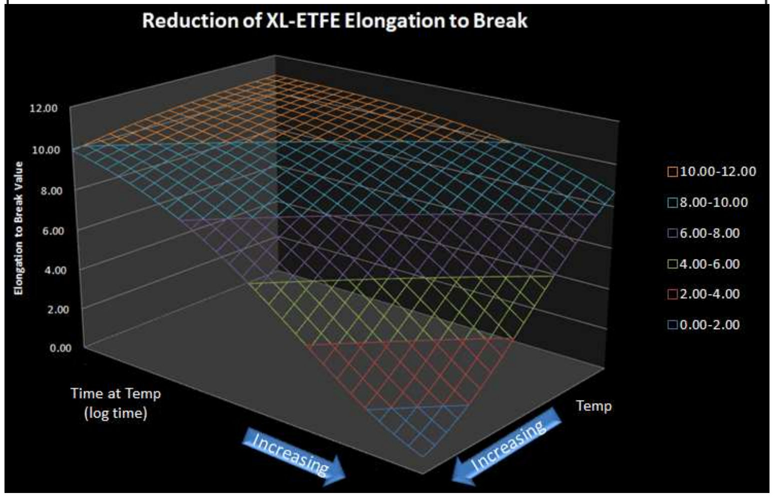
- Significant caution must be when evaluating fuel tank system wiring.
- Cannot be used to find wire/cable insulation degradation.
- Can have a long setup time both for hardware and software.

Sustainment – Degradation Assessment

Lectromec

- Remaining life of EWIS components can be predicted.
- Degradation assessment can identify the current health of the EWIS.
- With knowledge of component age and background research, models can predict the remaining reliable life of EWIS up to twenty years.





Sustainment – Degradation Assessment

Lectromec

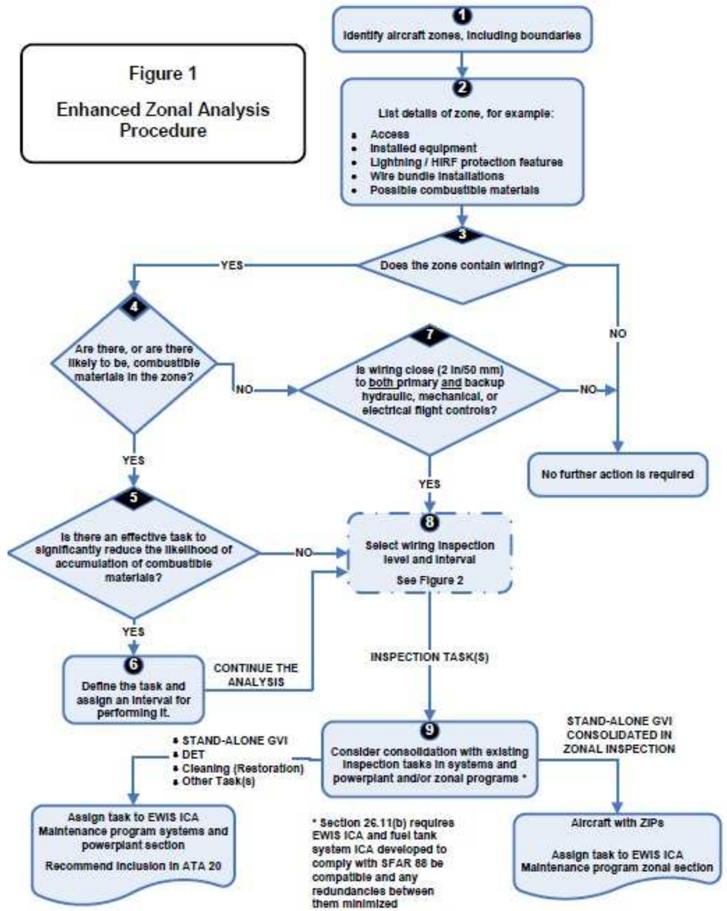
- Example of degradation assessment performed on wiring for >20 year old fleet.
- Several zones were examined: Two zones identified wire replacement need in 9-14 years.

	Years	Zone #1	Zone #2	Zone #3	Zone #4
Best Case Condition	0	71%	64%	61%	86%
	5	67%	60%	56%	83%
	10	64%	56%	52%	81%
	15	61%	52%	48%	79%
	20	58%	49%	44%	77%
Worst Case Condition	0	68%	61%	58%	82%
	5	64%	57%	53%	80%
	10	61%	53%	49%	78%
	15	58%	49%	45%	76%
	20	55%	46%	42%	75%
Years Until Recommended Replacement (Best Case)		>20	18	12	>20
Years Until Recommended Replacement (Worst Case)		>20	14	9	>20
Years Until Recommended Inspection (Best Case)		9	0	0	>20
Years Until Recommended Inspection (Worst Case)		4	0	0	>20

EWIS Inspection Interval – How Often?

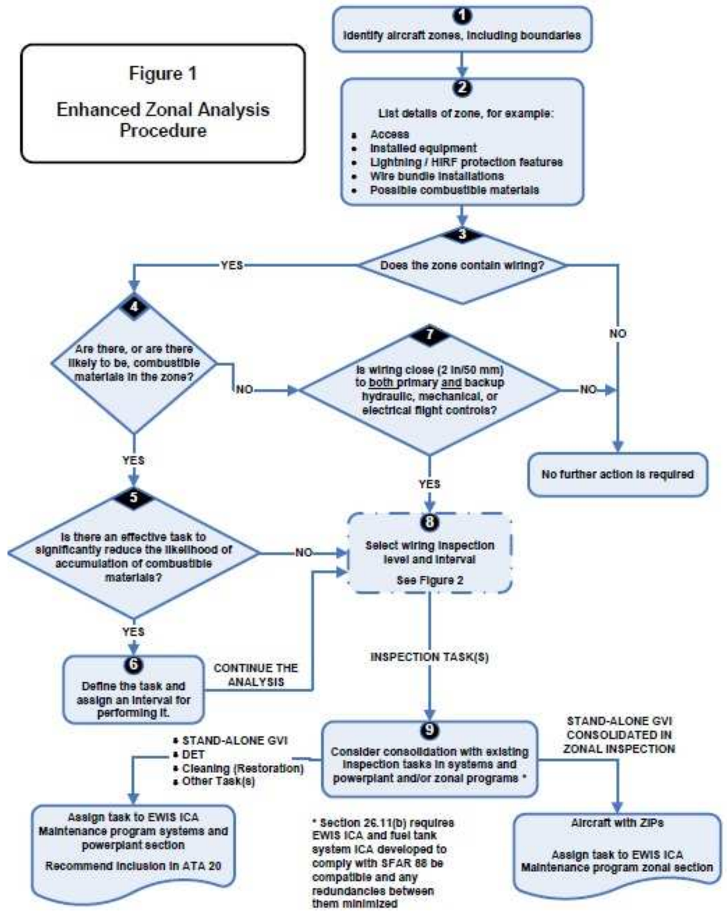
Lectromec

- The Enhanced Zonal Awareness Procedures (EZAP) was introduced in 2005 (AC 25.1701-1)
- This required existing fleet operators to develop plans for regular assessment and inspection of the Electrical Wire Interconnection System (EWIS).



EWIS Inspection Interval – How Often?

- The EZAP process must cover the inspection interval and specific cleaning tasks for each zone to minimize the presence of combustible materials.
- General Visual Inspection (GVI) and Detailed Visual Inspection (DET).
- GVI is described as a limited inspection within touching distance of the wiring within a zone.
- The DET is an intensive wire bundle examination that may include mirrors, magnifying lens, or other tools to assist in physical examination of the wiring.



Takeaway #1 – The Complexity is Increasing

Lectromec

- The concepts of More Electric Aircraft (MEA) mean that more components are being electrically driven.
- The system noise and power requirements mean that more complex EWIS components are needed to support these systems.
- With increased component complexity comes increase maintenance and modification complexity.

Takeaway #2 – The Tools are Changing

Lectromec

- A good multimeter and a set of crimping tools are not enough to maintain the EWIS.
- There are engineering and maintenance tools to evaluate the wiring systems are evolving.
- Technologies for health evaluation and remaining life prediction are also improving and can help with maintenance forecasting.

Takeaway #3 – Available Information

Lectromec

There is a lot of information publicly available on EWIS.

- Articles and Whitepapers: www.lectromec.com
- How to Videos and Reports: http://www.navair.navy.mil/jswag/
- Guidance: https://www.faa.gov/search/?omni=MainSearch&q=EWIS
- Supplier websites

THANK YOU

+1 (703) 263-7100

mtraskos@lectromec.com

info@lectromec.com

www.lectromec.com