Design factors influencing Wiring of an Aircraft

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Abstract *— Location of the wiring in the aircraft determines the combination of vibration, moisture, heat and physical installation stresses that the wire will be exposed to. Different locations will have some or all of these factors, and at varying levels, and as such, the aging rates will vary. FAR Part 25.1353, paragraph (a) defines the requirement to prevent a single point failure in electrical equipment, controls and wiring, and states: "Electrical equipment, controls, and wiring must be installed so that operation of any one unit or system will not adversely affect the simultaneous operation of any other electrical unit essential to the safe operation." Paragraph (b) deals with the wire grouping, routing and spacing, and states: "Cables must be grouped, routed, and spaced so that damage to essential circuits will be minimized if there are faults in heavy current carrying cables." So, the factors which influence wiring design of aircraft systems should be addressed properly. This paper describes about the factors that degrade the EWIS and guidelines about the wiring components which play important role in EWIS*

Keywords — *Wiring, degradation, bundles etc..*

I. Introduction

Many aircraft have been in service for around thirty years and the wiring installations have generally performed very well, with only one aircraft accident currently attributable to wiring failure. However numerous aircraft accidents investigated by international agencies implicate deteriorated wiring as a major contributing factor. While varying amounts of wiring have been replaced in aircraft, all airframes contain a substantial amount of original wire that has obviously deteriorated to some degree since its installation.

Wire insulation deteriorates through factors such as chronological ageing and temperature cycling over which we have no control; however we do have control over other factors such as incorrect or inappropriate maintenance procedures. Wire may appear to be robust and strong; however minor abuse or apparently insignificant damage will exacerbate deterioration of the insulation with time.

Maintenance activity can vary greatly from aircraft to aircraft. The disruptive effects of maintenance activity can be more random than the environmental factors that can lead to accelerated wire degradation. Maintenance practices should focus on maintaining the integrity of the wiring system.

II. LITERATURE SURVEY

In the late 1980s, wiring safety concerns are raised due accidents & incidents. Investigations found common degrading factors in airplane electrical wiring systems. Lot of Investigations into wiring issues is done by industry, civil aviation authorities and other government agencies.

III. WIRING DEGRADATION

Historically, wiring and associated components are installed without much thought given to the aging aspects:

- Fit and forget.
- Unanticipated failure modes and their severity.
  - Arc tracking.
  - Arcing.
  - Insulation flashover.

Wiring needs to be treated as an important system on airplanes. Wiring is now referred to as the Electrical Wiring Interconnection System (EWIS). EWIS defined as 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 between two or more intended termination points. EWIS is not any portable devices or an Electrical equipment or avionics qualified to acceptable environmental conditions and testing procedures.

The manner in which wiring degrades is therefore dependent upon the wire type, how it was originally installed, the overall time and environment exposed to in service, and how the wiring was maintained.

IV. CAUSES OF WIRE DEGRADATION

The investigation of the aircraft wiring revealed there are several factors, together with time, that play a role in wiring degradation.

Wiring is affected by:

A. Vibration **-** High vibration areas tend to accelerate degradation over time, resulting in "chattering" contacts and intermittent symptoms. High vibration can also cause tie-wraps, or string ties to damage insulation. In addition, high vibration will exacerbate any existing problem with wire insulation cracking and wiring installed with inadequate support (loose clamps & tie-wraps) and clearances.

B. Moisture **-** High moisture areas generally accelerate corrosion of terminals, pins, sockets, and conductors. It should be noted that wiring installed in clean, dry areas with moderate temperatures appears to hold up well.

C. Maintenance **-** Maintenance activities, if done carelessly and improperly, can contribute to long term problems and wiring degradation. Repairs made to minimum airworthiness standards may have limited durability and should be evaluated to ascertain if rework may be necessary. Repairs that conform to manufacturers recommended maintenance practices are generally considered permanent and should not require rework. e.g. Metal shavings and debris have been discovered on wire bundles after maintenance or repairs have been conducted. As a general rule, wiring that is undisturbed will have less degradation than wiring that is reworked. As wiring and components become more brittle with age, this effect becomes more pronounced.

D. Indirect Damage **-** Events such as pneumatic duct ruptures can cause damage that, while not initially evident, can later cause wiring problems. When such an event has occurred, surrounding wire should be carefully inspected to ensure no damage is evident.

E. Chemical Contamination **-** Chemicals such as hydraulic fluid, battery electrolytes, fuel, corrosion inhibiting compounds, waste system chemicals, cleaning agents, de-icing fluids, paint, and soft drinks can contribute to degradation of wiring. Insignificant things like spills of medication left in a wiring loom can contribute to wiring damage. Wiring in the vicinity of these chemicals should be inspected for damage or degradation.

Recommended original equipment manufacturer cleaning instructions should be followed. Hydraulic fluids, for example, require special consideration. Hydraulic fluid is very damaging to connector grommet and wire bundle, clamps, leading to indirect damage, such as arcing and chafing. Wiring that may have been exposed to hydraulic fluid should be given special attention during wiring inspections.

F. Heat **-** Wiring exposed to high heat can accelerate degradation, insulation dryness, and cracking. Direct contact with a high heat source can quickly damage insulation. Even low levels of heat can degrade wiring over long periods of time. This type of degradation is sometimes seen on engines, in galleys, and behind lights.

• Cleaning - Overzealous cleaning and use of inappropriate solvents can cause rapid wiring degradation

The history states "how the wiring is installed" has a direct effect on wire degradation. In other words, wiring that is not selected or installed properly has an increased potential to degrade at an accelerated rate Therefore, good aircraft wiring practices are a fundamental requirement for wiring to remain safely intact.

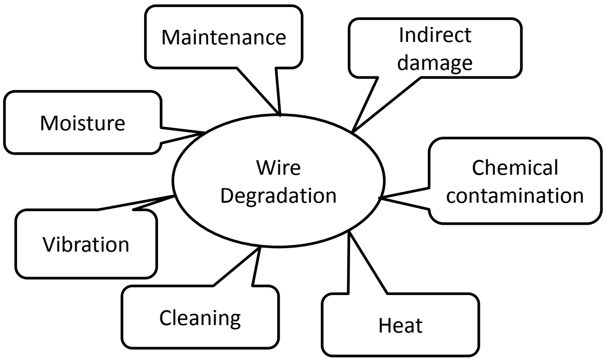


Fig. 1 Wire degradation factors

V: GUIDELINES OF WIRING

A. Load Analysis:

- Ensure that total electrical load can be safely controlled or managed within rated limits of affected components of aircraft's electrical system.
- New or additional electrical devices should not be installed without an electrical load analysis

B. Circuit Breaker Devices:

- Must be sized to open before current rating of attached wire is exceeded, or before cumulative rating of all connected loads is exceeded, whichever is lower.
- Protective devices as CB's to be used to minimize distress to the electrical system and minimize hazard to the airplane in the event of wiring faults or serious malfunction of the system or connected equipment.

C. Wire Selection:

- Have sufficient mechanical strength.
- Do not exceed allowable voltage drop levels.
- Are protected by circuit protection devices.
- Meet circuit current-carrying requirements.

D. Clamping:

- Support wires by suitable clamps, grommets, or other devices at intervals of not more that 24 inches.
- Supporting devices should be of suitable size and type with wire and/or cables held securely in place without damage to wire or wire insulation.

E. Clamp distortion:

Distortion may happen due to improper clamp position with distortion of the rubber at the top of one clamp and bottom of another clamp. Distorted clamps/clamp grommets can cause wire bundle damage over time.

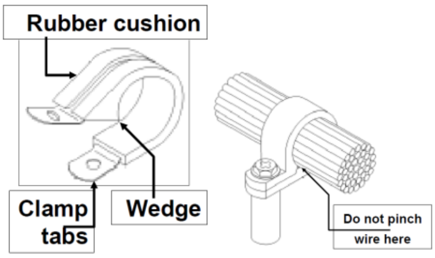
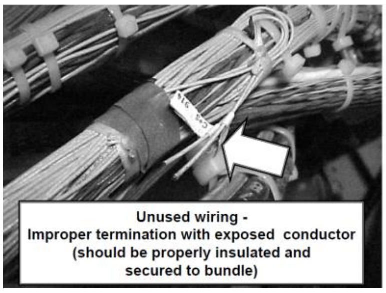


Fig. 2: Clamp Installation

F. Unused Wires:

- Ensure that unused wires are individually dead-ended, tied into a bundle, and secured to a permanent structure.
- Each wire should have strands cut even with the insulation and a pre-insulated closed end connector or a 1-inch piece of insulating tubing placed over the wire with its end folded back and tied.



- In few cases we use coiling and stowing method for wiring as shown in figure to safely secure the wire bundle to prevent excessive movement or contact with other equipment that could damage the EWIS.

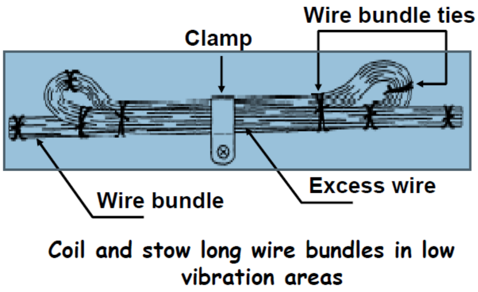


Fig. 3: Unused Wires

G. Terminal lugs:

- Connect wiring to terminal block studs.
- No more than 4 lugs, or 3 lugs and a bus bar, per stud.
- Lug hole size should match stud diameter.

H. Conductor Stranding:

- Minimizes fatigue breakage.
- Plated because bare copper develops surface oxide film. Usually different plating's used are:
  Tin < 150° C
  Silver < 200° C
  Nickel < 260° C

G. Wire Substitution for Repairs and Maintenance

There are few observations where Wiring that has been subjected to chafing or fraying, that has been damaged or that primary insulation is suspected of being penetrated. Chances of cracks on wiring when slightly flexed or insulation damage due to over heating or deterioration of wire due to effects of electrolyte.

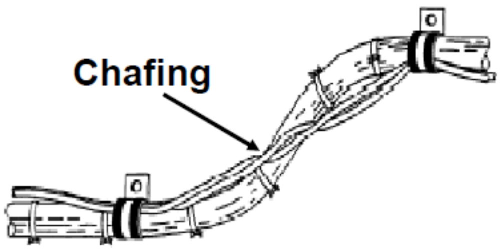


Fig. 4: Example of improper Chafing

- When replacement wire is required, review aircraft maintenance manual to determine if original aircraft manufacturer (OAM) has approved any substitution.
- Wire should be replaced when:
  - Wire bears evidence of being crushed or kinked

  - Shield on shielded wire if frayed and/or corroded
  - Wire shows evidence of breaks, cracks, dirt, or moisture in plastic sleeving
  - Sections of wire have splices occurring at less than 10-ft intervals
- Replacement wires must have the same shielding characteristics as the original wire, such as shield optical coverage and resistance per unit length.
- Replacement wires should not be installed outside the bundle shield.

H. Wiring routing:

- Eliminate potential for chafing against structure or other components.
- Position to eliminate/minimize use as handhold or support.
- Minimize exposure to damage by maintenance crews or shifting cargo.
- Avoid battery electrolytes or other corrosive fluids.
- Protect wires in wheel wells and other exposed areas.
- Route wires above fluid lines, if practicable.
- Use drip loops to control fluids or condensed moisture.
- Keep slack to allow maintenance and prevent mechanical strain.

I. Wire Bend radii:

- Minimum bend radius - 10 times the outside diameter of the largest wire or cable in the group — unsupported.
- Exceptions
  - Terminations/reversing direction in bundle (supported at both ends of loop) - 3 times the diameter.
  - RF cables - 6 times the diameter.
  - Thermocouple wire - 20 times the diameter.

J. Wire Splicing:

- Keep to a minimum.
- Avoid in high vibration areas.
- Locate to permit inspection.
- Stagger in bundles to minimize increase in bundle size.
- Use self-insulated splice connector, if possible.

K. Terminals:

- Tensile strength of the wire-to terminal joint should be at least the equivalent tensile strength of the wire.
- Resistance of the wire-to-terminal joint should be negligible relative to the normal resistance of the wire.

L. Terminal lugs:

- Connect wiring to terminal block studs No more than 4 lugs, or 3 lugs and a bus bar, per stud.
- Lug hole size should match stud diameter.
  - Greatest diameter on bottom, smallest on top
  - Tightening terminal connections should not deform lugs

M. Grounding:

One of the more important factors in the design and maintenance of aircraft electrical systems is proper bonding and grounding. Inadequate bonding or grounding can lead to unreliable operation of systems, such as EMI, electrostatic discharge damage to sensitive electronics, personnel shock hazard, or damage from lightning strike.

If wires carrying return currents from different types of sources, such as signals or DC and AC generators, are connected to the same ground point or have a common connection in the return paths, an interaction of the currents will occur. This interaction may not be a problem, or it could be a major non repeatable anomaly.
To minimize the interaction between various return currents, different types of grounds should be identified and used.

- Types of grounding: AC returns, DC returns and others.
- Avoid mixing return currents from various sources.
- Noise will be coupled from one source to another.
- Design of ground path should be given as much attention as other leads in the system.
- Grounding should provide constant impedance.
- Ground equipment items externally even when internally grounded.
- Avoid direct connections to magnesium structure for ground return.
- Accommodate normal and fault currents of system without creating excessive voltage drop or damage to structure.
- Give special attention to composite aircraft.

N. Bonding:

- Low impedance paths to aircraft structure required for electronic equipment to provide radio frequency return circuits.
- Facilitates reduction in EMI for most electrical equipment.
- Cases of components that produce EMI should be grounded to structure.
- Electrically connecting conductive exterior airframe components through mechanical joints, conductive hinges, or bond straps.
- Required for all isolated conducting parts with area greater than 3 in2 and a linear dimension over 3" subjected to appreciable electrostatic charging due to precipitation, fluid, or air in motion.

O. Wire marking:

- There can be serious repercussions when there is a situation in which a number of unmarked cables are disconnected. When the cables reconnected, the chances are high that they will be connected incorrectly, thus causing numerous problems.
- Wire marking is necessary for:
  - Safety of operation
  - Safety to maintenance personnel
  - Ease of maintenance
- To identify performance capability, use wire material part number and five digit/letter code identifying manufacturer.
- Wire identification marks identify wire, circuit, and gauge size.
- Markings should be legible in size, type, and color at 15-inch maximum intervals along the wire [directly on wire or indirect (sleeve/tag)]
- <3 inches needs no marking.

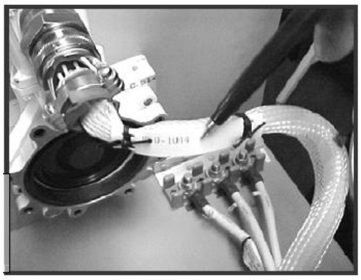


Fig. 5: Proper Wire marking

P. Connectors:

The proper choice and application of connectors is a significant part of the aircraft EWIS system. Connectors should be kept to a minimum, selected, and installed to provide the maximum degree of safety and reliability to the aircraft. For the installation of any particular connector assembly, the specification of the manufacturer should be followed.

The connector used for each application should be selected only after a careful determination of the electrical and environmental requirements. Consider the size, weight, tooling, logistic, maintenance support, and compatibility with standardization programs.

- There are many types, however crimped contacts generally used
  - Circular type
  - Rectangular
  - Module blocks
- Selected to provide maximum degree of safety and reliability given electrical and environmental requirements
  - Usage of environmentally-sealed connectors to prevent moisture penetration.

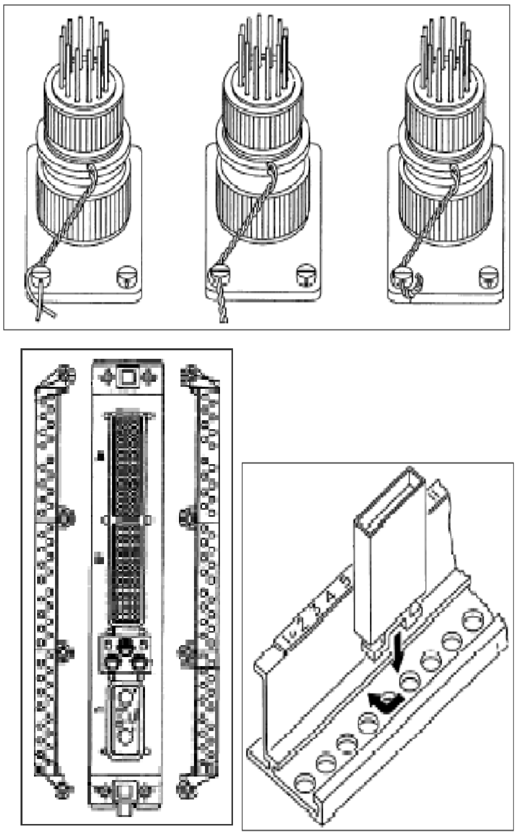


Fig. 6: Connector Types

Q. Conduits:

- Purpose
  - Mechanical protection of wires and cables
  - Grouping and routing wires
- Standards

- Absence of abrasion at end fittings
- Proper clamping
- Adequate drain holes free of obstructions
- Minimized damage from moving objects
- Proper bend radii

Do not locate conduit where service or maintenance personnel might use as handhold or footstep. Provide inspectable drain holes at the lowest point in conduit run — remove drilling burrs carefully. Support conduit to prevent chafing against structure and avoid stressing end fittings.

R. Wire Insulation Properties:

- Chose characteristics based on environment
  - Abrasion resistance
  - Arc resistance
  - Corrosion resistance
  - Cut-through strength
  - Dielectric strength
  - Flame resistant
  - Mechanical strength
  - Smoke emission
  - Fluid resistance
  - Heat distortion

V. CONCLUSIONS

EWIS is a very complex and important system because of the cross linking with various equipment and systems. So EWIS wiring design is an important factor to be considered while selecting the components. Following need to be checked:

- Determine if the type of wiring protection is appropriate for a given environment.
- Determine if the number and type of clamps, the feed throughs/pass throughs, and conduits selected are appropriate.
- Evaluate the routing of the wire to ensure it has been done in an optimum manner to prevent damage. Determine if the circuit breakers, conductors, and connectors are sized appropriately.
- Identify what wiring information has to be in the Instructions for Continued Airworthiness.

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