A PLANNED MAINTENANCE PROGRAM FOR AIRCRAFT WIRING

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Abstract
Aging wiring has been identified as a national concern and is a major topic for those involved in aerospace electrical systems. This paper identifies some of the major contributions why wiring installed on legacy aircraft has taken center stage. It suggests a planned approach to enhance wiring safety that will improve electronic system performance and reliability [1]. We suggest a two pronged approach:

1. Become cognizant of the technical and operational issues that govern electronic systems robustness and determination of useful life. This is accomplished by providing training to those individuals directly exposed to the aircraft electrical systems during operations. Training can aid management, engineering and technical positions by providing the latest practices that are applicable to the tasks at hand.

2. Apply available technology complementary to the issues of legacy and new design aircraft for systems level diagnostics, prognostics and enhanced life expectancy [2].

Several alternatives in obtaining both of these objectives will be presented in this document and is only meant to stimulate the thinking of those readers involved in the everyday operations of aircraft into a more proactive approach to maintaining aircraft electrical systems.

According to an FAA study conducted in 1998 "current maintenance practices do not adequately address wiring components (wire, wire bundles, connectors, clamps, ground, shielding) or their effect on electronic systems. Inspection criteria are too general. Typically a zonal inspection task card for wiring states: ‘Perform a general inspection’. Important details pertaining to unacceptable conditions are lacking. Airlines report shortcomings in the manufacture maintenance and repair manual on wire. The current arrangement of standard practices makes it difficult for an aircraft maintenance technician to locate and extract the pertinent and applicable data necessary to effect a satisfactory repair. Wire replacement is not adequate. Under current maintenance philosophy wire in conduit is not inspected. Onsite inspection and reporting indicate many examples of improper installation and repair of wiring. A review of incidence reports and maintenance records indicate that current reporting systems lack visibility for wire making it difficult to identify wire failures. These difficulties can be overcome by development and use of non-destructive test (NDT) tools to assess the state of wiring in aircraft.”

Introduction
The above statement defines fairly well where the industry’s practices are today. This paper defines some of the phenomenology that is taking place in wiring during the process of deterioration [3]. As technology becomes obsolete, operators need to take actions that reduce maintenance dollars (and Time) incurred to support such platforms. Training at all levels is “KEY”, and a systems engineering approach is necessary to arrive at a solution to this extremely complicated aircraft subsystem (wiring)[4].

When aircraft are manufactured, wiring and electronic systems are baselined. This is first done by the manufacturer prior to the certification process of the aircraft in a large simulation laboratory. Then again in an electronic flight test aircraft as part of the certification process and again to a lesser degree to the delivery aircraft prior to the customer receiving the aircraft. The customer has already received the series of manufacturer prepared maintenance manuals which are integrated into the repair station license of the operator in preparation for receiving delivery of new aircraft. The manual will cover in some degree of detail the tools and procedures for condition monitoring. This covers the non-destructive test manuals covering required maintenance and overhaul of the baselined
items. The manual inspection methods detail visual and hand-held operator dependent equipment and processes which are not as through as the original manufacturer inspection equipment and processes used in aircraft assembly and testing. To insure a no growth design, the original inspection test results and noted defects must be supplied to the aircraft customer to further monitor and test for any performance degradation and in-service faults. Non advanced technology industry wide inspection methods for required field level aircraft maintenance and overhaul are not capable of precision mapping of systems performance and fault location and characteristics compared to the original manufactures' inspection baseline.

The industry is gradually turning to condition based maintenance from time based maintenance. Condition based maintenance (CBM) is a process that provides cost effective maintenance through the extensive use of sensing technology, sophisticated software programming and computer processing. CBM provides the benefit of lowering maintenance costs while providing warning of future unsafe conditions before they take places where time based maintenance conditions cannot [4].

Current or time-based maintenance requires inspections at regular time intervals to find and repair defects. The inspection interval is defined based on an average time a particular defect would require to progress into an unsafe or non-useable condition. Since the interval is determined by fleet averages it is insufficient for those aircraft that operate in particularly severe environments. CBM relies on sensor technology that can accurately acquire data on wire and other electronic equipment.

When aircraft are manufactured their wiring and electronic systems must be base-lined. As the aircraft ages the same systems need to be condition monitored as part of a condition monitoring maintenance (CBM) program. By obtaining base line data and monitoring trends for the life of the aircraft it is possible to plan for maintenance actions instead of responding to a system failure, mission failure or experience the risk of an in-flight fire or wire event.

**Condition Of The Fleet**

The average age of commercial and military aircraft has increased dramatically over the past 3 decades and the burden for maintaining aircraft with high service and cycle times has become a major challenge to the economic and technical abilities of all operators. Much of this difficulty is caused by non-availability or non-use by the operators of advanced technology tooling for applying adequate diagnostic processes to maintenance, lacking the availability of prognostic software programming, mediation of fault occurrence and verification processes after repair for total health management.

Testing for systems component condition, systems performance and systems circuit stability must be understand and incorporated into avionics systems diagnostics and prognostics (Figures 1-9). What is in common use today provides only connectivity and conductivity information of the wiring system. The more advanced NDT systems on the market add fault location, insulation degradation (wire insulation cracking, voids, and chafing information and insulation voltage breakdown strength), system conformity to drawings and some degree of prognostics. However, few systems begin to approach this capable. Until we provide systems related information at this level and above concerning the functional operational complexity of the avionics system to be tested we will not comprehend the

| Table 1. Antidotal Causation Of Electrical Faults |
|-----------------|--------------------------------------------------|
| Percent         | Specifics Concerning Wiring Faults               |
| 90%             | Faults repeated aircraft to aircraft of a single type by kind & location |
| 10%             | Fault types that are seldom encountered and hard to detect |
| 80%             | Faults that are human induced                    |
| 25%             | Effectiveness of visual inspection               |
| 95+%            | Effectiveness of advanced wire inspection techniques |
| 20 X            | The number of times a fault may have to be repaired until it is correct |

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full nature of the issues we face or meet our goal of near zero avionics systems failures [5]. Wiring is only part of the electrical system. The system also includes connectors, circuit breakers, transformers, relays, power distribution panels, LRU/LRM, antennas, generators, etc. These components are often electronic in the modern aircraft. Electronic systems degraded performance can occur at almost any time during the useful life of the aircraft.

Figure 1. Wire Testing In Progress. The Yellow Boxes Are Used To Test For Connectivity, Conductivity, Insulation Condition And Conformity To Drawings

Figure 2. Systems Diagnostics And Fault Locating Through Reflectometry

Technology For Legacy Aircraft

The probability of failure in several hundred miles of wire in a typical transport aircraft is significant. This and the high risk of fire, smoke or wire event has reached sufficient proportions to drive into existence a national wire program. Several non-destructive test devices are on the market, most use intrusive methods for performing wire diagnostics and locating the fault, prognostics, repair support and repair verification.

These advanced tools are the cost reducing elements for reaching an economical proactive wire maintenance program. The restriction on prognostics is non-availability of adequate software programs. In some cases standardized software programs are being adapted to fill the void.

Table 1: defines why systems faults take place. Figures 1 through 9 are examples of advanced test equipment for diagnostics. When used at the systems level faults can be found and their location determined within inches. Data from the hand held reflectometer and signal analyzer can be processed for trend analysis and overlaid against fleet wide charts, the avionics system tested for performance, the systems deterioration rate defined and previous repair information obtained manually. Software will soon be available to predict useful remaining life. Field use of the hand held equipment is just now beginning for legacy aircraft. Figure 3 is a combination signal generator and signal analyzer capable of measuring path-loss of a wire system and can be used to define minimum standards that a system can be allowed to degrade. This adds to the available tool set and processes for condition monitoring. Path-loss is the relative ability of an electronic signal to transition from source to load as a transmission line verses free space measured in dB.

Figures 1 through 6 are quite powerful diagnostic tools when operated together with a laptop and appropriate software programs. The diagnostic and prognostic technology must compliment both the level of electrical/electronic technology used in legacy aircraft and designed to recognize specialized installation issues. Wire systems diagnostics and prognostics must be effective without being destructive. However, to be effective data must be obtained from legacy aircraft on an intrusive basis. Only when electrical systems change-out is considered will technology for new design be used on legacy aircraft and be based on economical reasons.
The Process Of Condition Based Maintenance

Condition based maintenance works equally well for (metal/composite) structures as it does for electronics. The following is a simplified explanation in structural parlance and provided for the purpose of clarity and understandability. Monolithic CFRP design requires only single sided access using ultrasonics as a means of inspection. To achieve "no growth design," full laser ultrasonics testing data in which defects are noted and mapped must be monitored for the life of the aircraft (monitor composite delamination growth, lack of bond, air bubbles and voids.)
inspection equipment and processes used in aircraft assembly and testing.

To ensure a "no growth" design, the original inspection scans and noted defects must be supplied to the aircraft customer to further monitor and test for any defect growth and new in-service defects. Present industry-wide inspection methods for required field-level aircraft maintenance and overhaul are not capable of distinguishing growth or precision mapping defect size and location (compared to the original manufacturers' inspection baseline.)

What this technology offers the operator is the capability to precisely monitor electrical and metal/composite defect growth (deterioration process) to specific aircraft part coordinates/systems performance overlaying the results as more in-service hours are accumulated, which results in predictive modeling and trend analysis of such aircraft systems performance, part defects and failure, whether structural or electronic.

Condition based monitoring methods, precise monitoring of such aircraft defects, predictive modeling and trend analysis reports allows the operators the capability to monitor in-service aircraft condition as well as ensuring that operators are accomplishing proper maintenance and overhaul in accordance with manufacturer guidelines. A system of using multiple advanced nondestructive inspection methods (which precisely finds any aircraft systems defects) provides the operator a true, accurate condition of the model, series aircraft fleet. Aircraft inspections of 4-5 year intervals would dramatically improve in-flight safety, decrease liability for the operators as well as boost public opinion that here is a manufacturer and operator that has the best aircraft and in-service maintenance program and really cares about aircraft safety and human life.

Technology For New Design Aircraft Wiring

For new design an option for monitoring load distribution systems is fiber optics [7]. It performs distributed temperature sensing along the length of the cables and at the load centers. Fiber optics provides a continuous fast, repeatable measurement, in real time of the location and temperature of the sensor at many thousands of points along the optical fiber. The system is composed of a distributed temperature sensor opto-electronics unit and a fiber optic sensor. This information opens up a range of decision-making options not only for the power cable, but also the entire circuit.

- Provides condition monitoring & checks cable Integrity
- Identifies hot spots
- Provides a cable temperature footprint
- Provides a thermal profile
- Provides fire detection in a cable duct
- Can activate an alarm in an overheat situation

![Figure 7. Thermal Optical Sensor Cable for Power Distribution Application. (Courtesy of Luna)](image)

Normally long term increasing temperature changes indicates a loss of system function, high leakage current or impending failure. Wire deterioration can remain hidden until a secondary failure occurs resulting in a high cost of repair, risk of fire or wire event and loss of system function. Because the temperature data is collected from positional information the system provides total temperature profiling with no prior knowledge of the power cables characteristics or inherent weak spots.

Where data profiling is required the system is cost effective and simplifies installation, maintenance and calibration. The temperature profile of Figure 8 is an example from a power cable where the insulation has broken down near the center of a two-mile section of wire.
Figure 8. Breach In Insulation Of A Power Cable Midway Down A Two-mile Section. (Courtesy of Luna)

Technology Principles

Temperature measurements and positions along the optical fiber are achieved by launching laser pulses down the fiber and analyzing the backscatter as shown in figure 9.

Figure 9. Technical Principles Of The Distributed Temperature Measurement System. (Courtesy of Luna)

Recommendations and Conclusions

Electrical and structural systems of today can be monitored for temperature, corrosion, cracking, chemical composition, pressure oil contamination and strain for starters. When these sensors are integrated with sophisticated software they can be combined into a system that measures all (if desired) critical functions in real time and relay that information back to the operators technical operations center for immediate action. This will create the next generation of aircraft health management capability. Work is being conducted on aircraft today to determine if original installation and retrofit is possible using a wireless LAN for data collection without interference to open ended systems.

Condition based maintenance (CBM) and sophisticated software augmented by optical sensors offers the aviation industry one of the greatest breakthroughs with the reduction of maintenance costs to nearly half with a parallel increase in flight safety when maintenance is scheduled on a production basis under planned conditions. Knowing life remaining for critical components allows the health monitoring of the aircraft while still in-service.

References


Disclaimer

This is one of a series of papers describing potential improvement over existing practices in use today to help ensure the continued airworthiness of all aircraft. It should be considered as a possible addition to the process of wire husbandry and condition based maintenance. It is offered as a possible technical addition to the FAA’s EAPAS program where applicable.