INSPECTION PROCESSES MUST COMPLIMENT SYSTEMS INSPECTED

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Abstract

Current wire system inspection processes do not compliment aircraft electrical and electronic systems technology nor do many proposed systems. The wire inspection tools in common use today can be represented by the volt/ohm meter, the meg/ohm meter, and visual techniques. The two meters only measure conductivity, connectivity, and voltage breakdown strength of the insulation. Visual techniques, mirror and flashlight methods can only reach about 25 percent of the aircraft wiring system and subjectively identify only physical faults of the insulation surface and simple damaged components, (Table 1). Little can be determined relative to the wire, wire insulation, wire bundle, connector, connector pins & backshell, wire supports, grounding, shielding or intended electrical systems performance as a transmission line and part of the larger avionics system of the aircraft. All items where data is necessary to analyze and manage the health of the wire system. In reaching the overall solution the community has gotten engrossed in the details of locating faults of a given wire and not always insitu.

Guidance material is not available for the electrical repairman to perform even a simplified zonal inspection to identify performance loss of a given wire. Existing instructions only call for 'perform a general inspection' [1]. Important details, even for locating physical faults of the electrical wiring are missing let alone some of the larger questions of wire useful life, repair schedules for the C & D checks based on delayed maintenance, etc., best tools and repair processes, consumables, etc. [2]. The user community also reports gross shortcomings in the guidance supplied by the manufacture’s maintenance and repair manuals on wiring systems. These limitations can be overcome by training for the aircraft designer, aircraft manufacturing personnel, certification specialists, and aircraft operations related personnel [3]. By developing a closer relationship between the avionics OEM and the aircraft fleet operator electrical/electronic systems can be placed under a condition based maintenance (CBM) program where the two entities can share in the combined responsibility for system performance. This allows the operator to concentrate on the aircraft wire systems performance and the avionics OEM on the LRU/LRM performance [4].

Table 1. Antidotal Causation of Electrical Faults

<table>
<thead>
<tr>
<th>Percent</th>
<th>Specifics Concerning Wiring Faults</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 %</td>
<td>Faults repeated aircraft to aircraft of a single type by kind &amp; location</td>
</tr>
<tr>
<td>10%</td>
<td>Fault types that are seldom encountered and hard to detect</td>
</tr>
<tr>
<td>80 %</td>
<td>Faults that are human induced</td>
</tr>
<tr>
<td>25 %</td>
<td>Effectiveness of visual inspection</td>
</tr>
<tr>
<td>95%+</td>
<td>Effectiveness of advanced wire inspection techniques</td>
</tr>
<tr>
<td>20 X</td>
<td>The number of times a fault may have to be repaired until it is correct</td>
</tr>
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The goal is to reduce cost and improve reliability. Far better methods for wire systems diagnostic, prognostic, mediation, repair, and validation of wire systems using non-destructive test (NDT) equipment are on the market or in development that would assist the aircraft operator of health management for aircraft wiring systems

Introduction

Two issues are clear when dealing with condition based monitoring and maintenance (CBM) of aircraft avionics (wiring) systems:

1. Awareness training for aircraft trade related personnel is key to avionics systems performance.
2. The technical training introduces the conceptual operation of advanced electronic

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avionics systems, the dominate mechanisms of systems failure and how the advanced diagnostic and prognostic test tooling stimulates the wire systems failure modes to identify not only the fault but also where in the system the fault is located [5].

The causes of systems failure and location of the fault are many, which requires considerable insight of the electronic repairman. The best method of inspection is to allow the fault induced electrical characteristics within the system to identify the nature of the fault and the fault’s location by using advanced technology test equipment [5].

Take several additional steps into the future and consider using inspection technology complimentary to the avionics system being tested. This allows moving forward into health management at the systems level where the entire aircraft avionics systems can be managed automatically. The sensors, wire systems, load centers, LRU/LRM, responders, displays, etc., all parts of the avionics system. Then download the processed information to the Technical Operations Center (TOC) in real time for planning corrective action. The electrical problem can now be corrected when and where appropriate to minimize any disruption in the scheduled flight operations. The repairman will know the problem ahead of time, where the problem exists and what is required to solve it with minimum disruption. This is possible today technically but the pieces are not all physically in place. This concept is already in operation for monitoring in real time engine performance by at least one major commercial operator. It has worked well and can be worked again on the avionics system through health management concepts and the integration of available technology [6].

**Technology Issues**

The avionics can be broken down by function into electrical load distribution systems (DC to 400 Hz), signal/sensor/COMNAV (high frequency) and flight critical control systems (high frequency). Each of these systems requires a slightly different application in the use of test electronics for looking into and testing for required systems performance and possible location of faults. At a minimum, to cleanup legacy aircraft wire systems baselining and CBM is required at several levels. Each level of wire systems testing varies by purpose, degree of difficulty and available schedule i.e. [7].

1. Depot, intermediates and flight line
2. Aircraft operator: Department of Defense or commercial operator (different mission)
3. Level of maintenance being performed:
   a. Diagnostics: detect, locate, repair, verification or
   b. Prognostics: obtain data for condition based monitoring and management to plan proactive actions

A critical area where technology has been forgotten or is an afterthought at best is performance monitoring, health management and advanced technology maintenance inspection. This is as critical for electrical systems as it is for structure, particularly composites and starts with the aircraft preliminary design. Wiring has been the cause of a number of high visibility accidents over the years. The aircraft designers in the past have not realized that baselining a system and condition monitoring it for the life of the aircraft go hand in hand. Advancing testing design and inspection processes have largely been overlooked in the design process of aircraft [8].

**Single and Double Ended Testing for Legacy Aircraft**

Balanced circuits can be single ended tested with a VSWReflectometer for systems performance. Systems performance is an excellent indicator of the state of health of the avionics system. Automatic Test Equipment (ATE) requires two ended testing and performs wire systems health in terms of conductivity, connectivity, wire systems insulation breakdown strength to ground, faulted system performance and conformity to design. This applies to most high-speed electronics but little attention has been given power systems to date.

Load distribution systems are often designed to use a common return thus ruling out the understanding we have gained in either the use of the SWReflectometer or the ATE. An additional fault that is found in many systems degradation is corrosion. Corrosion causes an increase in
impedance thus an increase in heating placing thermography as an additional option for testing the load distribution systems for faults. The question immediately raised, is does the corrosion exist in the wire system or the structural system return path.

**Programming Test System To Accommodate Wire System Operational Frequency**

Most electrical circuits in common use operate at low frequency and are considered to have lumped components, connected by perfect conductors with zero resistance and insignificant length. As electronic systems reach higher operating frequencies, above 300 MHz circuit component characteristics begin to change and the impedance in the conductor becomes significant \([S, 91]\). This change also affects the phase relationship between current and voltage and the inherent stability of the circuit. As these changes take place in the EUT circuits similar changes need to take place in the NDT and analysis equipment to define systems performance characteristics against norms and to recognize how frequency and degradation of the equivalent circuit effects the wire systems performance.

**Measured Characteristics By Single End Testing**

Circuit characteristics change with systems operating frequency and circuit faults such as a void in the insulation causing excessive leakage current (wet or dry arc fault) or increased circuit element impedance. Since circuits operating at high frequency usually are operating as a transmission line Reflectometry works well to define the existence of faults. This means the load impedance and line impedance is essentially equal or balanced. Each of these typical faults cause a changed in the circuit elements or a phase shift between the circuit voltage and current resulting in a change of the circuit stability and formation of standing waves. The purpose of the VSWReflectometer is to measure the SW reflections in the circuit \([10]\).

However, load distribution systems are often designed with common grounds where there is limited history for understand the practicable limitations of various inspection technologies.

**Desired Information From The Wire System**

The reflectometer reports the system as “OK”, “Degraded” or “Failed” and if a fault exists, where the fault is located. If this process has been previously accomplished across a fleet of aircraft (six or more) and the wire system performance downloaded to a notebook computer the good systems performance will be displayed as a perfect sine wave. Each aircraft of same type and system will display a similar sine wave overlaying all previously tested like systems, Figure 1(A). A degraded system will display an averaged sum of sine waves as shown in Figure 1(B) where the peaks appear clipped. A failed system will display nothing but unrecognizable confusion, Figure 1(C).

![Figure 1A. All Normal System Performance Overlay](image)

![Figure 1B. Degraded Performance, Multiple Overlays](image)
Data Processing, Systems Repair & Verification

By plotting performance trends for degraded and failed systems versus age on the same notebook computer useful remaining life is obtained. By plotting useful life and aircraft availability or next scheduled maintenance cycle the maintenance department can schedule repair of the system without any lost time in the operational use of the aircraft. However, experience has shown that after the aircraft wiring is cleaned up for older aircraft these faults can very often be detected and cleared in reasonably short time. Five minutes to detect and a half-hour or so to fix a simple failure like corrosion in a connector (Figure 2).

Figure 2. Hypothetical Curve for Useful Life

The curve in figure 2 is hypothetical and generalized from actual data obtained from a single system on each aircraft in a fleet of identical aircraft. The rate of wire deterioration was determined from paper records difficult to use in old files. Had condition based monitoring been in place this would have been the pattern unless non-electrical maintenance personnel had created an out-lier requiring earlier repair or replacement. In most populations today there will be one or two aircraft where several systems fall into this category. However, the tools are available to clean-up out-lier aircraft or decide the risk and cost is too great and the aircraft should be retired. Based on the information the Navy has provided on the P-3 aircraft the deterioration rate will vary by zone based on the environment that zone experiences.

The systems manufacturer, as in the case of TCAS specifies the minimum degraded standard for the cable and antenna system. The VHF standard has been established by user acceptance. Condition monitoring of all systems should be accomplished every 4 years or at the C and D check until nominal standards have been homed in on from experience for legacy aircraft and incorporated into the LRU learn how to use them [11].

Automatic Test Equipment

High-speed automatic test equipment (ATE) checks for faulted system performance, degraded insulation, wire systems connectivity, conductivity and conformity to systems design. This form of testing works for all avionics including load distribution systems. ATE assists in baselining and health monitoring of aircraft wire systems. By
integrating ATE and intelligent systems testing (IST) capability wire systems baselining and health monitoring has become practical, straightforward and economical. This capability can start at midlife for an aircraft or follow an aircraft from design to retirement. The wire systems architecture is captured in electronic media and used to drive automatic test and checkout software for the aircraft wire systems with the resulting data captured for further analysis and comparison to the original design.

Figure 4. A Hand Held VSWR Reflectometer

Figure 5. Wire System Design Verification On A Navy C-2 Aircraft

Describing The Tools And Tool Output

Figures 1A, 1B and 1C are the outputs from the reflectometer when displayed through the graphics of a notebook computer. Figure 2 is the display of useful life as collected by a combination of HP signal generator and signal analyzer and displayed on a notebook computer. Figure 3 is the wire condition data collected by the ATE equipment and displayed on a notebook computer. Figure 4 is a picture of the hand held VSWR Reflectometer. The reflectometer reads out directly whether a wire is OK, Degraded or Faulty.

Figure 6. Harness Testing at an Engine Overhaul Facility

Figure 5 is a picture of an ATE setup configured for testing a PW 2000 engine harness prior to engine run after rebuild. Figure 6 is an ATE setup for conducting configuration management following a rewire of a Navy C-2.

These units are portable and quick to set up, are ruggedized and designed for use during heavy maintenance, in the shop or on the flight line. This particular equipment has been certified to MIL-STD-810 for use on fueled aircraft. One simple wire harness connects the aircraft to the test equipment. Variations in aircraft subsystems only require simple changes in the wire harness and software. When a fault is located a standing wave reflectometer (VSWR) is used to pinpoint the fault to within inches for quick resolution.

Diagnostics, Prognostics and Verification

ATE contains a self-learn mode for a quick non-destructive test (NDT) to capture the subsystem path to the test equipment. Diagnostic, prognostic and automated data collecting software is used to collect and store data and information to map system impedance, trends, and useful life or apriori
information to guide preventive maintenance actions. These tools are also used for verification of correctness for all repairs [11].

**Cost Information, MH Comparisons**

A typical comparison in the efficiency of using automatic wire testing on an engine harness is 20 hours using conventional methods without data collection or analysis. This can be compared to 5 minutes using automatic wire testing. Each case requires up to 45-minutes to setup the adapter harness prior to testing. To open a single system for testing a setup time for the VSWR requires only 5 minutes in total to test a system for system performance and locate the fault if any. That is 240 times faster. It is not unusual in some wire systems to change out or repair a suspected fault 20 times before the fault is correctly located, repaired and verified. In this worst case where the fault has not been correctly defined the automatic system would be 4800 times faster.

Speed lines can also be established which produce very large cost reductions by reducing the number of processes necessary and accelerating major portions of the remaining activities. In one recent case this resulted in a cost saving for DOD of $30,000 per aircraft for

**Repair Information, Pictures, Manuals**

Repair manuals, repair procedures, various software analysis programs such as useful wire life remaining, circuit schematics, required repair tools parts and consumables are all contained in the notebook computer in electronic form.

**Recommendations & Conclusions**

- Wire systems data clearly indicates training of all aircraft related tradesmen and the common usage of advanced diagnostic, prognostic and verification tooling as the number one need to correct wiring issues. As the avionics issues are understood so too will the fire and wire event issues be understood.
- Aircraft avionics standards and commercial communications media standards need to be coordinated.

Avionics systems problems are increasing with the risk of accidents as Wi-Fi networks proliferate particularly from 802.11b protocol. This author has witnessed FAA certified flight critical systems receivers controlled and captured by FCC certified UWB PEDs. These phenomena take place without the aircrew having any reference of systems takeover until full capture takes place.

- Avionics wire standards, systems stability requirements and communications media standards, including media with virtually unlimited bandwidth and linear dynamic range need to be coordinated. Usually such documentation is found to be 20 to 40 years out of date.
- Establish an avionics systems husbandry program for each operator's fleet and incorporate avionics systems husbandry practices into their repair station license or consider the consequences resulting from not doing so. This program must establish a company wide awareness of aircraft related practices aimed at increasing the reliability of avionics systems and reducing the total avionics related maintenance costs. One facet of this program would be to establish a series of seminars relating to the care and well being of electrical/electronic avionics. Another would be to cleanup all foreign material where wiring is present, perform a fleet wide inspection of the wiring and LRU and LRM related items, perform a fleet wide wire systems health assessment.
- To reach the avionics systems reliability levels necessary for war fighters systems engineering practices must be incorporated into the electrical/electronic systems maintenance practices and the wiring/electronics/response element approached as an entire system.
- Transition to advanced technology wire/fiber optics communications media systems health management practices using advanced diagnostic/prognostic, mitigation and verification testing and
analysis equipment. Establish a contractual relationship with the avionics OEM relative to condition based maintenance (CBM) based around reliability improvement and MTBF/MTBUR ratios.
- Convert all record keeping to electronic media for both existing records and new records. Follow a system similar to the developing system described in the Navy’s AWIS Program.
- Incorporate a systems database of information relating to various avionics packages for both ATE and VSWReflectometer diagnostic tools. Master the software packages available for processing the database and conduct systems analysis. Compare avionics systems performance against systems design performance for both the ATE and VSWReflectometer.
- Follow industry wide efforts in the development of wire husbandry practices, training, systems diagnostics and prognostics, repair procedures for various communication media, verification techniques, and aircraft and fleet trend analysis.

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.