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Wire Integrity Field Survey of USAF Legacy Aircraft

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Introduction

Wiring is so fundamental to current aerospace equipment that we often forget it is a system unto itself. The aging of a wire system can result in loss of critical functions in equipment powered by the system or in loss of critical information regarding the operation of certain parts of the equipment. Either result can lead to catastrophic equipment failure or to smoke and fire. Consequently, the safety of aerospace wire systems is an issue of major importance to us all.

Background

Aging of wire systems was first identified as an issue of national concern for the United States as a result of the White House Commission on Aviation Safety and Security. Efforts to address wiring issues in aviation revealed that aging wiring affects all electrical and information systems. With public attention being drawn to commercial aircraft wiring issues, a White House Interagency Working Group (IWG) was formed in June 2000 to examine policy, programs, investment priorities, and direction across the Executive Branch. Findings by the White House IWG were published in a report titled Review of Federal Programs for Wire System Safety, issued in November 2000 (See Figure 1). This report can be found at: <http://scitech.dot.gov/polplan/wirerpt/index.html>. The report highlights the importance of wiring systems and concern for aging of these systems.

Also in 2000, the Air Force Research Laboratory (AFRL) conducted a field survey of the 3 United States Air Force (USAF) Air Logistics Centers (ALCs) and two F-16 field units. Results from the field survey were incorporated in part into the White House report.

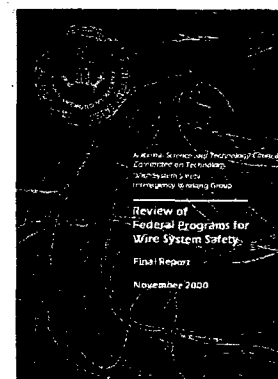


Figure 1: White House Report

Definitions

A wire/wiring system is defined as hardware which provides power, control, and information distribution. Wiring is just one part of the electrical interconnection system. Wiring, connectors, relays, switches, circuit breakers, power distribution panels, and generators are the components that makeup the wire/wiring system (See Figure 2).

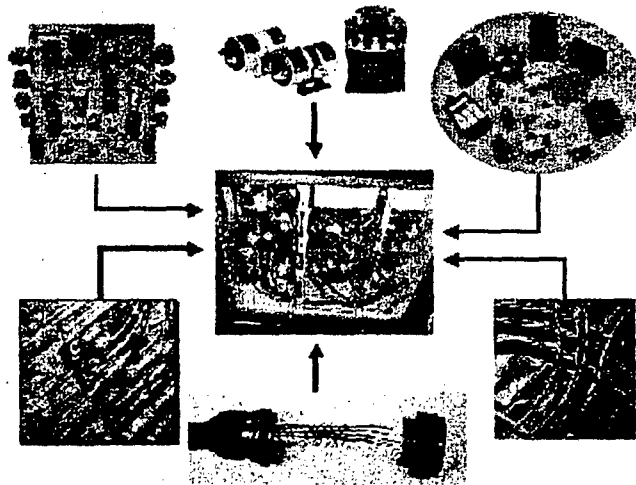


Figure 2: A wire/wiring system has multiple components.

The Issues

Wiring is the infrastructure linking electrical, electro-mechanical, electronic, and information systems in air vehicles. Wiring has emerged as vital in the control and safety of these systems, due to their ever increasing complexity:

- Increased emphasis on avionics: Fly-by-wire systems and glass cockpit
- Approximately 150 miles of wiring and over 500 connectors in a bomber or transport.
- Continuous exposure to harsh environments and mechanical stresses.
- Multiple wiring types used and use of materials with imperfect properties: Best commercial practices.
- Continuous wiring upgrades and modifications.

Aging Mechanisms

All wiring systems are subject to aging during their normal service life. Aging is the progressive deterioration of physical properties and performance of wiring systems with the passage of time, as well as with handling and usage. Stresses are often induced by the operational environment, as well as installation and maintenance practices. Wiring failures often appear as broken conductors and damaged insulation, which can disrupt electrical signals and/or lead to arcing. This aging is caused by the accumulated damage from exposure to the following stresses (See Figure 3):

- Chemical, including corrosion and moisture intrusion.
- Thermal, including fluctuations in temperature, which cause embrittlement... Radiological can also cause embrittlement.
- Electrical discharges, such as surges or arcs, and partial discharge transients.
- Mechanical, including vibration, chafing, overload, and fatigue.

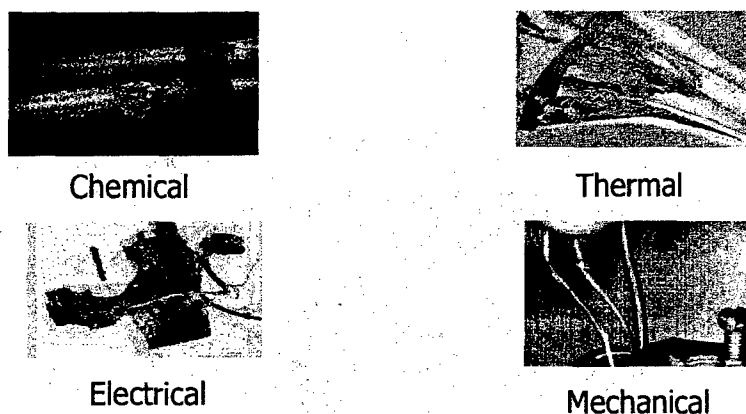


Figure 3: Wire failure mechanisms

Lack of Data

Military aircraft wiring integrity has gained increased visibility in the past two years as a significant aging aircraft issue. Problems in the wiring system can have a profound effect on flight control, avionics, and information systems critical to flight safety, as well as mission effectiveness. Similar to the commercial sector, the military does not typically report wiring maintenance and repair actions. The magnitude and pervasiveness of wire integrity issues are not well documented since the various parts of the wiring system are treated as low cost, throwaway, commodity items. The lack of an adequate data base poses a challenge in trying to determine just how extensive the aging wiring problem is in the current USAF fleet, as well as its actual impact on aircraft availability. Two available data sources are USAF and Navy mishap data (shown in Figures 4 and 5).

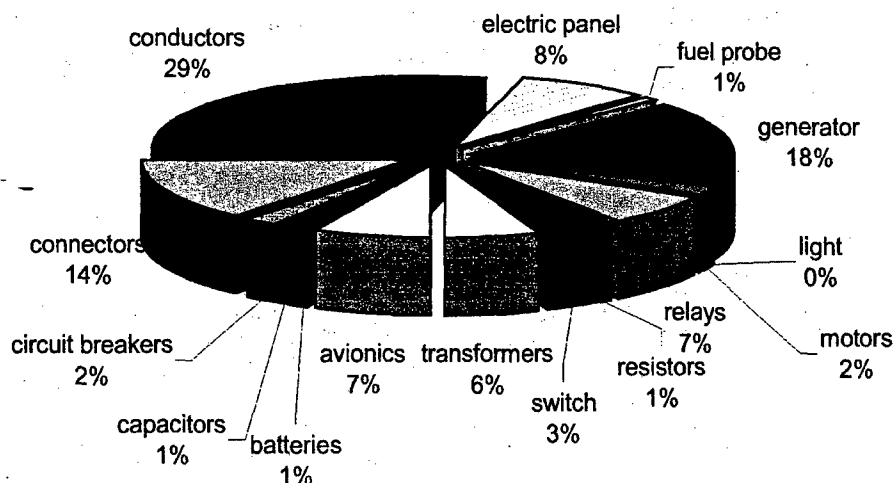


Figure 4: Electrical components contributing to USAF aircraft mishaps.

(Based on U.S. Air Force Safety Center Electronics Failure Data for 1989-1999.)

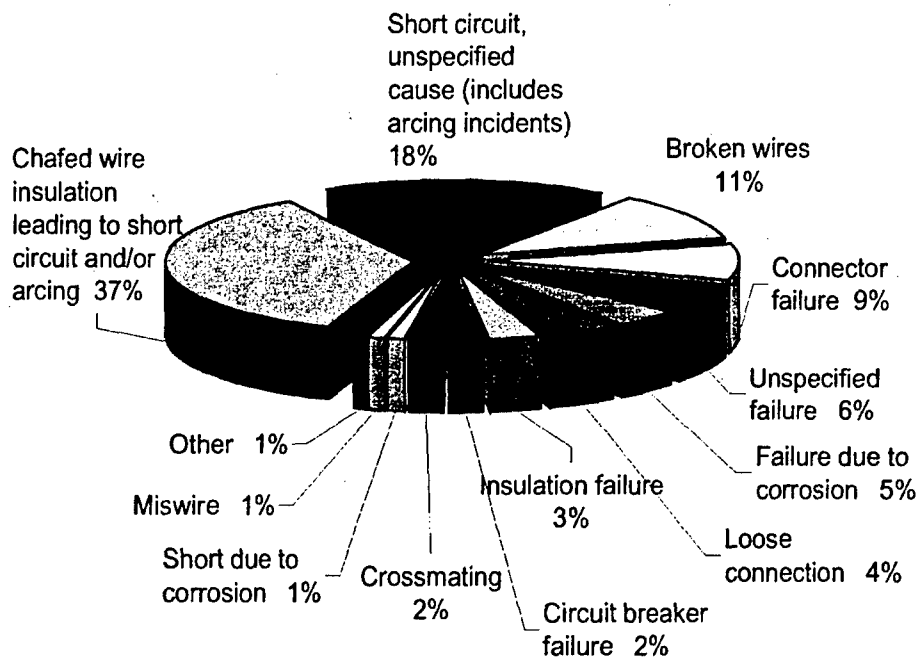


Figure 5: Typical wire system failure modes for aircraft.

(Based on U.S. Navy Safety Center Hazardous Incident Data for 1980-1999.)

USAF Legacy Aircraft

As the Air Force's aircraft fleet continues to age and accumulate increased operating hours, aging effects may result in the electrical systems. Lack of an adequate wiring system data base has to date precluded the determination of trends, aging characterization, and the degree various electrical systems are effected. Lacking a data base, AFRL conducted a seven month wire integrity survey (29 February through 30 September 2000) at all three ALCs and two USAF field units (Luke AFB, AZ and Springfield Air National Guard Base, OH). These field surveys included multi-site reviews of test methods, techniques, and types of wiring faults found at the ALCs and field units. The site surveys served to document wiring and maintenance issues at each location, as well as determine needs.

Survey Findings

On-site inspections of various USAF aircraft showed that some deterioration of wiring components (i.e., wire, wire bundles, connectors, grounds, clamps and shielding) is occurring in aircraft. During site surveys on fighter aircraft, most wiring problem areas identified were in the wing and flaps, fuel tanks, wheel wells and avionics bays. Further, it was found that almost two thirds of the failures occurred close to a connector or termination point. Many of the problem areas contained high wiring density and the limited space associated with these areas made them susceptible to chafing.

Most large transport type aircraft wiring faults occurred outside pressurized compartments where faults resulted from exposure to moisture, chemical contamination, heat, maintenance activities and indirect damage. These high wire system maintenance areas included landing gear and wheel well areas, leading and trailing edge flap areas, fuel cell wiring, flight control column wiring and other areas where wires were continually flexed. Wiring density was

lower than in fighter aircraft and wire harness routing space generally was not an issue; however, long distances between termination points presented challenges in spatially locating faults. Maintenance personnel readily pointed out causes of wiring degradation include vibration, moisture, chemical contamination, heat, indirect damage and induced damage from maintenance actions (metal shavings, etc.). Wiring failures were most frequent in areas the wiring is directly exposed to the outside environment (wheel wells and leading edges), moving parts, and high maintenance areas (radar's, communication equipment and the cockpit). The majority of maintainers interviewed stressed the importance of checking wire clamping, connectors, terminations, conduits and grounding points. Failures tended to be from "wear and tear", chafing, environmental conditions, or from handling during modifications and upgrades. It was noted that most wire problems are not documented in recoverable database. The majority of wiring is also not tested during programmed depot maintenance periods. Only wiring that is modified or replaced is tested.

In discussions with maintenance technicians, it was found that most wiring problems are found through trouble-shooting not through visual inspection. Trouble-shooting is primarily accomplished by multi-meter. Maintainers expressed a high interest in the inspection, maintenance and repair of aircraft wiring. It was widely acknowledged that these areas must be given greater consideration as aircraft age. The routine inspection of wiring in a nonspecific nature was not found effective. Wiring problems often manifested themselves in the faulty operation of components that are controlled or powered by the wiring. Because of the high redundancy and conservative designs in these systems, for the most part a failure leads to a repair action and not a safety incident.

It was noted that wiring failures were often found only after an inability to resolve a system failure or during visual inspections. The field survey showed that wiring failures may have a significant impact on maintenance costs since:

- Maintenance tracking data bases do not show extent of problems.
- The evidence is primarily anecdotal.
- Damage to the wiring system is often due to maintenance actions, as well as exposure to moving parts and external environment.
- Material degradation was only apparent in older insulation materials (20+ years).

User Needs

After completion of the survey, a users' conference was held on 21 September 2000 at Wright-Patterson AFB, Ohio. The following near-term needs were identified and agreed to by the using community:

- Wiring codes and the establishment of a wiring system data base,
- Arc fault circuit protection,
- Additional wiring system inspection, troubleshooting, and test equipment,
- Additional repair tools, techniques, and materials.

With respect to inspection, troubleshooting, and test, as well as repair, the following equipment requirements were identified:

- The equipment must be simple, portable, compact, and easy to use with a minimum amount of setup time required.
- It must integrate with current test equipment and practices.
- It must be able to locate opens and shorts, as well as identify their location...with a strong desire to be able to identify and locate some intermittent and degraded conditions.

- The equipment should be capable of verifying the corrective action/repair.
- It should record and store the data/results.

Summary

AFRL is currently working with the Navy, Federal Aviation Administration, and the National Aeronautical and Space Administration to address the aforementioned needs, which are common to both commercial and military aviation. In summary, wiring systems can be managed with

- Emphasis on proper design, materials selection, installation, training, and maintenance practices,
- Collection and analysis of maintenance data,
- Understanding failure mechanisms,
- Use of surveillance programs,
- Treating wiring as an electrical interconnection system...not low cost, throw away, commodity,
- Use of proactive repair and replacement programs.

Bibliography

1. Review of Federal Programs for Wire System Safety, National Science and Technology Council, Committee on Technology, Wire System Safety Interagency Working Group, November 2000.
2. Wiring Integrity Analysis of Air Force Weapon Systems, GRC International, Inc., September 2000.