NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

February 10, 2000

SYSTEMS GROUP CHAIRMAN FACTUAL REPORT ADDENDUM FOR ELECTRICAL WIRING INFORMATION

A. ACCIDENT: DCA96MA070

Location : East Moriches, New York

Date : July 17, 1996

Time : 2031 Eastern Daylight Time

Airplane : Boeing 747-131, N93119
Operated as Trans World Airlines (TWA) Flight 800

B. SYSTEMS GROUP

Chairman : Robert L. Swaim
National Transportation Safety Board
Washington, D.C.

C. SUMMARY

On July 17, 1996, at 2031 EDT, a Boeing 747-131, N93119, crashed into the Atlantic Ocean, about 8 miles south of East Moriches, New York, after taking off from John F. Kennedy International Airport (JFK). All 230 people aboard were killed. The airplane was being operated as a 14 Code of Federal Regulations (CFR) Part 121 flight to Charles De Gaulle International Airport (CDG) at Paris, France, as Trans World Airlines (TWA) flight 800. Wreckage from the airplane was recovered from more than nine square miles of ocean. Reconstruction of portions of the wreckage found evidence of an explosion in the center wing fuel tank (CWT).

The Systems Group collected information about electrical wiring during the TWA flight 800 accident investigation. The purpose of this addendum is to enter this information into the docket and the information is divided into the following five subject areas:

1. Ages of transport airplanes and wire in service.

2. Wiring installation standards and inspection techniques. Inspection methods and techniques from Federal Aviation Administration (FAA) Advisory Circulars (AC), TWA, and Boeing are included, as well as the results of a Navy comparison of visual and electronic inspection techniques.

3. Service Conditions. Attachments identify materials and chemicals that are used in the vicinity of wiring during operation and maintenance, as well as for cleaning of aircraft electrical system components.

4. Wiring data. Attachments discuss brittleness and cracks in wire insulation, background information from Raychem about development and properties of Alkane-Imide (aliphatic polyimide) wire insulation, as well as similarities and differences between it and aromatic polyimides, Boeing material specifications (BMS) for Alkane-Imide wire insulations, reports from the U. S. Navy that discuss relative properties and failures of Alkane-Imide (also identified in NAFI-TR-2199 as "Poly-X") and aromatic polyimide (also identified in NAFI-TR-2199 as "Kapton") wire insulations (and others), and the results of Lectromechanical Design Company research into how polyimide wire insulation ages.

5. Wire protection. Attachments discuss FQIS surge protection and separation of vulnerable wires from potential sources of power. Attachments describe FAA and Air Force plans to identify and address aging non-structural systems.

D. DETAILS OF THE INVESTIGATION

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AGES OF TRANSPORT AIRPLANES AND WIRE IN SERVICE

The Airclaims 1998 Turbine Airliner Fleet Survey (TAFS) Directory contains a chart that shows average ages for the overall fleet of commercial transport airplanes and for the various configurations of the Boeing 747. (Attached as "AIRCLAIMS DATA")

At the September 20-23, 1999, Third Joint FAA/DoD/NASA Conference on Aging Aircraft, Dr. Christopher Smith, FAA Manager for Aging Non-Structural Systems Research, presented a paper about FAA research into aging nonstructural systems. The paper included a chart that shows the types of electrical wires primarily used in different models of transport airplanes and how much of each type had been in service for more than 20 years. (Attached as "FAA AGE DATA")

WIRING INSTALLATION AND INSPECTION

DESIGN REQUIREMENTS

On April 1, 1999, Mr. James F. Hunt of Du Pont Corporation, made a presentation to the Society of Automotive Engineers titled "Selecting Non Flame Propagation Low-Smoke Materials for Aircraft Wiring." The presentation showed relative properties of different types of wire insulation. (Attached as "DuPont SAE PRESENTATION 4-1-99")

Boeing agreed to a partial release of the proprietary restriction on Boeing Specification document D6-13046 by citing selected pages. The abstract in the document states that "This document defines methods and practices to be used in the electrical/electronic area for presenting circuit information and wire assembly and installation on the Model 747 aircraft." (Attached as "BOEING SPEC D6-13046")

Boeing Specification 60B40037, section 3.1.2 contains [Model 747 electrical system] DESIGN REQUIREMENTS. (Attached as "B-747 SCD 60B40037")

FAA ADVISORY CIRCULAR (AC) 43.13-1B, ACCEPTABLE METHODS, TECHNIQUES, AND PRACTICES, AIRCRAFT INSPECTION AND REPAIR

The following lists the Section Titles of AC43.13-1B information that are attached (marked as "FAA AC43.13-1B"):

Chapter 6. Corrosion Control (Was not in same section of 1988 AC43.13-1A)

Corrosion Control Work Procedures, includes discussion of graphite pencils and [metal] chips.

Chapter 11, Aircraft Electrical Systems

Section 1. Inspection and care of electrical systems (Most material is also in 1988 AC43.13-1A)

General
Inspection and Operation Checks
Cleaning and Preservation
Bus Bars

Section 4. Inspection of Circuit-Protection Devices (Most material is also in 1988 AC43.13-1A)
Determination of Circuit Breaker Ratings

Section 6. Aircraft Electrical Wire Selection (Most material is also in 1988 AC43.13-1A)
General
Aircraft Wire Materials
Substitutions

Section 8. Wiring Installation Inspection Requirements (Most material is also in 1988 AC43.13-1A)
General
Wiring Replacement
Connectors
System Separation

Section 9. Environmental Protection and Inspection (Most material is also in 1988 AC43.13-1A)
Maintenance and Operations
Slack
Protection Against Personnel and Cargo
Flammable Fluids and Gases

Section 12. Wire Insulation and Lacing String Tie (Most material is also in 1988 AC43.13-1A)
General
Insulation Materials

Section 16. Wire Marking (Most material is also in 1988 AC43.13-1A)
General
Hot Stamp Marking

FAA ADVISORY CIRCULAR (AC) 65-15, AIRFRAME & POWERPLANT MECHANICS AIRFRAME HANDBOOK

The following lists the Section Titles of AC65-15 information that are attached (marked as "FAA AC65-15"):

Conductor Insulation
Electrical Wiring Installation
Wire Groups or Bundles
Spliced Connections in Wire Bundles
Slack in Wiring Bundles
Bend Radii
Routing and Installations
Protection Against Chafing
Protection Against Solvents and Fluids
Routing Precautions
Solderless Terminals and Splices
Types of Connectors
Conduit
Circuit Protection Devices

INSPECTION TECHNIQUES

The Trans World Airlines General Policies and Procedures Manual "Inspection Policy - Specific Instructions" page (Section 2-1-5, Page 12, Paragraph 5, May 15/94) provides generic descriptions for how to conduct a visual inspection and a detailed inspection. (Attached as "TWA LEVELS OF INSPECTION")

On June 17, 1999, Lectromechanical Design Company (Lectromec) summarized the results of a comparison of wire inspection methods that the company conducted for the United States Navy (Report N193-RPT14MY9). An electrical inspection method (DelTest) was compared to visual inspections in five airplanes and the electrical method found discrepancies that the visual inspections did not identify. (Attached as "LECTROMEC INSPECTION METHOD")

On September 3, 1999, the GRC and Eclypse International Companies submitted information regarding wire automated system quality assurance (ASQA) and Intelligent Wire Testing. (Attached as "GRCI/ECLYPSE WIRE TEST")

The July 22, 1999, World Wide Web pages of the Electronic Characterization and Diagnostic (ECAD) Company contained description of electrically-based wire inspection systems. These include time domain reflectometry, tests for cable "end-of-life" in the nuclear power industry, and measurement/calculation of insulation Quality Factor and Insulation Resistance. (Attached as "ECAD INFO")

On December 15, 1999, Mr. Francis Scullion of DIT-MCO International Company submitted information regarding DIT-MCO electrical test equipment. (Attached as "DIT-MCO")

Universal Synaptics Corporation has developed an analyzer for detecting intermittent faults in electronic devices and sent a description. (Attached as "UNIVERSAL SYNAPTICS")

REFERENCES TO THE CONDITION OF GENERAL AIRPLANE AND FQIS WIRING

On June 16, 1998, the FAA updated their web-site with results of inspections into fuel pump conduit cables removed from B-737 airplanes. The information shows that 267 of 500 airplanes inspected had chafed through protective Teflon wrapping. (Attached as "737 CONDUIT INSPECTIONS")

On July 24, 1998, the FAA issued NPRM 98-NM-163-AD, which contained descriptions of wire damage and wiring conditions that had been found in the center wing fuel tanks of 747 airplanes. The NPRM proposed replacement of all FQIS components in the CWT of specified "Classic" 747 airplanes. The resulting AD 98-08-02 was issued March 29, 1999, which was subsequently revised on July 7, 1999. (Attached as "NPRM 98-NM-163-AD" and "AD 98-08-02R1")

The July 1999, Boeing AERO Magazine (Issue 7) contained the findings of Boeing wire inspections and the title of the article was AGING AIRPLANE SYSTEMS INVESTIGATION. (Attached as "BOEING AERO AGING ARTICLE")

At the September 20-23, 1999, Third Joint FAA/DoD/NASA Conference on Aging Aircraft, Mr. Randy Pope presented a paper for David Marcontell, titled PRELIMINARY DATA FROM THE ATA FLEET SURVEY. The paper included the Air Transport Association (ATA) Aging Systems Task Force (ASTF) findings from wire inspections. (Attached viewgraphs marked "ATA ASTF" includes an ATA description of the organization.)

At the September 20-23, 1999, Third Joint FAA/DoD/NASA Conference on Aging Aircraft, George Slenski presented a paper for Ms. Abigail Cooley, titled SURVEY OF ELECTRICAL FAILURES IN AIRCRAFT MISHAPS. The paper contained 1989-1999 data and followed a similar May 21, 1990 Air Force study, presented to the National Aerospace and Electronics Convention. (Attached as "USAF 1999 STUDY")

At the September 20-23, 1999, Third Joint FAA/DoD/NASA Conference on Aging Aircraft, was an Air Force group presentation of a paper titled IMPLEMENTATION OF FUNCTIONAL SYSTEMS INTEGRITY PROGRAMS: AN ALC AND MAJCOM PERSPECTIVE. The paper contained references to reactive and proactive maintenance practices. (Attached as "USAF FSIP")

SERVICE CONDITIONS

ENVIRONMENT AND CHEMICAL EXPOSURE

The January 1999, issue of Boeing AERO Magazine (Issue 5) showed that water condensate may develop in airplanes, noting for example that Boeing found 80 pounds of water in a shipset of 737 airplane insulation blankets, and citing water as the cause of electrical equipment failures. (Attached as "BOEING AERO ARTICLE, JAN 1999")

Boeing 747 Maintenance Manual (MM) contains a figure that shows "Possible Fire Resistant Hydraulic Fluid Contamination Areas" in Chapter 51-20-00, page 2. (Attached as "51-20-00")

The Boeing 747 Structural Repair Manual (SRM) and MM cite usage of chemicals from the following alphabetized list for maintenance and repairs, with usage and protection instructions for wire and other components. The usage noted for some entries is taken from the cited pages. The list is compiled from MM pages 51-21-01 (pages 701-702), 51-21-02 (page 701), and 51-21-03 (page 701-702).

Alodine[1] 1000 and 1200S,
Ardrox 204, used as paint stripper,
BMS3-23[2], used as corrosion preventive compound,
Calcium sulphate
CeeBee A290, used as paint stripper,
Chromic acid
Del Chem EZ Strip 19AC, used as paint stripper,
DuBois R2134, used as paint stripper,
DuBow 1800 Sure-Strip, used as paint stripper,
Ethyl Alchohol, used as solvent,
Ethylene Glycol Monobutyl Ether (Butyl Cellosolve) , used as solvent,
GMC 801, used as corrosion remover,
Grease (unspecified type)
Jet Clean E, used as alkaline cleaner,
Kelite Process K, used as corrosion remover,
Kelite L-20, used as acid brightener for aluminum,
Magna 28-C-1, used as static conditioner,
Magna 8-W-5, used as surfacer (separate hardener and reducer),
Metal Glo No. 2, used as acid brightener for aluminum,
Methyl ethyl Ketone (MEK), used as solvent,
Methyl Iso-Butyl Ketone (MIBK) , used as solvent,
Nitric Acid,
Nuvite 631-3A Paint stripper, used as paint stripper,
Oakite 31, used as corrosion remover,
Oil (unspecified type),
Potassium dichromate,
Sodium dichromate,
TEC 86-2, used as alkaline cleaner,
Thinner , TL-52, used as solvent,
Toluene and MEK-Toluen mixture, used as solvent,
Turco Prepaint, used as corrosion remover,
Turco 5351, used as paint stripper,
Turco W.O. 1, used as corrosion remover,
Xylene, used as solvent,
Unpsecified alkaline cleaning agent, emulsion cleaning agent, solvent degreaser, and stripper

A December 10, 1999, Boeing letter described fuel leaks that were discovered as a result of inspections conducted for accomplishment of SB 747-28-2205. (Attached as "BOEING LETTER OF DEC 10, 1999")

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[1] Boeing 747 Structural Repair Manual (SRM) page 51-10-02 states that alodine is the registered trade name of a proprietary process marketed by the American Chemical Paint Company and notes that it is a corrosive process. (Attached as 51-10-02, page 1)

[2] The Boeing 747 Maintenance Manual (MM) 51-24-13, page 701-703, contains characteristics and limits for water displacing corrosion preventive compound BMS 3-23 (Attached as "51-24-13"). The Structural Repair Manual (SRM) identifies materials to use as the corrosion preventive compound, the properties of the materials, and their use. (Attached as "51-10-02, pages 6-10C").

A September 10, 1999, Boeing letter contained a description of fluids used for immersion tests of wiring, which was revised on September 13, 1999. (Attached as "BOEING LETTER OF SEPT 13, 1999")

An August 4, 1998, Boeing letter stated that wires received from service or for specific problems are inspected "to determine the integrity of the component" and that Boeing performs some "ad hoc" inspections of airplanes that have been in service. (Attached as "BOEING LETTER OF AUGUST 4, 1998")

A Boeing Alert Service Bulletin (747-28A2194) addressed fuel pump electrical connectors that had water and contaminant migration between the connector shell and potting. (Attached as "BOEING SB 747-28A2194")

WIRE CLEANING

The Boeing Standard Wiring Practices Manual (SWPM) recommends use of isopropyl alcohol (later mentions use of methyl alcohol), acetone, and freon to clean electrical connectors (not wires). (SWPM Section 20-60-01, attached as "SWPM CLEANING")

A September 13, 1999, letter from Boeing stated that the SWPM did not address inspection or cleaning of lint or metal debris. (Attached as "BOEING (CLEANLINESS) LETTER OF SEPT 13, 99")

WIRING DATA

"AGE DETERIORATION" AND CRACKS IN WIRE INSULATION

On July 18, 1995, Boeing responded to Safety Board questions of March 17, 1995, regarding "age deterioration" of certain types of wire insulation (including "Poly-X"). (Attached as "BOEING LETTER, JULY 18, 1995")

On July 20, 1995, Douglas Aircraft Company (DAC) responded to Safety Board questions regarding "age deterioration" of certain types of wire insulation. (Attached as "DOUGLAS LETTER, JULY 20, 1995")

On May 4, 1998, Boeing responded to a Safety Board question regarding radial cracks at hot stamp markings. (Attached as "BOEING LETTER, MAY 4, 1998")

ALKANE-IMIDE WIRE INSULATION

In December 1969, Raychem released a paper titled A NEW EXTRUDED ALKANE-IMIDE WIRE, which was the earliest description found for alkane-imide wire (also identified on page 2 as an aliphatic polyimide). Page 4 states that "the topcoat of the wire is several very thin layers of a modified aromatic polyimide which serve as the base for a compatible polyimide coat which carries the color." (Attached as "RAYCHEM, DEC 69")[3]

NAVY REPORTS REGARDING "POLY-X" AND "KAPTON" WIRE INSULATION

On August 11, 1976, the Naval Avionics Facility (now the Wiring Qualification Group of Raytheon Systems Company) released Part I of a report titled FLUID RESISTANCE TESTING OF ELECTRICAL WIRE USED IN AIRCRAFT AND MISSILES. The report contained the fluid resistance testing results of MIL-W-81044/16 through /19, MIL-W-81381, and other types of wires. Solvent resistance tests conducted for longer than existing specification requirements resulted in insulation failures and a recommendation (#6) that the test time be extended to one week. (Attached as "NAFI-TR-2145")

On August 11, 1977, the Naval Avionics Facility released Part II of the report concerning results of further cleaner and paint remover fluid resistance tests of MIL-W-81044/16 through /19 (identified in the report as "Poly-X") and MIL-W-81381 (identified in the report as "Kapton"). Recommendation #1 states that "All Navy aircraft currently in service and wired with Poly-X wire to MIL-W-81044/16 through /19 should be inspected on a regular basis for insulation damage." (Attached as "NAFI-TR-2199")

On September 13, 1977, the Naval Avionics Facility released Part III of the report concerning results of further cleaner and paint remover fluid resistance tests of "Poly-X" and "Kapton." Testing in this report was conducted at elevated temperatures. (Attached as "NAFI-TR-2201")

On October 19, 1977, the Naval Avionics Facility released Part IV of the report, citing reported failures in service of "Poly-X" and "Kapton," discussing similarities and a comparison of the failure rates of the two. (Attached as "NAFI-TR-2210")

On September 20, 1985, a Naval Air Systems Command Memorandum was released that was titled "TECHNICAL EVALUATION OF MIL-W-81381 ELECTRICAL WIRE INSULATION." The memorandum discusses differences between laboratory failures and failures found in service. The memorandum contains discussion of previous research into "Poly-X" and "MIL-W-81044/16/18" wires. (Attached as "NAVY MEMO OF 9/20/85")

LECTROMEC RESEARCH INTO AGING OF WIRING

On July 10, 1997, Dr. Armin Bruning of Lectromec presented a paper about aging processes of [aromatic polyimide] wiring to the First Joint DoD/FAA/NASA Conference on Aging Aircraft. The title of the paper was "AGING MEASUREMENTS OF OPERATING

[3] A Technical Paper for Presentation at the 18th International Wire and Cable Symposium, Atlantic City, New Jersey, December 3, 4, & 5, 1969.

AIRCRAFT WIRING; IMPLICATIONS FOR SPECIFICATION WRITING & A/C RELIABILITY." (Attached as "LECTROMEC, July 10, 1997")

On November 11, 1998, Lectromec released a paper titled DESCRIPTION OF LECTROMEC WIDAS AGEING SUPPORT PROGRAM, which describes a predictive method of "improving aircraft wire reliability" by "selective sampling of aircraft wires [from different areas of airplanes and] accelerated ageing [tests to] estimate the condition of the wire insulation [life remaining]." (Attached as "LECTROMEC WIDAS")

At the September 20-23, 1999, Third Joint FAA/DoD/NASA Conference on Aging Aircraft, RADM Donald R. Eaton (retired) and Dr. Armin Bruning presented a paper, titled ECONOMIC AIRCRAFT WIRE MAINTENANCE, INSPECTION AND REPAIR: PERFORMANCE IMPLICATIONS. The paper contained historic and estimated failure data for wiring in military and commercial aircraft. (Attached as "EATON")

WIRE PROTECTION

The Engineer's Relay Handbook, Appendix C, contains a chart that shows how much voltage is required break down an air gap between two conductors and the lowest voltage value shown is between 300 and 400 volts. (Attached as "VOLTAGE BREAKDOWN")

On October 15-17, 1963, Mr. G.J. King presented Douglas Aircraft Company Paper 1661 to the Ninth Tri-Service Conference on Electromagnetic Compatibility, titled ACHIEVING ELECTROMAGNETIC COMPATIBILITY BY CONTROL OF THE WIRING INSTALLATION." The paper abstract stated that "Wire routing control is mandatory to prevent the interaction of individual systems." (Attached as "1963 DOUGLAS PAPER 1661")

The August 1, 1996, revision of the "Wire Harness Functional Separation" section of the Boeing Standard Wiring Practices Manual (SWPM, Section 3A) shows wire harness separation in pressurized areas to be ¼ inch (typ.). Where the separation is not possible due to space or other constraints, SWPM Section 3B contains "Separation by an Insulation Material" and Section 3C contains "Separation by a Fusible Link Circuit Breaker." (SWPM 20-10-19, dated AUG 01/1996, attached as "SWPM HARNESS SEPARATION")

On October 12, 1999, a Boeing letter responded to Safety Board questions about how surge suppression systems had been developed. (Attached as "BOEING LETTER OF OCT 12, 1999")

On November 3, 1999, a Boeing letter described the status of wire separation and shielding testing for the 747 classic FQIS compliance with AD 98-20-40. The letter invites the Safety Board to witness the testing that began on the same date. (Attached as "BOEING LETTER OF NOV 3, 1999")

At least two manufacturers of FQIS were found who had developed transient suppression devices for fuel quantity indication systems. The BFGoodrich surge-protected system has received supplemental type certification (STC) and been retrofitted in 747 airplanes. Literature from Smith's Industries shows that the company has developed systems designed for the 737 and 747 airplanes. (Attached as "BFGoodrich FQIS" and "SMITHS FQIS")

On December 1, 1997, the FAA issued NPRM 97-NM-272-AD, which proposed adoption of an airworthiness directive that "would require the installation of components for the suppression of electrical transients and/or the installation of shielding and separation of the electrical wiring for [747 "Classic"] FQIS." The NPRM also described electrical wire with damaged insulation at fuel probes. (Attached as "NPRM 97-NM-272-AD")

On May 26, 1998, Boeing sent the FAA a letter of reponse to NPRM 97-NM-272-AD. The Boeing letter described the condition of electrical wiring routed to fuel probes, in fuel tanks, and in wiring raceways that are located outside of fuel tanks. The letter contains discussion of Boeing positions regarding surge protection and wire separation of FQIS in B-747 airplanes. (Attached as "BOEING LETTER OF MAY 26, 1998")

In a letter of May 26, 1998, Mr. J. M. Gay of United Airlines wrote to the FAA docket for the NPRM and discussed the United Airlines position regarding FQIS surge protection and wire separation. (Attached as "UNITED LETTER, MAY 26, 1998")

On September 30, 1998, the FAA issued Airworthiness Directive (AD) 98-20-40. The AD required shielding of FQIS wires and separation of the FQIS wires from other systems. The AD discusses why the FAA did not require surge suppression. (Attached as "AD 98-20-40")

On April 7, 1999, Mr. Donald Riggn, Manager of the FAA Aircraft Certification Office, sent a letter (signed by Mr. Al Habbestad) to Mr. R. C. Shields of Boeing regarding the timeliness of Boeing proposed circuit separation for AD 98-20-40. (Attached as "FAA LETTER, APRIL 7, 1999")

On November 2, 1998, Mr. Yves Benoist, Director of Flight Safety for Airbus Industrie, responded in a letter to Safety Board questions about wire separation and other subjects. (Attached as "AIRBUS LETTER NOV 2, 1998")

On May 25, 1999, Ronald Hinderberger of Boeing sent a letter to the Safety Board that described development of the wire separation standards. (Attached as "BOEING LETTER OF MAY 25, 1999") .

On October 12, 1999, Boeing submitted a letter to the Safety Board about surge suppressor development. (Attached as "BOEING LETTER OF OCTOBER 12, 1999") .

On January 10, 2000, Boeing submitted a letter to the Safety Board about Boeing positions with respect to safety recommendaitons developed during the accident investigation. (Attached as "BOEING LETTER OF JANUARY 10, 2000") .

On May 6, 1999, George Slenski, the Air Force Research Laboratory Electrical Group Leader, wrote an email that described changes that the Society of Automotive Engineers (AE-8A Committee) are pursuing to isolate fuel quantity system wiring. (Attached as "SAE WIRING SEPARATION")

An electronic mail (email) of July 28, 1999, from George Slenski described wire separation standards in Society of Automotive Engineer documents sae ard50055 (In draft form) and AS50881A (similar to MIL-W-5088). (Attached as "AFRL EMAIL JULY 28, 1999")

AGING AIRCRAFT SYSTEMS RESEARCH AND PROGRAMS

The October 31, 1996, revision to MIL-HDBK-1530, titled "AIRCRAFT STRUCTURAL INTRGRITY PROGRAM, GENERAL GUIDELINES FOR," contains a definition for Aging Aircraft. (Attached as "MIL-HDBK-1530")

On February 24, 1999, Dr. Raymond Pyles of RAND testified before the Procurement Subcommittee of the House Armed Services Committee. In his statement, he noted that this USAF interest in aging aircraft originated in 1994 and that a RAND analysis had reviewed historical and planned heavy-maintenance workloads for the KC-135, 727, 737, DC-9, and DC-10. Dr. Pyles discussed age-related hazards and mitigation strategies. (The Testimony is attached as "RAND TESTIMONY." The project description attached as "USAF/RAND PROJECT")

On July 25, 1996, the White House Commission on Aviation Safety and Security (WHCSS) was chartered, which resulted in a recommendation that the FAA "Aging Aircraft program should be expanded to cover non-structural systems." The recommendation and an Executive Summary of work being undertaken by both NASA and the FAA was contained in a Department of Transportation status report of June 29, 1999. (Attached as "DOT WHCSS SUMMARY")

On March 5, 1997, Mr. Gerald Dillingham of the General Accounting Office noted in testimony that the WHCSS recommended changes to aging aircraft programs regarding electrical wiring, fuel lines, and pumps and cited challenges that GAO found for the FAA. (Attached as "COMMISSION")

In October 1998, the FAA released the FAA AGING TRANSPORT NON-STRUCTURAL SYSTEMS PLAN, dated July 1998. After the Safety Board's TWA800 investigation inspected 16 airplanes on February 21-25, 1998, the FAA inspected five other airplanes (three DC-10s, a DC-9, and one B-727) with airline representatives and five engineers from Boeing. The plan describes what the FAA found in the electrical wire inspections and listed the following seven areas for action. (Attached as "FAA AGING SYSTEMS PLAN")

TASK 1. Establish an Aging Transport Systems Oversight Committee to coordinate the various aging systems initiatives within the FAA.

TASK 2. Conduct an in-depth review of the aging transport fleet and make model-specific safety recommendations related to airplane systems.

TASK 3. Enhance airplane maintenance to better address aging airplane systems.

TASK 4. Add aging systems taks to the aging airplane research program.

TASK 5. Improve reporting of accident/incident and maintenance actions involving wiring system components.

TASK 6. Evaluate the need for additional maintenance of transport airplane fuel system wiring and address any unsafe conditions.

TASK 7. Improve wiring installation drawings and instructions for continuing airworthiness.

At the September 20-23, 1999, Third Joint FAA/DoD/NASA Conference on Aging Aircraft, Mr. Stewart Miller, FAA Aging Systems Program Manager, presented a paper titled THE FAA'S AGING SYSTEMS PROGRAM: STRATEGY AND PROBLEMS. The paper discussed the FAA AGING TRANSPORT NON-STRUCTURAL SYSTEMS PLAN, dated July 1998, and progress made since release of the plan. (Attached as "FAA PROGRESS")

On September 10, 1999, the Air Force sent a letter that responded to Safety Board questions. The questions pertained to fuel probes, sulfidation, aging wiring, and information transfer from military airplane findings to commercial airplane usage. (Attached as "USAF LETTER OF SEPT 10, 1999")

Robert L. Swaim
Robert L. Swaim
TWA 800 Systems Group Chairman

J. DeLisi 2/10/00

AGES OF TRANSPORT AIRPLANES AND WIRE IN SERVICE

AIRCLAIMS DATA

FAA AGE DATA

(About Airclaims, from company web-site:)

AIRCLAIMS

For over 35 years, Airclaims has been serving the Aviation industry in sectors ranging from hull and liability claims handling, airline and operator safety audits, to airline and aircraft valuation and technical inspections, lease monitoring, securitisation, and a full range of consultancy services. We have earned a reputation for excellence in the industry that is reflected in the timeliness and accuracy of the information we provide to thousands of clients world-wide.

This site will give you an idea of the breadth and depth of our constantly expanding information resources: from CASE® and SpaceTrak®, the world's most comprehensive aircraft and commercial aerospace databases to a full range of electronic and hardcopy publications.

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FROM AIRCLAIMS TAF:

Summary - Jets

	YEAR OF BUILD													
	Pre 1971	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Western Built Jets	1924	149	192	238	302	262	222	186	284	414	457	409	335	283
Eastern Built Jets	12	41	84	127	152	171	235	175	164	162	158	112	102	81
Total Jets	1936	190	276	365	454	433	457	361	448	576	615	521	437	364

	YEAR OF BUILD																
	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total	Ave. Fleet Age	On Order
Western Built Jets	274	339	409	449	528	579	686	861	796	602	487	453	495	699	366	13680	14.2	3340
Eastern Built Jets	94	72	95	87	103	90	101	97	105	96	33	13	10	1		2773	17.2	73
Total Jets	368	411	504	536	631	669	787	958	901	698	520	466	505	700	366	16453	14.7	3413

AIRCLAIMS DATA

TYPE	Pre 1971	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total	Ave. Fleet Age	On Order
Boeing 747																																
747-100	25	8	8	6	4	1	2																							54	27.2	-
747-100 (CRAF)	1	1																												2	28.5	-
747-100 (RR Trent 800 Testbed)	1																													1	30.5	-
747-100B (P&W)										1																				1	19.5	-
747-100B (RR)												6	1																	7	17.4	-
747-100B/SR (P&W)										2					1															3	17.8	-
747-100B/SR (SUD) (P&W)																	2													2	12.5	-
747-100F	34	10																												44	28.5	-
747-200B (GE)									4	3	2	4	1			1	5	1		1										22	16.4	-
747-200B (P&W)	3	22	11	8	8	6	2	4	4	24	18	6	4	2	2		4	2												130	21.9	-
747-200B (RR)							1	3	3	3	7	6	3	1				1												28	18.5	-
747-200B (SUD) (GE)										1	2																			3	18.8	-
747-200B Combi (GE)								2	4	2	3	1	1				2		1											16	18.1	-
747-200B Combi (P&W)					1	3	2	1	4			4				1		1	1											18	19.4	-
747-200B Combi (RR)										1	1							2	1											5	14.3	-
747-200B Combi [SUD] (GE)									2	2		3																		7	18.9	-
747-200C (P&W)				2	1	1			1																					5	23.9	-
747-200C [SCD] (GE)																		1	1											2	11.0	-
747-200C [SCD] (P&W)							2						1																	3	20.5	-
747-200C/F [SCD] (GE)										1	1	1																		3	18.5	-
747-200F (P&W)		1						1	3	2																				7	21.4	-
747-200F [SCD] (GE)							1		3	2		3	1		1	3	1	1	2		3	2								23	14.5	-
747-200F [SCD] (P&W)					3	4		1	1	5	11	1	1				1	3	3	1	1									36	17.8	-
747-200F [SCD] (RR)											1							1	1		1									4	12.3	-
747-200SF (GE)							4		1	6	9	2	1		1	3	3													30	17.9	-
747-200SF (P&W)		1		2	2				2	3	5	2		1																18	20.6	-
747-200SF (RR)											1	1			1															3	16.8	-
747-200SF (SUD) (GE)						2																								2	23.5	-
747-300 (GE)																		2	3											5	10.9	-
747-300 (P&W)														11	4	6	3	2	1											27	14.1	-
747-300 (RR)															2	9	7	3	1											22	12.9	-
747-300 Combi (GE)														1	1	2	4		2		1									11	12.4	-
747-300 Combi (P&W)													1	1			4	1	3											10	12.5	-
747-300/SR (P&W)																		4												4	11.5	-
747-400 (engines unann.)																														-		1
747-400 (GE)																			3	8	17	19	19	11	10	1	5	12	6	111	6.0	51
747-400 (P&W)																			7	12	13	12	19	21	14	10	14	14	4	140	5.6	45
747-400 (RR)																			1	13	22	12	13	7	5	3	2	6	8	92	6.4	23
747-400 Combi (GE)																				9	2	11	4	9	2	2	3	2		44	6.5	3
747-400 Combi (P&W)																				1	3	3						2		9	6.7	3
747-400D (GE)																						3	6	6		2				17	6.0	-
747-400F (Engines Unannounced)																														-		1
747-400F (GE)																								3	1	1	1	2		8	3.8	12
747-400F (P&W)																									3	1	2	2		8	3.1	4
747-400F (RR)																									1	1				2	4.0	5
E-4B			2		1	1																								4	25.3	-
747SP (P&W)						2	8	3	2	6	9	2	2																	34	20.1	-
747SP (RR)									1		1	2	1					1												6	17.0	-
747SR-100				1																										1	25.5	-
747SR-100B (GE)									2	5	4	4	1																	16	18.7	-
747SR-100B/F (GE)													1																	1	16.5	-
747SR-100F					2	1																								3	24.2	-
VC-25A																		2												2	11.5	-
	64	43	21	19	22	21	22	15	37	69	75	48	20	17	13	25	36	28	31	45	63	62	61	57	36	21	27	40	18	1056	14.2	148
Boeing 757																																
757-200 (P&W)													1		10	21	21	17	14	15	39	37	48	28	3	6	24	16	10	310	7.7	58
757-200 (RR)													12	17	11	13	14	19	23	33	35	39	42	43	44	25	15	21	12	418	7.7	35
757-200 Combi (RR)																			1											1	10.5	-

Pre 1971 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 Total Ave. Fleet Age On Order
YEAR OF BUILD

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FAA AGING NONSTRU CTU RAL SYSTEMS RESEARCH

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Abstract

The Federal Aviation Administration's (FAA) Aging Transport Nonstructural Systems Plan describes various maintenance, training and reporting initiatives, development of advisory material, research programs, and other activities that have already started or will be undertaken by the FAA in order to address the White House Commission on Aviation Safety and Security.

This paper describes the FAA's approach to specifying and executing both near- and long-term research. Two specific initiatives, the establishment of a "validation infrastructure" and the development of arc-fault circuit interrupters, will be discussed in some detail.

In establishing the research program, the FAA has committed to the principal that a fully effective research program must be based on service data analysis and teardown evaluations. As such the program will work closely with - and draw on the findings of - the FAA's Aging Transport Systems Rulemaking Advisory Committee (ATSRAC) and the Air Transport Association's (ATA) Aging Systems Task Force (ASTF). Joint FAA-ASTF activities to assess the state of aging wiring have already been initiated.

The FAA's validation infrastructure will be used to determine the effectiveness of various technologies and techniques for mitigating nonstructural systems failures. For researchers and developers, the validation function will include services ranging from introducing researchers to aircraft systems issues to assisting developers in the transfer and commercialization of proven technology. Services to aircraft operators and manufacturers will include assistance in determining the adequacy of technology and techniques for specific applications.

Arc-fault circuit interrupter technology has the potential to mitigate the consequence of wire failure without requiring the redesign of aircraft circuitry. Plans call for a device sensitive to arc faulting and meeting all performance and design specification of existing circuit breakers.

The FAA is working closely with the aviation community, the Air Force, the Navy, and NASA to effectively specify and execute research to mitigate the hazards of aging nonstructural systems.

Introduction

In October 1998, the FAA released the Aging Transport Nonstructural Systems Plan (not to be confused with the Nonstructural Systems Research Plan (NSRP)). The intent of the Aging Transport Nonstructural Systems Plan is to evaluate the effectiveness of the current processes for design and routine inspection, maintenance, and repair of aircraft systems in mitigating the effects of aging of systems components. The evaluation will include the effectiveness of present systems in addressing environmental and accidental damage. Environmental damage is defined as degradation due to exposure to the atmosphere, damaging fluids, vibration, heat, ultraviolet exposure, and other such effects. Accidental damage includes wear and tear due to normal maintenance activities. Recommendations will be made for changes to the current processes

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under which systems are designed, inspected, maintained, and repaired as necessary to assure adequate consideration of systems aging effects.

The Aging Transport Nonstructural Systems Plan calls for the FAA to add six specific tasks to the Aging Aircraft Research Program. These tasks are

- To determine if a service life for airplane wire is appropriate, and - if appropriate - determine the service life for all types of wire used in transport aircraft.
- To establish the condition of aging systems wiring components and validate the adequacy of visual inspection.
- To develop nondestructive testing tools for inspection and testing of wiring systems.
- To establish aging effects on aircraft lightning and high-intensity radiated fields (HIRF) protection systems.
- To develop an arc-fault circuit interrupter for transport aircraft.
- To perform destructive testing of flight control linkages.

In establishing the NSRP the FAA has committed to the principal that a fully effective research program must be based on service data analysis and teardown evaluations. As such the NSRP will be coordinated with - and draw on the findings of - the FAA's Aging Transport Systems Rulemaking Advisory Committee and the Air Transport Association's Aging Systems Task Force.

The NSRP consists of two major research areas: electrical systems research and mechanical systems research. The planned efforts in each of these areas are described in highly structured Research Program Documents (RPDs). RPDs are used by sponsors and oversight organizations to prioritize and assess specific research programs, projects, and tasks. The NSRP RPDs were developed by the NSRP manager in response to a research request from the Technical Community Representation Group (TCRG).

Though endorsed by the Aging Transport Nonstructural Systems Plan, the support of efforts to address aging effects on aircraft lightning and HIRF protection systems is an ongoing program established by and remaining in the Atmospheric Hazards Program.

Issues

Table 1 shows a break down of airplane-related primary cause factors for serious

	Worldwide		**U.S. Operators**	
	Total	Percentage	Total	Percentage
Power plant or thrust reverser	15	3.2%	4	2.9%
Landing gear, brakes, tires	13	2.7%	3	2.1%
Flight controls	[illegible]	1.3%	2	1.4%
Electrical system, instruments	[illegible]	1.3%	3	2.1%
Structures	4	0.8%	0	0%
Hydraulics	[illegible]	0.4%	0	0%
Passenger accommodations	2	0.4%	1	0.7%
Auxiliary power	1	0.2%	1	0.7%
Fuel systems	1	0.2%	1	0.7%
	50	10.5%	15	10.7%

Table 1: Airplane (Design Related) Primary Cause Factors - Hull Loss Accidents 1959 - 1996

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accidents between 1959 and 1996. The shaded areas represent items that are the subject of the NSRP.[2] Up to 3 percent of all cause factors or 30 percent of airplane-related cause factors may be attributable to nonstructural systems.[3]

Electrical Interconnect Failure

Aircraft electrical systems have been implicated in a number of recent accidents and incidents. Since 1983 there were at least 26 well investigated reports of accidents or serious incidents involving electrical interconnect system failures and preliminary findings seem to implicate such systems in the catastrophic crashes of TWA 800 in 1996 and Swiss Air 111 in 1998. While this number is small in the greater context of the over 300 million successful commercial flights in that same time period, the trend of keeping airplanes in service well past their original economic design life requires that we devote additional effort to studying the effect of aging on critical airplane systems and functions.

Still, civil aviation service and incident data - which in many cases can indicate the potential for more serious failure - is in short supply.[4] The Department of Defense (DoD) generated substantial quantitative data on the malfunctioning of electrical interconnect systems. Though civil aircraft do differ in design and operation, it is not unreasonable to use this data as guidance in focusing FAA efforts. The kinds of damage seen in the military fleet can be expected in the commercial fleet, although it would seem that the incidence of damage in the commercial fleet may be much lower due to more benign operating conditions. Table 2 shows the kinds of failure seen on a typical Air Force fighter aircraft.[5]

Broken Wire	46%
Insulation Chafing Damage	30%
Outer Layer Chafing	14%
Failure in Connector	10%

Table 2: Wire Failure Data for a Typical Fighter

The Navy's Aircraft Power & Propulsion Division at the Naval Air Warfare Center, Aircraft Division estimates that the Navy spends $10,000,000 per year on finding and replacing faulty wires. This includes more than 4800 power wire removals per year for the Navy Fleet of approximately 4670 aircraft. More serious incidents include 64 in-flight electrical fires over a 30-month period on 17 different aircraft platforms (July 1994 through January 1997) and 2 lost aircraft.

Data more specific to commercial aircraft is presented in Table 3 (and associated Figure 1).

AC Flight Hours	AC Inspected	Fleet Sample Flight Hours	50% Local Reduction of Insulation			Bare Wire Exposed Locally		
			Number of AC	Portion of Sample	Rate/10^6 Flight Hrs	Number of AC	Portion of Sample	Rate/10^6 Flight Hrs
70K+	19	1330000	6	32%	4.51	3	16%	2.26
60-70K	37	2405000	7	19%	2.91	3	8%	1.25
50-60K	73	4015000	11	15%	2.74	3	4%	0.75
40-50K	135	6075000	3	2%	0.49	0	0%	0.00
30-40K	194	6790000	2	1%	0.29	1	1%	0.15
Fleet	458	20615000	29		1.41	10		0.49

Table 3: Boeing 737 Fuel Tank Wiring[6]

Though this data is based on a very specific sample set and there was no effort to identify wire type or age, the figures are suggestive of age-related failure. The aging factors could

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include both wire degradation (e.g., cracking, embrittlement) and nonwire-related aircraft aging. Aging factors independent of wire degradation may include an increased frequency of collateral wire damage associated with nonwire-related maintenance actions.

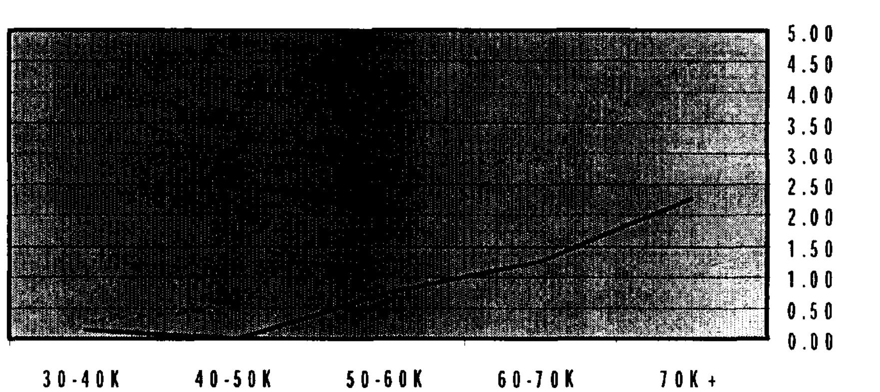

Figure 1: Age-Related Wire Failure

Electrical interconnect failure can occur in several ways.

- ***An open circuit.*** Though perhaps the most benign failure mode[7], it is also the most prevalent and not always inconsequential. In 1983 a DC-10 experienced a serious autopilot failure induced by the failure of an electrical wire. Cascade effects associated with the interruption of current in one circuit - though theoretically taken into consideration by FAR 25.1309 - are hard to predict and may result in more serious failure in some other part of the electrical system.
- ***A bolted short circuit.*** A bolted short circuit will generally trip the aircraft's thermal circuit breakers and prevent their reset. If, however, the circuit breaker fails - a known contributing cause of at least one DC-9 aircraft in 1987 - the consequences can be very serious.
- ***An intermittent open circuit.*** Around half of the electrical components removed for cause are returned to service with no fault found (NFF). Some of these NFF incidents may be the result of intermittent electrical interconnect failures. Though the threat of any component's failure to the safety of the aircraft may be slight, a high frequency of intermittent failure may eventually lead to serious consequences either by the more critical failure of components or by a more critical failure of the interconnect system (e.g., electrical arcing).
- ***An intermittent instantaneous discharge (arcing).*** This is perhaps the most serious failure mode for electrical interconnect components. Often the shunt current is not sufficient to cause failure at the load or circuit breaker. This can result in a dangerous sparking condition in flammable environments with no means of early detection or mitigation.
- ***Degraded shielding.*** Degraded shielding may result in the introduction of undesirable noise and/or electrical energy with potential adverse affects to the safety of the systems.

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The causes of an open circuit may be stress related or environmental. Stress-related failures may be the result of operational or maintenance-induced distress, including frequent disconnect and reconnect of wires, displacement of wires or wire bundles during the maintenance-inspection process, and corrosion of wire grounds, connections, and splices. Most such failures are in accessible locations subject to routine maintenance.

The causes of a short circuit or degraded signal wire performance include chaffing or cut through - possibly resulting from poor installation - or environmental degradation of the insulation through excessive temperature, hydrolysis, or contamination by abrasive solids or caustic fluids. Lavatory toilet fluid and anticorrosion compounds are known to degrade may types of aircraft electrical wire. Short circuits can also occur where wire terminations are exposed to contamination by metallic and nonmetallic deposits, including metal chips or shavings from other maintenance activities.

Poor design, manufacture, or repair can aggravate the incidence of wire failure in the following ways:

- Failure to designate or install wire with the appropriate functional and environment-resistance characteristics - designated categories include fire zone, fuel quantity indicator systems, general purpose, general purpose pressurized, general purpose unpressurized, high temperature/vibration/engine, modules, power feeders, power panels, and wire wrap integration center. Appendix A contains a list of general purpose wire types and their prevalence in commercial aircraft.
- Inappropriate retrofit of wire without adherence to manufacturer's standard practice - inadequate installation of in-flight entertainment systems, for example.
- Bad splices resulting in heat buildup or moisture contamination.
- Lack of wire segregation, sags, excessive tension - often the result of wire re-installation to accommodate structural modification or repair.
- Poor circuit breaker performance in the presence of arcing faults
- Degradation of circuit breaker performance with age
- Poor segregation of electrical and mechanical systems - there have been instances of hydraulic systems and flight control linkages damaged by arcing erosion of metallic components.
- Accelerated degradation of insulation due to excessive irradiation of cross-linked polymers - possibly the result of a bundle jacket being irradiated.
- Abusive hot stamping practice which can thin, breach, or locally degrade insulation - a B-757 accident in January 1985 was the result of wet arc tracking originating from an insulation defect coincident with a hot stamp mark.
- Poor crimp connections due to wire gauge anomalies - standard wire gauge leaves room for variability in conductor mass, which has changed over time.

Once an electrical system is in a state of failure or pending failure there are several mitigating and aggravating factors:

- The flammability of electrical insulation itself. In addition to the very obvious concerns regarding flammable substances in aircraft interiors, there is the added concern that burning wire will lead to the failure of multiple critical circuits.
- Latent faults can, in certain circumstances, be found by inspection. However, the degradation of wire may not be visually detectable.
- Wire functional testing is often used by airlines to support their reliability programs. There is little, if any, application of sophisticated test equipment to address the safety

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threat of degraded wire, although newer designs include reasonably capable built-in test equipment reporting to maintenance readouts on a daily basis.

The NSRP will not support initiatives into the examination of flammability requirements for wire but will require that any proposed electrical interconnect technology acknowledge these requirements.

The adequacy of visual inspection and the development of nondestructive inspection and testing tools will be subjects of the NSRP.

Mechanical System Failure

Highly complex mechanical systems are subject to failure modes which may be difficult to anticipate. Systems of large transport aircraft are certified on a fail-safe design concept that is meant to ensure that any failure with catastrophic consequence is "extremely improbable" and the failure of any system which would reduce the ability of the crew to deal with adverse operating conditions is "improbable."[8] The regulation contains provisions that require the designer take into account "the probability of multiple [dependent or independent system] failures and undetected failures."

Nevertheless such failures do occur: A DC-10 accident in 1989 was the result of the severing of all hydraulic lines in a multiple-redundant system due to an engine disk failure. Less severe accidents have occurred when electrical short circuits have damaged flight control cables and hydraulic lines.

As with aircraft wiring, many mechanical systems were assumed to have a service life greater than or equivalent to original design life limits for the aircraft itself. Within this service life, potential system failure modes may have been dismissed as extremely improbable or improbable. Because aircraft in operation today are greatly exceeding their design life limits, reconsideration of these assessments is necessary.

The gradual uniform degradation of mechanical systems presents some difficult issues. Current certification regulations require a probabilistic assessment, the simultaneous degradation of redundant or dependent systems, but do not necessarily require the specification of degradation interdependency. As such the failure probability of a backup or dependent system may be assumed as its failure probability in an undegraded state. This may be valid for inspectable systems (i.e., when the operator can periodically verify that such systems are not degraded), but some redundant systems are not inspectable. Some flight control linkages, for example, consist of concentric tubes with all surfaces except the outer surface of the outer tube being uninspectable.

Current Initiatives Program Intiatives

Development of an Aging Nonstructural Systems Test and Validation Infrastructure

One of the first initiatives of the NSRP is the development of a systems test and validation center which will take advantage of the existing inspection validation infrastructure at the Validation Center at Sandia National Labs. The Validation Center's two major aircraft (a Boeing 737 and a McDonnell Douglas DC-9) will be augmented with the acquisition of a 1971 Boeing 747 with over 100,000 hours of service. With the help of airline inspectors, the B-747 will be subject to an intensive visual inspection of its wiring systems and - where the condition of wire is suspect - destructive testing of wire insulation. In addition to this, select electrical systems on both the B-747 and DC-9 test bed aircraft will be baselined by the application of a

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state-of-the-art wire test system. Together these activities will provide two test bed aircraft capable of validating emerging wire test and inspection technology and valuable insight regarding the state of health of aged wiring components.

Development of Wire Testing Equipment

The FAA and US Air Force Office of Productivity, Reliability, Availability, and Maintainability (PRAM) are jointly sponsoring a short-term effort to enhance an automated wire test system. The state-of-the-art equipment will be used to help baseline the Validation Center's test aircraft and test articles and to establish a benchmark for future testing equipment developed and tested under the NSRP.

Assessment of Visual Inspection

The ASTF survey of wiring faults will provide data on physically observable faults in wiring and obvious functional failures. It cannot, unfortunately, provide data on certain latent defects and invisible degenerative conditions nor can it provide data on the degraded performance of wire and insulation (as indicated by variation from some manufacturer established or observed baseline.) This data will only be available from a complementary FAA-funded effort involving enhanced *in situ* testing and teardown.

Working in conjunction with the ATA, the Validation Center will perform supplemental nondestructive and destructive testing on interconnect system components identified by ATA inspection teams. Tests may include

- impedance spectroscopy, time domain reflectometry
- TEM, SEM, optical microscopy
- microhardness, indentation creep, abrasion and cut-through testing
- analytical chemical analysis

Development, Testing, and Validation of an Aircraft Arc Fault Circuit Breaker

The FAA is working with the US Navy's Office of Naval Research and the Naval Air System Command, Aircraft Division to develop aircraft arc-fault circuit breakers. An arc fault is the undesired, momentary discharge of current from a conductor - i.e., a spark. This type of short circuit is particularly pernicious because of the high temperature of the sparks it generates and the absence of any current excursions, which might trip standard thermal circuit breakers typically used on aircraft. Arc-fault circuit interrupter technology has the potential to mitigate the consequence of wire failure without requiring the redesign of aircraft circuitry. The execution plan for this initiative calls for a device sensitive to arc faulting while still meeting all performance and design specification of existing circuit breakers.

The joint effort will focus on the development of a specific circuit breaker for an aircraft platform with both military and civil applications. The FAA and Navy have accepted the C-9/DC-9 as this aircraft platform. Furthermore, it was agreed that the specific circuit breaker application be one that conforms to Military Specification 25017. There are at least three such applications on the C-9 (the ground support panel and two galleys). The selection of this application has at least four distinct advantages:

- Among aircraft circuit breakers, the design specification is minimally restrictive. The circuit breaker is a relatively large circuit breaker.
- The circuit breaker controls power to wires presumed susceptible to safety-hazarding arc faults. Galleys are used in flight, and the wire runs are not fire proof.

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- The controlled circuits are not flight critical. Nuisance tripping - though a major concern of this effort - will not be a flight safety problem during testing.
- The applications are similar in both the military and commercial aircraft. Other civil uses of this particular circuit breaker include applications in the B-707, B-737, and B-777 aircraft.

Mechanical Systems

There are no current initiatives specifically supporting mechanical systems research. The acquisition, decommissioning, and baselining of the B-747 will be in support of both electrical and mechanical systems research.

Future Initiatives

The FAA will be proactive in identifying and addressing aging systems safety issues. Initiatives will be established when

- accidents/incident or other operational data indicate a potential safety problem whose solution may require research.
- design or operation philosophy have changed significantly since the original aircraft design or introduction into service.
- significantly more powerful design tools are available to update certification analysis.
- significantly more capable technologies or techniques are available to enhance. maintenance efficacy.

Proposed technologies, techniques, or practices which require major philosophical, organizational, or other institutional change will have to exhibit advantages which clearly outweigh the cost of implementation. Conversely, proposed technologies, techniques, or practices which do not conflict with

- existing FAA regulation and advisory material
- the ATA's Maintenance Steering Group (MSG) process for establishment of maintenance programs
- manufacturer recommended standard practice

will be favored because of their likely acceptability to the aviation community.

Assessment of Wire Service Life

The purpose of this task is to establish - if possible - a predictive technique to determine when a wire, subject to certain known conditions, will no longer be able to ensure the safe transfer of electrical current.

It is anticipated that this task will be coordinated by the Validation Center at Sandia National Labs. It will be the responsibility of the Validation Center to identify general criteria and ground rules for the assessment. These criteria and ground rules should be sufficient to ensure that (1) the process of assessment is generally acceptable to the aviation community and (2) the results of the assessment are reproducible and comparable with other analytical or empirical assessments.

Once these criteria are established, the Validation Center will supervise the execution of several assessment exercises at independent facilities. Though the criteria for the assessments will be established by the Validation Center, the details of the assessment process will be the responsibility of the participating facilities. The conduct of these exercises will be such that at

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least some of the wire types assessed will be similar at different facilities. In particular, each facility will

- propose specific wire types to be assessed[9],
- identify one or more specific failure criteria,
- propose an accelerated aging process, and
- design and conduct experiments to determine service life of the wire.

Upon completion of these assessment exercises, the Validation Center will attempt to correlate the results of several exercises with each other and - if possible - with service experience.

Assessment of Circuit Protection Devices

Aircraft circuit protection devices (CPDs) are typically thermal-trip breakers with assumed safe-life performance. Although circuit breakers have been repeatedly tested for their response to various circuit failures[10], the bases for all of these tests have included the assumption that circuit breaker performance is not affected by age. Though not unreasonable, this assumption must be verified.

Wire Inspection and Testing

The purpose of this task is to develop systems that determine the material or structural flaws, which may impair the safe and effective electrical transmission of power and signals. The systems may be used for infrequent comprehensive examinations or more frequent focused inspection. As such user projected capability, capital cost, and equipment costs are not pre-specified but must be established in some balance that optimally serves an identified need in the aviation community.

It is anticipated that there will be several awards in this area of research. Successful proposals will identify some inspection or testing technology or technique with sensitivity to conditions which correlate well with the degradation of electrical interconnect systems. Evaluation of system development proposals will be based on the proposed system's apparent technical merits and on evidence of endorsement and participation of aircraft manufacturers or operators.

Risk assessment

The NSRP will fund certain risk assessment tasks. Fundamentally, any risk assessment effort must be

- *Relevant*: model assumptions cannot be brushed off as simple parameters that can be changed as necessary. A risk model has no virtue if its assumptions are unjustifiable or parameters unknown or unavailable.
- *Practical*: The end users of the risk assessment tools developed under this program will most likely be airline maintenance organizations. The risk assessment tools will have no virtue if the end users can't embrace the tools because they are too complicated or because the tools seriously violate constraints of their operations (e.g., require unavailable data)
- *Useful*: the tools should do more than confirm the obvious.

It is anticipated that such a tools might have particular virtue for mechanical systems subject to multiple common failure modes (e.g., jamming, breakage, wear of control linkages).

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Coordination

The White House Commission on Aviation Safety and Security recommends that: *In cooperation with airlines and manufacturers*, the FAA's Aging Aircraft Program should be expanded to cover nonstructural systems. The report further endorses the expansion of the FAA-DoD-NASA cooperative research program. In response to this, the FAA has committed to work formally and informally with

- Aging Transport Systems Rulemaking Advisory Committee (ATSRAC)
- The ATA and in particular the ATA's Aging Systems Task Force
- Airframe manufacturers - either individually or through their trade organization, the Aircraft Industries Association (AIA)
- Individual aircraft operators - USAir and Airborne have been very supportive of the NSRP
- Professional organizations such as the Society of Automotive Engineers (SAE) and the National Electrical Manufacturers Association (NEMA). And in particular:
  - SAE Committee AE 8 Aerospace Electrical/Electronic Distribution Systems Committee
  - SAE Committee A 6 Aerospace Fluid Power, Actuation, & Control Technologies Committee
  - SAE Committee G 3 Aerospace Couplings, Fittings, Hose & Tubing Assemblies
  - SAE Committee S 18 Airplane Safety Assessment
- The Department of Defense (activities with the USAF PRAM Office and the Office of Naval Research are already underway)

Conclusions

The FAA's Nonstructural Systems Research Program is fully committed to enabling and encouraging the aviation community to improve its already excellent safety record. In doing so, the FAA realizes the virtue in partnering with the aviation community including operators, airframers, and our military counterparts.

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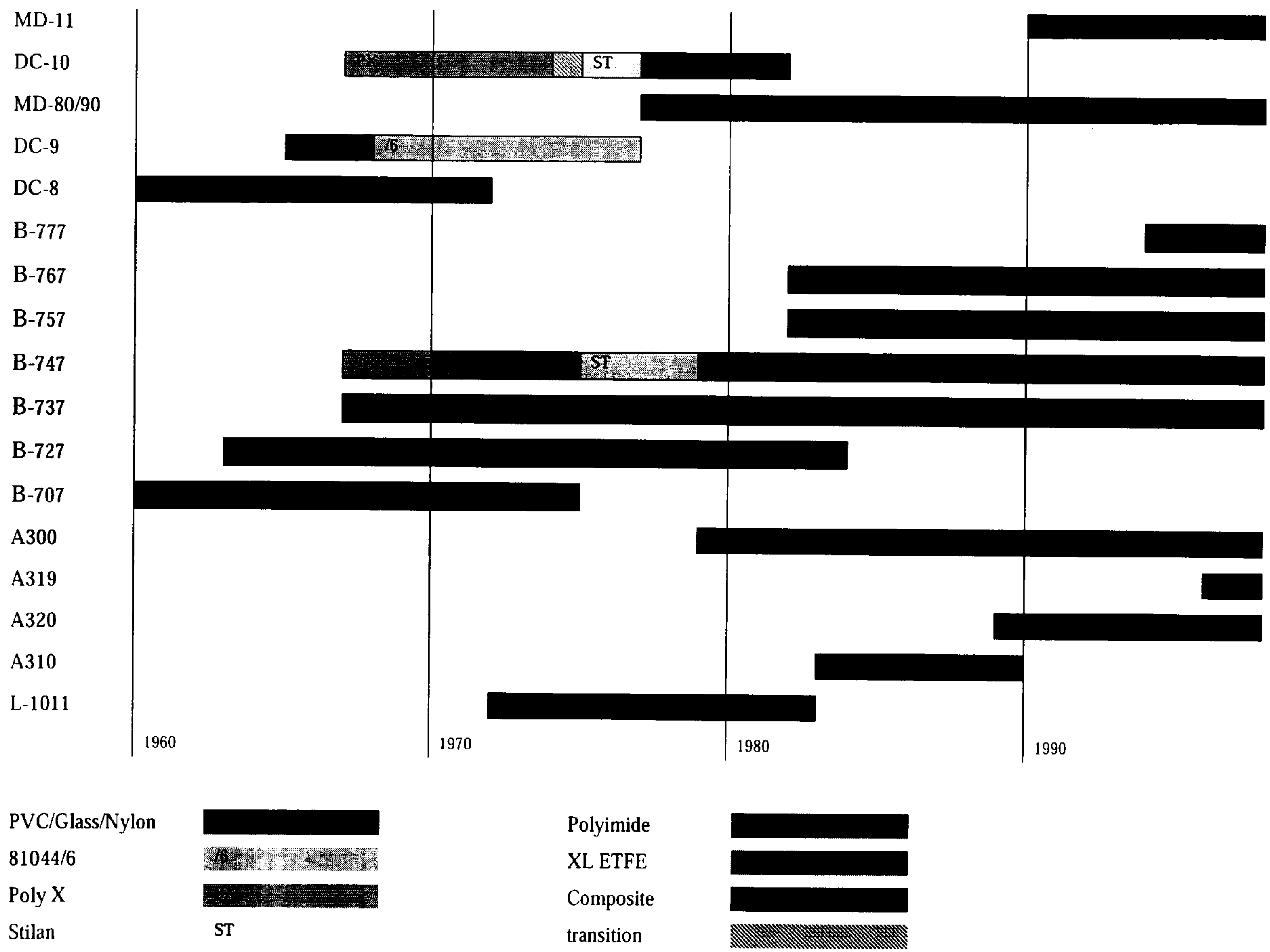
APPENDIX A: AIRCRAFT WIRE U TILIZ ATION

Wire Type Table

Specification Class	Constituent Polymer s	Common Designations	Aircraft	Years	Percent	Percent Fleet	Percent > 20 yrs
Mil-W-5086/1,2; BMS 13-13;	PVC/Glass/Nylon	Q uad 4	DC-8	all dates		25%	68%
			DC-9	-1968			
			B-707	all dates			
			B-727	-1979			
			B-737	-1979			
Mil-W-81044/6; BMS13-38	Extruded XL-Polyalkene/PVDF	Spec 44®	DC-9	1968-77		3%	9%
			B-747	-1970			
Mil-W-81044/16, BMS13-42B	Alkane-Imide or Alaphatic Polyimide	Poly X	DC-10	1968-75		3%	8%
			B-747	1970-75			
Mil-W-81044/20; BMS13-42C&D	Polyarylene	Stilan	DC-10	1974-77		< 1%	1%
			B-747	1975-79			
Mil-W-81381; BMS13-51; BXS7007;	Aromatic Polyimide	K apton® Apical®	MD-80	1980-95		48%	5-6%
			MD-80	1995-present	30%		
			DC-10	1980 and later			
			MD-11	all	30%		
			MD-90	all dates	30%		
			B-727	1979-and later			
			B-737	1979-93			
			B-747	1985-93 †			
			B-757	-1993			
			B-767	-1993 †			
			L1011				
			Airbus	all dates‡			
Mil-W-22759/34; BMS13-48; BXS7008	Cross-Linked ETFE	XL-Tefzel® ; Spec 55®	MD-80	1977-80		6%	1-2%
			DC-10	1977-80			
			B-747	1979-85, 1993-present ‡			
			B-747	79-present §			
			B-767	1982-93 §			
			B-767	1993 and later			
			B-777	all dates			
Mil-W-22759/80-92; BMS13-60	PTFE Polymide Composite	TK T Tensolite Oasis	MD-80	1995-present	70%	12-13%	0%
			MD-11	all	70%		
			MD-90	all dates	70%		
			B-737	1993-present			
			B-757	1993-present			

FAA AGE DATA

Aircraft General Purpose Wire Types



FAA AGE DATA

Wire Table Notes

This data was generated using information available in the public domain (cross checked with manufacturers proprietary data) and the FAA's tail number database. It represents the US registered fleet only. Note in particular that Airbus aircraft dates on the graph correspond to the oldest and most recently manufactured Airbus aircraft in US service, which is not necessarily equivalent to first and last date of manufacturer of those aircraft models.

Symbols used in wire type table

- † pressurized only
- ‡ all pressurized areas
- § unpressurized areas

Wire types were first associated with aircraft by date, not serial or line number. In years where the wire type changed, I assumed half of the production to have the old wire type and half to have the new wire type. Information regarding wire type changes associated with series changes and the assumption that sister ships would have the same wire type was used to establish wire type for individual aircraft. Because these assumptions will not always hold, the numbers are approximate.

These statistics are for the "general-purpose" wire. General-purpose wire represents about 90-95 percent of wire in an aircraft but not all wire. Where a distinction between pressurized and upressurized was made, I chose to use data for pressurized.

The percentages are based on the number of aircraft having a particular general-purpose wire relative to the total fleet. Total installed length and the critically of the application are not considered.

Because of approximations, omitted wire types, and unknown types, the numbers don't necessarily add to 100.

The last column is restricted to aircraft produced before 1979.

The PVC/Glass/Nylon includes PVC/Nylon also.

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Spec 44 and Spec 55 are registered trademarks of Raychem Corporation
Apical is a registered trademark of Kanegafuchi Kagaku Kogyo Kabushiki Kaisha

FAA AGE DATA

ENDNOTES

1. Industry Safety Strategy Team Presentation, October 1997.

2. Though landing gear and engines and fuel systems contain nonstructural subsystems, these systems are subject to special certification and regulation requirements. As such they are not addressed as part of the NSRP.

3. The category, electrical systems and instruments, includes avionics which are not the subject of the FAA Aging Nonstructural Systems Research.

4. In recognition of this, the Aging Transport Nonstructural Systems Plan calls for the improvement of reporting of accident/incident and maintenance actions involving wiring systems.

5. George Slenski, Aging Wire Activities and Programs Presentation.

6. FAA APA Statistics as of June 16, 1998, available on the web at www.faa.gov/apa/737iu.htm.

7. FAR 25.1309 (4) requires the safe operation of the aircraft under the assumption of this sort of failure.

8. FAR 25.1309

9. It is anticipated that wire degradation characteristics will be specific to wire type. Wire types of interest to the FAA and the aviation community include primarily aromatic polyimide, PVC/Glass/Nylon, Poly X, Polyalkene, PVDF.

10. See, for example, DOT/FAA/CT-TN94/55, Electrical Short Circuit and Current Overload Tests on Aircraft Wiring.

FAA AGE DATA

DESIGN REQUIREMENTS

DuPont SAE PRESENTATION 4-1-99

BOEING SPEC D6-13046

BOEING SPECIFICATION CONTROL DRAWING 60B40037

Selecting Non Flame Propagation Low-Smoke Materials for Aircraft Wiring

James F. Hunt
DuPont

Agenda

- Compare Today's Flame Resistant Insulating Materials
- Emphasize Influence of Design, Installation and Maintenance
- Clarify Misconceptions

Du Pont SAE Presentation, 4-1-99

Fact:

There is no "perfect" insulation system for aerospace wire & cable

DUPONT

The Designer's Task:

- Consider trade-offs to secure best balance of properties
- Consider influence of design, installation and maintenance

.....For Each Application!

DUPONT

DUPONT SAE PRESENTATION, 4-1-99

Seek The Best Balance of Properties:

- Electrical
- Mechanical
- Chemical
- Thermal

Plus

- Nonflammability & low smoke

Flammability Rating of Materials used in wire insulation

UL std 94 ratings

PTFE	V-O
ETFE	V-O
Polyimide	V-O
PE	V-2

DuPont SAE Presentation, 4-1-99

Flammability Rating of Wire Insulation

ASTM Limiting	Oxygen Index
PTFE	>95
Polyimide	37
ETFE	30-36
PE	17

Comparative Properties of Wire Insulation systems

Relative Ranking	1	2	3	4
Weight	PI	ETFE	COMP	PTFE
Temperature	PTFE	COMP	PI	ETFE
Abrasion Resistance	PI	ETFE	COMP	PTFE
Cut-Through resistance	PI	COMP	ETFE	PTFE
Chemical resistance	PTFE	ETFE	COMP	PI
Flammability	PTFE	COMP	PI	ETFE
Smoke generation	PI	COMP	PTFE	ETFE
Flexibility	PTFE	ETFE	COMP	PI
Creep (at temperature)	PI	COMP	PTFE	ETFE
Arc Propagation Resistance	PTFE	ETFE	COMP	PI

DUPONT SAE PRESENTATION, 4-1-99

PTFE - ETFE - PI - COMPOSITE

- Best Balance of Properties
- Inherently resistant to Flame
- Low smoke generation

Aromatic Polyimide (mil spec 81381)

- Design Properties
  - abrasion/cut-through
  - low-smoke/non-flame
  - weight/space
- Limitations
  - arc-track resistance
  - flexibility

DU PONT SAE PRESENTATION, 4-1-99

PTFE
(mil spec 22759/12)

- Design Properties
  - 260 C thermal rating
  - low-smoke/non-flame
  - high flexibility
- Limitations
  - cut-through resistance
  - "creep" at temperature

DUPONT

ETFE
(mil spec 22759/16)

- Design Properties
  - chemical resistance
  - abrasion resistance
  - ease of use
- Limitations
  - high temperature cut-through
  - thermal rating (150 C)

DUPONT

DU PONT, SAE PRESENTATION, 4-1-99

Composite
(mil spec 22759/80-92)

- Construction
  - 1st layer: Fluoro/PI/Fluoro composite
  - 2nd layer: PTFE tape
- Design properties
  - high temperature rating (260 C)
  - cut-through resistance
  - arc-track resistance
- Limitations
  - outer layer scuffing

DUPONT

Insulation Selection

- Select with care
  - seek proper balance of properties for each application
- Consider outside influences
  - design requirements
  - installation conditions
  - proper maintenance
- Choose materials with <u>inherent</u> flame/smoke resistance

DUPONT

DU PONT SAE PRESENTATION, 4-1-98

Conclusion

- Aircraft designer can choose among many polymeric materials
- Physical and chemical properties are equally important
- Safest system combines "Balance of Properties" with <u>inherent</u> flame/smoke resistance

DU PONT SAE PRESENTATION, 4-1-99

ABSTRACT

This document defines the methods and practices to be used in the electrical/electronic area for presenting circuit information and wire assembly and installation on the Model 747 aircraft.

The data is intended for use during design and development by Engineering.

All hardware shall be manufactured and inspected for conformance to applicable drawings, and this document shall not be used as a substitute or supplement thereto.

KEY WORDS

Wiring Design

Wire Routing

Wire Bundle

Ships' Wiring

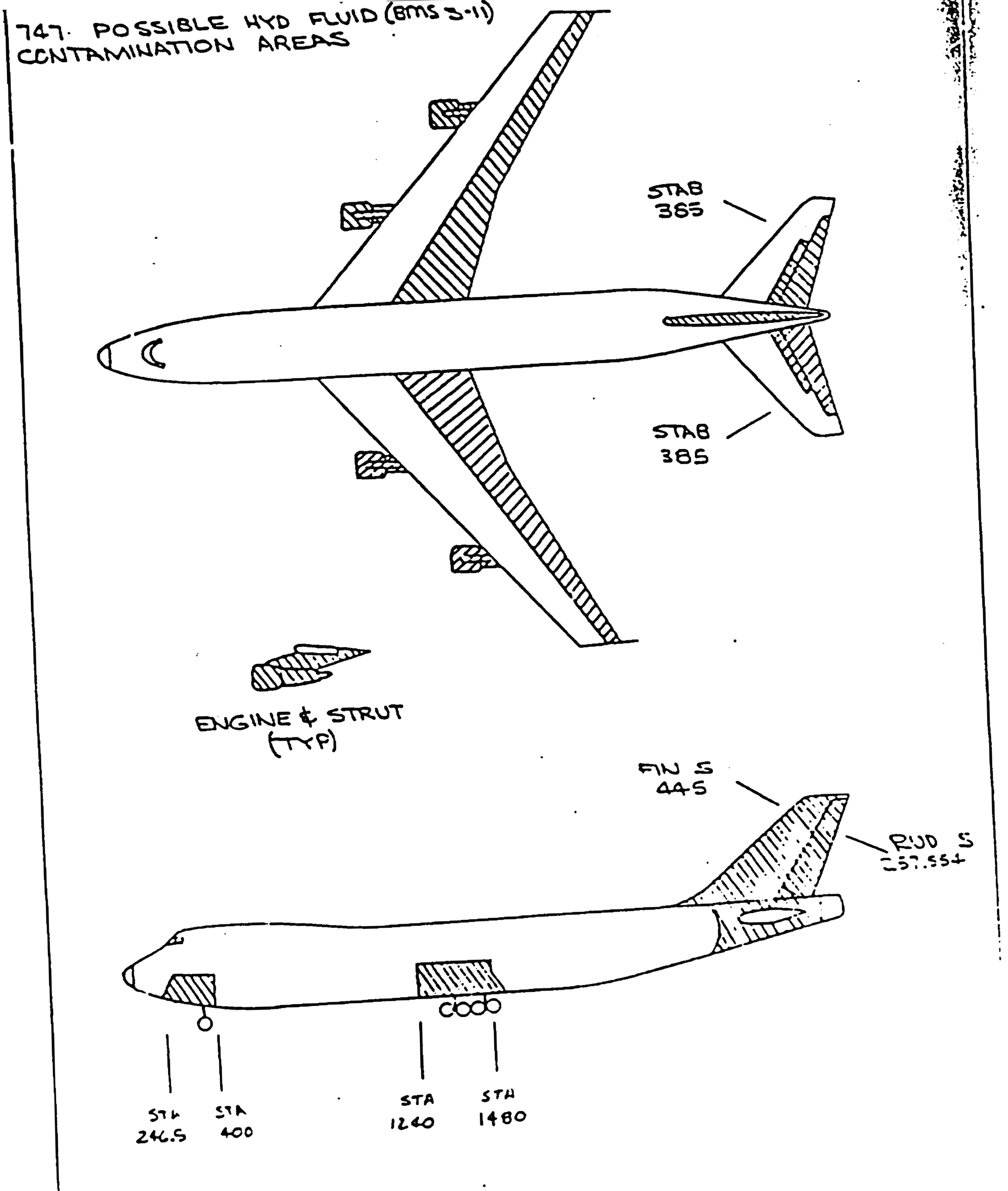
Wire Size

Integration Panels

Connectors

Crimp Contact

BOEING SPEC D6-13046



AD 1346 D

BOEING | NO. D6-13046
PAGE 11

REV SYM D

BOEING SPEC D6-13046

1.0 INTRODUCTION (Ref 4, para 42.1)

1.1 Definitions

The following definitions are for the meaning of words as they are used within this document:

A. Clamp - A device used to hold and support wire by gripping action.

B. Coaxial - A wire configuration in which there is an inner conductor surrounded by a dielectric and enclosed by an outer conductor; normally used for conducting radio frequency currents.

C. Connector - A device to make in-line connection(s) between one or more wires for continuous electrical path(s) at a location where the wires are subject to being disconnected and reconnected without mismatching circuits.

D. Contact - A device within a connector used to provide the electrical path joining two individual wires.

E. Crimp - A method of permanently joining a device to an electrical wire by mechanical pressure.

F. Drip-Loops - The loop formed by a wire bundle routed to a connector from above the level of the connector by looping below the connector in such a manner that condensed moisture will not flow along the wire to the connector.

G. Equipment Center - An area where several pieces of electrical or electronic equipment requiring interconnecting and incoming wiring are mounted.

H. Integration Panel - One or more sheet metal panels near an equipment center on which to mount connectors used for integrating the interconnecting and incoming wiring.

I. Module - The integration of an instrument and its associated switches and/or electronics into a unit.

J. Pigtails - Short wires from a piece of equipment that are not terminated in a connector.

K. Pin - A male contact within a connector that is normally round rod shaped, pointed or rounded on one end and connected to a wire on the other end.

L. Plug-to-Plug - To assemble a wire bundle from a connector on one end to a like connector on the other end without any splices, terminals, or other connectors in between.

M. Raceway - An area within the aircraft set aside for the routing of electrical wires. The area may be enclosed or open.

N. Shell - The outside structure of a connector which supports and holds together all of the parts.

BOEING SPEC D6-13046

1.1 Definitions (Continued)

O. Ships' Wiring - That wiring which is normally permanently mounted in the aircraft, as distinguished from wiring that may be removed with a panel or piece of equipment.

P. Splice - A device for permanently joining together the ends of two or more pieces of wire to provide a continuous electrical path in which the wires cannot be disconnected, without cutting the wire or destroying the device.

Q. Socket - A female contact within a connector normally shaped to receive the pin contacts of the mating connector.

R. Trunk Lines - A group of wire bundles routed between two equipment centers.

S. Wire - An individual insulated conductor used as a single current path.

T. Wire Bundle - Two or more individual insulated conductors tied together in a bundle.

U. Wire Harness - A wire bundle with many destinations.

1.2 General Practices

Design practices and procedures to be used for design and development of electrical and electronic wire bundles and installations shall be in accord with DM 72B1, Ref 8, Drafting Standards Manual, Ref 7, and this document. In case of conflict, this document shall take precedence.

All electrical and electronic wire bundles and installations shall be fabricated and installed in accordance with appropriate Ref 8, DM72B1 (Process Specifications), Ref 4, (D6-13053) and the engineering drawings. In case of conflict between the foregoing, the order of precedence shall be:

A. The engineering drawing

B. D6-13053

C. DM72B1 Section 2 (Process Specifications)

It is the objective of this project to produce wiring for the 747 airplane using a concept which standardizes wiring as much as possible for all airplanes with versatility for maximum accommodation of customer options. Wire bundle development and routing shall be accomplished to provide the minimum of differences between the passenger, the convertible, and the cargo aircraft.

To aid in accomplishing standardized wiring, to simplify modification capabilities, and to simplify maintenance concepts, connector integration panels shall be located in each major equipment center

1.2 General Practices (Continued)

Wire bundles between integration panels shall be considered ships' wiring and shall be treated as trunk lines constructed from connector to connector with a minimum of crossovers or multi-destinations. Wire bundles between the integration panels and the adjacent equipment center (instrument panel or electronic rack shelf) shall become the wire harness containing the cross-over interconnects and the bundle diversions. These cables shall be used to provide for customer variable with the minimum changes to the ships' wiring.

All panel instrument and module wiring shall be terminated in connectors for ease of removal. Switches, relays, indicator lamps, dial lamps, etc., shall be in modules and terminated in connectors on the module.

1.3 Engineering release of Wiring Information

Release of production electrical and electronic drawings shall be per PM 6.7 of Ref 3, (D6-13010) and Ref 7 (Drafting Standards Manual 94C1). All of the rules of PM 6.7 for release shall be followed with the following exception:

All wire bundles and wire routing drawings shall be released as variables for a particular customer block of airplanes. (Example RA001-RA009 Pan Am) Any new customer introduction (Example RA101-RA199 TWA) will be added on as they are committed if they are applicable to existing drawings. If existing drawings do not represent the needed configuration of the next customer block of airplanes then new drawings will be created using existing customer drawings as a base line.

5.1.8.2 System Function Letter (Continued)

B. System function letter may be preceded by digit indicating two or more identical systems under the same circuit function letter.

5.1.8.3 Wire Serial Number

A. The wire serial number will have one, two, three or four digits and will define each wire within the system.

B. For wires with the same circuit function wire numbers shall be assigned to each wire in numerical sequence beginning with the lowest digit insofar as practical.

C. Digits 1 through 8999 shall be used in the digital part of the wire number. Digits 9000 through 9999 shall be reserved for customer use.

D. Wire with the same circuit function having a common terminal connection or function should have a consecutive number (within the bundle) if possible.

E. A distinct block of numbers shall be provided if two or more identical systems exist under the same function letter. This separation is not required if no duality or triplicity within the overall system exists.

5.1.8.4 Shielded or Twisted Pairs, Triplets, and Quadruplets

A. Red ("R"), blue ("B"), yellow ("Y"), or green ("G") must be added in order to differentiate between hot (high), common (low) and other functions of the wires. Blue "B", is usually allocated to the common lead and red, "R", to the hot lead.

B. When assigning wire numbers to a pair, triplet, or quadruplet, proceed as follows:

Keep numbers in consecutive order.

Allocate lowest number to "red" wire.

5.1.8.5 Coaxial Cable

Wire number to a coaxial cable shall be allocated in the same manner as for ordinary wire.

5.1.8.6 ARINC Spares

Assign numbers using appropriate prefix for the system involved.

5.1.8.7 Ships" Wiring Spares

Spare wires will be designated in the wire list pages of the wiring diagram book and assigned consecutive numbers, prefixed with letter "Z". As spare wires are used out of sequence, they will appear on the appropriate wiring diagram retaining the "Z" numbers, and will be removed from the chart page. The wire number will be changed to a system number for follow-on in sequence airplanes. The chart page will always show the available spare wires by bundle and connector.

5.1.8.8 Wire Size (Gauge)

The wire size number follows the wire number and identifies the gauge of the wire. For coaxial cables and thermocouple wires, wire size entry shall not be made.

5.1.8.9 Wire Number Control

The wire number shall be controlled by the engineer responsible for the system. The engineer shall be continuously aware of the "last number used" within the system.

5.1.8.10 Phase Identification

Three-phase-power wires, which terminate in ring tongue terminals on the same piece of equipment, shall have each wire identified by phase. Phase identification sleeves shall be heat shrinkable polyolefin for temperatures 275°F or lower, and fiberglas for temperatures exceeding 275°F, and shall be installed per document D6-13053 when specified by the bundle assembly drawing. The heat shrinkable sleeves shall be red, yellow, and blue for phases "A", "B", and "C", respectively. The fiberglas sleeves shall be marked Phase "A", Phase "B", and Phase "C", as applicable.

5.1.9 Spare Wiring

5.1.9.1 General Spare Wiring

Ten percent spare wires shall be installed in the "trunk" type bundle assemblies between the equipment centers and between the cockpit and pressure seal at the end of the main cabin. Additional spare wire in each trunk shall be in accordance with each customer detail model specification. The spare wire requirements shall not apply to special bundles such as coaxial cables, power feeders and special system bundles such as critical circuits.

5.1.9.2 Power Plant Spare Wiring

Spare wiring to the engine nacelle areas varies greatly between customers and the customer model specification shall be consulted for these requirements in each case.

5.1.10 Terminations

8.0 ELECTRICAL INTERFERENCE

DM72B1, Section 74, is noted "To be Added Later." The following is applicable:

8.1 MAGNETIC OR ELECTROSTATIC COUPLING

Most magnetic and electrostatic coupling can be controlled by wire separation and shielding practices.

As a basic general separation philosophy for the 747 airplane, where system separation for safety is not involved, the heavy current carrying cables, power distribution, and switching cables shall be routed on the R.H. side of the fuselage and the electronic cables shall be routed on the L.H. side of the fuselage.

All items of equipment, wire bundles, etc., related to one power supply shall be separated from those related to another, insofar as practical.

9.0 ENVIRONMENTAL CRITERIA

DH 72B1, Section 180, is applicable with the following exceptions and additions:

Fig. 1 shows several major environmental areas in the 747 airplane, each requiring different types of wiring and installation treatment. These areas, and the environment with associated equipment problems to be expected in each, are defined as follows:

9.1 PRESSURIZED AREAS

Those areas inside the pressure skin which would normally be held at a low pressure altitude. This includes the airplane main body from the radome pressure bulkhead to the aft pressure bulkhead with the exception of the wheel wells.

Passenger cabin under normal conditions:

Temperature: Cool to 80°F sea level to 10,000 ft.
Cool to 70°F 20,000 ft altitude and above

Pressure: Cabin altitude of 8,000 ± 250 ft at a flight altitude of 45,100 ft.

Sea level cabin to flight altitude of 23,100 ft.

The maximum normal cabin pressure differential shall be 8.9 ± .1 psi.

Freighter cargo compartment under normal conditions:

Temperature: 40°F minimum two inches from interior lining.

Pressure: Cabin altitude of 8,000 ± 250 ft at a flight altitude of 45,100 ft.

The maximum normal cabin pressure differential shall be 8.5 ± .1 psi.

Humidity: As high as one-hundred percent, including condensation, may be encountered.

9.1.1 Condensation - Service experience has shown that in some locations moisture condensation collects and runs down wire bundles. The wire bundles must have drip-loops to stop the condensation from entering the plugs. Connectors must be oriented on equipment in a horizontal or downward direction so the condensation cannot collect in the plug backshell.

9.1.2 Fluids - A few cabin and cargo space locations, such as galleys and toilets, are designated as hydraulic fluid (BMS 3-11) exposure areas. Use of connectors in these areas should be avoided where possible; when used, wire and connectors shall be provided with moisture protection.

APPLICATION				PART NUMBER	SYM N
NEXT ASSY	USED ON	SECT. NO.	SERIAL NUMBER		
	65870199	12&44	R0001-R9995		

SPECIFICATION CONTROL DRAWING 24

DRAWN E. Simmerly	DATE 8-7-7	THE BOEING COMPANY COMMERCIAL AIRPLANE DIVISION RENTON, WASHINGTON
CHECKED J. McClintock	11-1-67	
STRUCT		CONNECTING COMPONENTS, FUEL QUANTITY SYSTEM - MODEL 747
ENGR.		
STAFF M. Buson	11/7/67	
GROUP W. Hunchinger	11/6/7	
PROJ H.C. Brown 11/9		CODE IDENT. NO. 81205 / SIZE A / 60B40037
		SCALE / SH 1 OF 102

AGX 4261C-R1

B-747 SCD 60B40037

SYM M

2.1.2.9	* BAC 5162-(5)	Assembly of MIL-C-26500 Solderless Connectors
2.1.2.10	D6-1100	Designing to Skydrol 500
2.1.2.11	D1655-59T	ASTM Designation, Aviation Turbine Fuels
2.1.2.12	P & WA 522	Pratt & Whitney Aircraft Specification "Fuel, Commercial".
2.1.2.13		Deleted
2.1.2.14	BAC D 2104	"O" Ring Grove Config. etc.
2.1.2.15	D6-5762-1	Reliability Guide For Suppliers
2.1.2.16	BAC 5162-6	Assembly of BAC 10-60479 and 60B40037 Connectors
2.1.2.17	10-60479	Connector Components, etc.
2.1.2.18	BAC S11W-4	Seal, Washer
2.1.2.19	BACC47CP	Contact, Electrical Socket
2.1.2.20	BACC47CN	Contact, Electrical Pin
2.1.2.21	BMS 13-10	Wire, Electric, Insulated High Temperature
2.1.2.22	BMS 13-16	Wire, Electric, Polytetrafluoroethlene Insulated Surface Treated
2.1.2.23	* BAC 5162	Assembly of Electric Connectors
2.1.2.24	* BAC 5152	Identification of Electric Wire Bundles

M

FAA AC43.13-1B

U.S. Department
of Transportation

**Federal Aviation
Administration**

ADVISORY CIRCULAR

AC 43.13-1B

ACCEPTABLE METHODS, TECHNIQUES, AND PRACTICES — AIRCRAFT INSPECTION AND REPAIR

September 8, 1998

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Flight Standard Service
Regulatory Support Division

For sale by the Superintendent of Documents; U.S. Government Printing Office; Washington, DC 20402

(14) In confined location, do not use solvents with a low flash point, (below 100 °F) such as Methyl Ethyl Ketone (MEK) and acetone.

(15) All equipment should be cleaned after work has been completed.

(16) Check and follow all applicable restrictions and requirements on the use of solvents, primers, and top coats.

(17) Check and follow all applicable restrictions and requirements for use and disposal of waste material.

b. Blasting. The following precautions should be taken when using any type of blasting equipment:

(1) Operators should be adequately protected with complete face and head covering equipment, and provided with pure breathing air.

(2) Static-ground the dry abrasive blaster and the material to be blasted.

(3) Magnesium cuttings and small shavings can ignite easily and are an extreme hazard. Fires of this metal must be extinguished with absolutely dry talc, calcium carbonate, sand, or graphite by applying the powder to a depth of 1/2 inch over the metal.

(4) Titanium alloys and high-tensile-strength steel create sparks during dry abrasive blasting. Care should be taken to ensure that hazardous concentrations of flammable vapors do not exist.

6-91. CORROSION CONTROL WORK PROCEDURES. The effectiveness of corrosion control depends on how well basic work procedures are followed. The following common work practices are recommended:

a. If rework procedures or materials are unknown, contact the aircraft manufacturer or FAA authorized Designated Engineering Representative (DER) before proceeding.

b. The work areas, equipment, and components should be clean and free of chips, grit, dirt, and foreign materials.

c. Do not mark on any metal surface with a graphite pencil or any type of sharp, pointed instrument. Temporary markings (defined as markings soluble in water or methyl chloroform) should be used for metal layout work or marking on the aircraft to indicate corroded areas.

d. Graphite should not be used as a lubricant for any component. Graphite is cathodic to all structural metals and will generate galvanic corrosion in the presence of moisture, especially if the graphite is applied in dry form.

e. Footwear and clothing should be inspected for metal chips, slivers, rivet cuttings, dirt, sand, etc., and all such material removed before walking or working on metal surfaces such as wings, stabilizers, fuel tanks, etc.

f. Do not abrade or scratch any surface unless it is an authorized procedure. If surfaces are accidentally scratched, the damage should be assessed and action taken to remove the scratch and treat the area.

g. Coated metal surfaces should not be polished for aesthetic purposes. Buffing would remove the protective coating and a brightly polished surface is normally not as corrosion resistant as a non-polished surface unless it is protected by wax or paint.

h. Protect surrounding areas when welding, grinding, or drilling, to prevent contamination with residue from these operations. In those areas where protective covering cannot be used, remove the residue by cleaning.

i. Severely corroded screws, bolts, and washers should be replaced. When a protective coating, such as a cadmium plating on bolts, or screws, is damaged, immediately apply an appropriate protective finish to prevent additional corrosion damage.

6-92.—6-112. [RESERVED.]

CHAPTER 11. AIRCRAFT ELECTRICAL SYSTEMS

SECTION 1. INSPECTION AND CARE OF ELECTRICAL SYSTEMS

11-1. GENERAL. The term "electrical system" as used in this AC means those parts of the aircraft that generate, distribute, and use electrical energy, including their support and attachments. The satisfactory performance of an aircraft is dependent upon the continued reliability of the electrical system. Damaged wiring or equipment in an aircraft, regardless of how minor it may appear to be, cannot be tolerated. Reliability of the system is proportional to the amount of maintenance received and the knowledge of those who perform such maintenance. It is, therefore, important that maintenance be accomplished using the best techniques and practices to minimize the possibility of failure. This chapter is not intended to supersede or replace any government specification or specific manufacturer's instruction regarding electrical system inspection and repair.

11-2. INSPECTION AND OPERATION CHECKS. Inspect equipment, electrical assemblies, and wiring installations for damage, general condition, and proper functioning to ensure the continued satisfactory operation of the electrical system. Adjust, repair, overhaul, and test electrical equipment and systems in accordance with the recommendations and procedures in the aircraft and/or component manufacturer's maintenance instructions. Replace components of the electrical system that are damaged or defective with identical parts, with aircraft manufacturer's approved equipment, or its equivalent to the original in operating characteristics, mechanical strength, and environmental specifications. A list of suggested problems to look for and checks (Refer to the glossary for a description of the check types) to be performed are:

a. Damaged, discolored, or overheated equipment, connections, wiring, and installations.

b. Excessive heat or discoloration at high current carrying connections.

c. Misalignment of electrically driven equipment.

d. Poor electrical bonding (broken, disconnected or corroded bonding strap) and grounding, including evidence of corrosion.

e. Dirty equipment and connections.

f. Improper, broken, inadequately supported wiring and conduit, loose connections of terminals, and loose ferrules.

g. Poor mechanical or cold solder joints.

h. Condition of circuit breaker and fuses.

i. Insufficient clearance between exposed current carrying parts and ground or poor insulation of exposed terminals.

j. Broken or missing safety wire, broken bundle lacing, cotter pins, etc.

k. Operational check of electrically operated equipment such as motors, inverters, generators, batteries, lights, protective devices, etc.

l. Ensure that ventilation and cooling air passages are clear and unobstructed.

FAA AC 43.13-1B

m. Voltage check of electrical system with portable precision voltmeter.

n. Condition of electric lamps.

o. Missing safety shields on exposed high-voltage terminals (i.e., 115/200V ac).

11-3. FUNCTIONAL CHECK OF STAND-BY OR EMERGENCY EQUIPMENT. An aircraft should have functional tests performed at regular intervals as prescribed by the manufacturer. The inspections or functional check periods should be clearly stated in the aircraft maintenance manual, along with the overhaul intervals.

11-4. CLEANING AND PRESERVATION. Annual cleaning of electrical equipment to remove dust, dirt, and grime is recommended. Suitable solvents or fine abrasives that will not score the surface or remove the plating may be used to clean the terminals and mating surfaces if they are corroded or dirty. Only cleaning agents that do not leave any type of residue must be used. Components must be cleaned and preserved in accordance with the aircraft handbooks or manufacturer's instructions. Avoid using emery cloth to polish commutators or slip rings because particles may cause shorting and burning. Be sure that protective finishes are not scored or damaged when cleaning. Ensure that metal-to-metal electrically bonded surfaces are treated at the interface with a suitable anti-corrosive conductive coating, and that the joint is sealed around the edges by restoring the original primer and paint finish. Connections that must withstand a highly corrosive environment may be encapsulated with an approved sealant in order to prevent corrosion.

CAUTION: Turn power off before cleaning.

11-5. BATTERY ELECTROLYTE CORROSION. Corrosion found on or near lead-acid batteries can be removed mechanically with a stiff bristle brush and then chemically neutralized with a 10 percent sodium bicarbonate and water solution. For Nickel Cadmium (NiCad) batteries, a 3 percent solution of acetic acid can be used to neutralize the electrolyte. After neutralizing, the battery should be washed with clean water and thoroughly dried.

11-6. ADJUSTMENT AND REPAIR. Accomplish adjustments to items of equipment such as regulators, alternators, generators, contactors, control devices, inverters, and relays at a location outside the aircraft, and on a test stand or test bench where all necessary instruments and test equipment are at hand. Follow the adjustment and repair procedures outlined by the equipment or aircraft manufacturer. Replacement or repair must be accomplished as a part of routine maintenance. Adjustment of a replacement voltage regulator is likely since there will always be a difference in impedance between the manufacturer's test equipment and the aircraft's electrical system.

11-7. INSULATION OF ELECTRICAL EQUIPMENT. In some cases, electrical equipment is connected into a heavy current circuit, perhaps as a control device or relay. Such equipment is normally insulated from the mounting structure since grounding the frame of the equipment may result in a serious ground fault in the event of equipment internal failure. Stranded 18 or 20 AWG wire should be used as a grounding strap to avoid shock hazard to equipment and personnel. If the end connection is used for shock hazard, the ground wire must be large enough to carry the highest possible current (0.1 to 0.2 ohms max.).

11-8. BUS BARS. Annually check bus bars for general condition, cleanliness, and security of all attachments and terminals. Grease, corrosion, or dirt on any electrical junction may cause the connections to overheat and eventually fail. Bus bars that exhibit corrosion, even in limited amounts, should be disassembled, cleaned and brightened, and reinstalled.

11-9.—11-14. [RESERVED.]

SECTION 4. INSPECTION OF CIRCUIT-PROTECTION DEVICES

11-47. GENERAL. All electrical wires must be provided with some means of circuit protection. Electrical wire should be protected with circuit breakers or fuses located as close as possible to the electrical power source bus. Normally, the manufacturer of electrical equipment will specify the fuse or breaker to be used when installing the respective equipment, or SAE publication, ARP 1199, may be referred to for recommended practices.

11-48. DETERMINATION OF CIRCUIT BREAKER RATINGS. Circuit protection devices must be sized to supply open circuit capability. A circuit breaker must be rated so that it will open before the current rating of the wire attached to it is exceeded, or before the cumulative rating of all loads connected to it are exceeded, whichever is lowest. A circuit breaker must always open before any component downstream can overheat and generate smoke or fire. Wires must be sized to carry continuous current in excess of the circuit protective device rating, including its time-current characteristics, and to avoid excessive voltage drop. Refer to section 5 for wire rating methods.

11-49. DC CIRCUIT PROTECTOR CHART. Table 11-3 may be used as a guide for the selection of circuit breaker and fuse rating to protect copper conductor wire. This chart was prepared for the conditions specified. If actual conditions deviate materially from those stated, ratings above or below the values recommended may be justified. For example, a wire run individually in the open air may possibly be protected by the circuit breaker of the next higher rating to that shown on the chart. In general, the chart is conservative for all ordinary aircraft electrical installations.

TABLE 11-3. DC wire and circuit protector chart.

Wire AN gauge copper	Circuit breaker amp.	Fuse amp.
22	5	5
20	7.5	5
18	10	10
16	15	10
14	20	15
12	30	20
10	40	30
8	50	50
6	80	70
4	100	70
2	125	100
1		150
0		150

Basis of chart:

(1) Wire bundles in 135 °F. ambient and altitudes up to 30,000 feet.

(2) Wire bundles of 15 or more wires, with wires carrying no more than 20 percent of the total current carrying capacity of the bundle as given in Specification MIL-W-5088 (ASG).

(3) Protectors in 75 to 85 °F. ambient.

(4) Copper wire Specification MIL-W-5088.

(5) Circuit breakers to Specification MIL-C-5809 or equivalent.

(6) Fuses to Specification MIL-F-15160 or equivalent.

11-50. RESETTABLE CIRCUIT PROTECTION DEVICES.

a. All resettable type circuit breakers must open the circuit irrespective of the position of the operating control when an overload or circuit fault exists. Such circuit breakers are referred to as "trip free."

b. Automatic reset circuit breakers, that automatically reset themselves periodically, are not recommended as circuit protection devices for aircraft.

11-51. CIRCUIT BREAKER USAGE. Circuit breakers are designed as circuit protection for the wire (see paragraph 11-48 and 11-49), not for protection of black boxes

FAA AC 43.13-1B

SECTION 6. AIRCRAFT ELECTRICAL WIRE SELECTION

11-76. GENERAL. Aircraft service imposes severe environmental condition on electrical wire. To ensure satisfactory service, inspect wire annually for abrasions, defective insulation, condition of terminations, and potential corrosion. Grounding connections for power, distribution equipment, and electromagnetic shielding must be given particular attention to ensure that electrical bonding resistance has not been significantly increased by the loosening of connections or corrosion.

a. Wire Size. Wires must have sufficient mechanical strength to allow for service conditions. Do not exceed allowable voltage drop levels. Ensure that the wires are protected by system circuit protection devices, and that they meet circuit current carrying requirements. If it is desirable to use wire sizes smaller than #20, particular attention should be given to the mechanical strength and installation handling of these wires, e.g. vibration, flexing, and termination. When used in interconnecting airframe application, #24 gauge wire must be made of high strength alloy.

b. Installation Precautions for Small Wires. As a general practice, wires smaller than size #20 must be provided with additional clamps, grouped with at least three other wires, and have additional support at terminations, such as connector grommets, strain-relief clamps, shrinkable sleeving, or telescoping bushings. They should not be used in applications where they will be subjected to excessive vibration, repeated bending, or frequent disconnection from screw terminations.

c. Identification. All wire used on aircraft must have its type identification imprinted along its length. It is common practice to follow this part number with the five digit/letter C.A.G.E. code identifying the wire manufacturer. Existing installed wire that needs replacement can thereby be identified as to its performance capabilities, and the inadvertent use of a lower performance and unsuitable replacement wire avoided.

(1) In addition to the type identification imprinted by the original wire manufacturer, aircraft wire also contains its unique circuit identification coding that is put on at the time of harness assembly. The traditional "Hot Stamp" method has not been totally satisfactory in recent years when used on modern, ultra-thin-walled installations. Fracture of the insulation wall and penetration to the conductor of these materials by the stamping dies have occurred. Later in service, when these openings have been wetted by various fluids, serious arcing and surface tracking have damaged wire bundles.

(2) Extreme care must be taken during circuit identification by a hot stamp machine on wire with a 10 mil wall or thinner. Alternative identification methods, such as "Laser Printing" and "Ink Jet," are coming into increasing use by the industry. When such modern equipment is not available, the use of stamped identification sleeving should be considered on thin-walled wire, especially when insulation wall thickness falls below 10 mils.

11-77. AIRCRAFT WIRE MATERIALS. Only wire, specifically designed for airborne use, must be installed in aircraft.

a. Authentic Aircraft Wire. Most aircraft wire designs are to specifications that require manufacturers to pass rigorous testing of wires before being added to a Qualified Products List (QPL) and being permitted to produce the wire. Aircraft manufacturers who maintain their own wire specifications invariably exercise close control on their approved sources. Such military or original equipment manufacturer (OEM) wire used on aircraft should only have originated from these defined wire mills. Aircraft wire from other unauthorized firms, and fraudulently marked with the specified identification, must be regarded as "unapproved wire," and usually will be of inferior quality with little or no process control testing. Efforts must be taken to ensure obtaining authentic, fully tested aircraft wire.

b. Platings. Bare copper develops a surface oxide coating at a rate dependent on temperature. This oxide film is a poor conductor of electricity and inhibits retermination of wire. Therefore, all aircraft wiring has a coating of either tin, silver, or nickel, that have far slower oxidation rates.

(1) Tin coated copper is a very common plating material. Its ability to be successfully soldered without highly active fluxes diminishes rapidly with time after manufacture. It can be used up to the limiting temperature of 150 °C.

(2) Silver-coated wire is used where temperatures do not exceed 200 °C (392 °F).

(3) Nickel coated wire retains its properties beyond 260 °C, but most aircraft wire using such coated strands have insulation systems that cannot exceed that temperature on long-term exposure. Soldered terminations of nickel-plated conductor require the use of different solder sleeves or flux than those used with tin or silver-plated conductor.

c. Conductor Stranding. Because of flight vibration and flexing, conductor round wire should be stranded to minimize fatigue breakage.

d. Wire Construction Versus Application. The most important consideration in the selection of aircraft wire is properly matching the wire's construction to the application environment. Wire construction that is suitable for the most severe environmental condition to be encountered should be selected. Wires are typically categorized as being suitable for either "open wiring" or "protected wiring" applications. MIL-W-5088L, Appendix A table A-I lists wires considered to have sufficient abrasion and cut-through resistance to be suitable for open-harness construction. MIL-W-5088L, Appendix A table A-II lists wires for protected applications. These wires are not recommended for aircraft interconnection wiring unless the subject harness is covered throughout its length by a protective jacket. The wire temperature rating is typically a measure of the insulation's ability to withstand the combination of ambient temperature and current related conductor temperature rise.

e. Insulations. There are many insulation materials and combinations used on aircraft electrical wire. An explanation of many of the abbreviations are identified in the glossary.

11-78. SUBSTITUTIONS. In the repair and modification of existing aircraft, when a replacement wire is required, the maintenance manual for that aircraft must first be reviewed to determine if the original aircraft manufacturer (OAM) has approved any substitution. If not, then the OAM must be contacted for an acceptable replacement.

a. MIL-W-5088L Wiring, Aerospace Vehicle, Appendix A lists wire types that have been approved for military aerospace applications in open and protected wiring applications. These wires could potentially be used for substitution when approved by the OAM.

b. Areas designated as severe wind and moisture problem (SWAMP) areas differ from aircraft to aircraft but generally are considered to be areas such as wheel wells, near wing flaps, wing folds, pylons, and other exterior areas that may have a harsh environment. Wires for these applications often have design features incorporated into their construction that may make the wire unique; therefore an acceptable substitution may be difficult, if not impossible, to find. It is very important to use the wire type recommended in the aircraft manufacturer's maintenance handbook.

c. The use of current military specification, multi-conductor cables in place of OEM installed constructions may create problems such as color sequence. Some civilian aircraft are wired with the older color sequence employing "Red-Blue-Yellow" as the first three colors. Current military specification, multi-conductor cables, in accordance with MIL-C-27500, use "White-Blue-Orange" for the initial three colors. Use of an alternative color code during modification without adequate notation on wiring diagrams could severely complicate subsequent servicing of the aircraft. At the time of this writing, MIL-C-27500 is being revised to include the older color sequence and could eliminate this problem in the future.

11-79.—11-84. [RESERVED.]

SECTION 8. WIRING INSTALLATION INSPECTION REQUIREMENTS

11-96. GENERAL. Wires and cables should be inspected for adequacy of support, protection, and general condition throughout. The desirable and undesirable features in aircraft wiring installations are listed below and indicate conditions that may or may not exist. Accordingly, aircraft wiring must be visually inspected for the following requirements:

CAUTION: For personal safety, and to avoid the possibility of fire, turn off all electrical power prior to starting an inspection of the aircraft electrical system or performing maintenance.

a. Wires and cables are supported by suitable clamps, grommets, or other devices at intervals of not more than 24 inches, except when contained in troughs, ducts, or conduits. The supporting devices should be of a suitable size and type, with the wires and cables held securely in place without damage to the insulation.

b. Metal stand-offs must be used to maintain clearance between wires and structure. Employing tape or tubing is not acceptable as an alternative to stand-offs for maintaining clearance.

c. Phenolic blocks, plastic liners, or rubber grommets are installed in holes, bulkheads, floors, or structural members where it is impossible to install off-angle clamps to maintain wiring separation. In such cases, additional protection in the form of plastic or insulating tape may be used.

d. Wires and cables in junction boxes, panels, and bundles are properly supported and laced to provide proper grouping and routing.

e. Clamp retaining screws are properly secured so that the movement of wires and cables is restricted to the span between the points of support and not on soldered or mechanical connections at terminal posts or connectors.

f. Wire and cables are properly supported and bound so that there is no interference with other wires, cables, and equipment.

g. Wires and cables are adequately supported to prevent excessive movement in areas of high vibration.

h. Insulating tubing is secured by tying, tie straps or with clamps.

i. Continuous lacing (spaced 6 inches apart) is not used, except in panels and junction boxes where this practice is optional. When lacing is installed in this manner, outside junction boxes should be removed and replaced with individual loops.

j. Do not use tapes (such as friction or plastic tape) which will dry out in service, produce chemical reactions with wire or cable insulation, or absorb moisture.

k. Insulating tubing must be kept at a minimum and must be used to protect wire and cable from abrasion, chafing, exposure to fluid, and other conditions which could affect the cable insulation. However; the use of insulating tubing for support of wires and cable in lieu of stand-offs is prohibited.

l. Do not use moisture-absorbent material as "fill" for clamps or adapters.

m. Ensure that wires and cables are not tied or fastened together in conduit or insulating tubing.

n. Ensure cable supports do not restrict the wires or cables in such a manner as to interfere with operation of equipment shock mounts.

o. Do not use tape, tie straps, or cord for primary support.

p. Make sure that drain holes are present in drip loops or in the lowest portion of tubing placed over the wiring.

q. Ensure that wires and cables are routed in such a manner that chafing will not occur against the airframe or other components.

r. Ensure that wires and cables are positioned in such a manner that they are not likely to be used as handholds or as support for personal belongings and equipment.

s. Ensure that wires and cables are routed, insofar as practicable, so that they are not exposed to damage by personnel moving within the aircraft.

t. Ensure that wires and cables are located so as not to be susceptible to damage by the storage or shifting of cargo.

u. Ensure that wires and cables are routed so that there is not a possibility of damage from battery electrolytes or other corrosive fluids.

v. Ensure that wires and cables are adequately protected in wheel wells and other areas where they may be exposed to damage from impact of rocks, ice, mud, etc. (If rerouting of wires or cables is not practical, protective jacketing may be installed). This type of installation must be held to a minimum.

w. Where practical, route wires and cables above fluid lines. Wires and cables routed within 6 inches of any flammable liquid, fuel, or oxygen line should be closely and rigidly supported. A minimum of 2 inches must be maintained between wiring and such lines or related equipment, except when the wiring is positively clamped to maintain at least 1/2-inch separation or when it must be connected directly to the fluid-carrying equipment.

x. Ensure that a trap or drip loop is provided to prevent fluids or condensed moisture from running into wires and cables dressed downward to a connector, terminal block, panel, or junction box.

y. Wires and cables installed in bilges and other locations where fluids may be trapped are routed as far from the lowest point as possible or otherwise provided with a moisture-proof covering.

z. Separate wires from high-temperature equipment, such as resistors, exhaust stacks, heating ducts, etc., to prevent insulation breakdown. Insulate wires that must run through hot areas with a high-temperature insulation material such as fiberglass or PTFE. Avoid high-temperature areas when using cables having soft plastic insulation such as polyethylene, because these materials are subject to deterioration and deformation at elevated temperatures. Many coaxial cables have this type of insulation.

aa. The minimum radius of bends in wire groups or bundles must not be less than 10 times the outside diameter of the largest wire or cable, except that at the terminal strips where wires break out at terminations or reverse direction in a bundle. Where the wire is suitably supported, the radius may be 3 times the diameter of the wire or cable. Where it is not practical to install wiring or cables within the radius requirements, the bend should be enclosed in insulating tubing. The radius for thermocouple wire is 20 times the diameter.

bb. Ensure that RF cables, e.g., coaxial and triaxial, are bent at a radius of no less than 6 times the outside diameter of the cable.

cc. Ensure that wires and cables, that are attached to assemblies where relative movement occurs (such as at hinges and rotating pieces; particularly doors, control sticks, control wheels, columns, and flight control surfaces), are installed or protected in such a manner as to prevent deterioration of the wires and cables caused by the relative movement of the assembled parts.

dd. Ensure that wires and electrical cables are separated from mechanical control cables. In no instance should wire be able to come closer than 1/2 inch to such controls when light hand pressure is applied to wires or controls. In cases where clearance is less than this, adequate support must be provided to prevent chafing.

ee. Ensure that wires and cables are provided with enough slack to meet the following requirements:

(1) Permit ease of maintenance.

(2) Prevent mechanical strain on the wires, cables, junctions, and supports.

(3) Permit free movement of shock and vibration mounted equipment.

(4) Allow shifting of equipment, as necessary, to perform alignment, servicing, tuning, removal of dust covers, and changing of internal components while installed in aircraft.

ff. 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.

gg. Ensure that all wires and cables are identified properly at intervals of not more than 15 inches. Coaxial cables are identified at both equipment ends.

11-97. WIRING REPLACEMENT. Wiring must be replaced with equivalent wire (see paragraph 11-78) when found to have any of the following defects:

a. Wiring that has been subjected to chafing or fraying, that has been severely damaged, or that primary insulation is suspected of being penetrated.

b. Wiring on which the outer insulation is brittle to the point that slight flexing causes it to crack.

c. Wiring having weather-cracked outer insulation.

d. Wiring that is known to have been exposed to electrolyte or on which the insulation appears to be, or is suspected of being, in an initial stage of deterioration due to the effects of electrolyte.

e. Check wiring that shows evidence of overheating (even if only to a minor degree) for the cause of the overheating.

f. Wiring on which the insulation has become saturated with engine oil, hydraulic fluid, or another lubricant.

g. Wiring that bears evidence of having been crushed or severely kinked.

h. Shielded wiring on which the metallic shield is frayed and/or corroded. Cleaning agents or preservatives should not be used to minimize the effects of corrosion or deterioration of wire shields.

i. Wiring showing evidence of breaks, cracks, dirt, or moisture in the plastic sleeves placed over wire splices or terminal lugs.

j. Sections of wire in which splices occur at less than 10-foot intervals, unless specifically authorized, due to parallel connections, locations, or inaccessibility.

k. When replacing wiring or coaxial cables, identify them properly at both equipment power source ends.

l. Testing of the electrical and chemical integrity of the insulation of sample wires taken from areas of the aircraft that have experienced wiring problems in the past, can be used to supplement visual examination of the wire. The test for chemical integrity should be specific for the degradation mode of the insulation. If the samples fail either the electrical or chemical integrity tests, then the wiring in the area surrounding the sampling area is a candidate for replacement.

11-98. TERMINALS AND TERMINAL BLOCKS. Inspect to ensure that the following installation requirements are met:

a. Insulating tubing is placed over terminals (except pre-insulated types) to provide electrical protection and mechanical support and is secured to prevent slippage of the tubing from the terminal.

b. Terminal module blocks are securely mounted and provided with adequate electrical clearances or insulation strips between mounting hardware and conductive parts, except when the terminal block is used for grounding purposes.

c. Terminal connections to terminal module block studs and nuts on unused studs are tight.

d. Evidence of overheating and corrosion is not present on connections to terminal module block studs.

e. Physical damage to studs, stud threads, and terminal module blocks is not evident. Replace cracked terminal strips and those studs with stripped threads.

f. The number of terminal connections to a terminal block stud does not exceed four, unless specifically authorized.

g. Shielding should be dead-ended with suitable insulated terminals.

h. All wires, terminal blocks, and individual studs are clearly identified to correspond to aircraft wiring manuals.

i. Terminations should be made using terminals of the proper size and the appropriate terminal crimping tools.

11-99. FUSES AND FUSE HOLDERS. Inspect as follows:

a. Check security of connections to fuse holders.

b. Inspect for the presence of corrosion and evidence of overheating on fuses and fuse holders. Replace corroded fuses and clean fuse holders. If evidence of overheating is found, check for correct rating of fuse.

c. Check mounting security of fuse holder.

d. Inspect for replenishment of spare fuses used in flight. Replace with fuses of appropriate current rating only.

e. Inspect for exposed fuses susceptible to shorting. Install cover of nonconducting material if required.

11-100. CONNECTORS. Ensure reliability of connectors by verifying that the following conditions are met or that repairs are effected as required.

a. Inspect connectors for security and evidence of overheating (cause of over-heating must be corrected), and exteriors for corrosion and cracks. Also, wires leading to connectors must be inspected for deterioration due to overheating. Replace corroded connections and overheated connectors.

b. Ensure installation of cable clamp (reference MIL-C-85049) adapters on applicable MS connectors, except those that are moisture-proof.

c. See that silicone tape is wrapped around wires in MS3057 cable clamp adapters so that tightening of the cable clamp adapter cap provides sufficient grip on the wires to keep tension from being applied to the connector pins.

d. Make sure unused plugs and receptacles are covered to prevent inclusion of dust and moisture. Receptacles should have metal or composite dust caps attached by their normal mating method. Plugs may have a dust cap similar to above or have a piece of polyolefin shrink sleeving shrunk over the connector, starting from the backshell threads, with a tail sufficiently long enough to double-back over the connector and be tied with polyester lacing tape behind the coupling nut. The cable identification label should be visible behind the connector or a tag should be attached identifying the associated circuit or attaching equipment. The connector should be attached to structure by its normal mounting means or by the use of appropriate clamps.

e. Ensure that connectors are fully mated by checking position and tightness of coupling ring or its alignment with fully mated indicator line on receptacle, if applicable.

f. Ensure that the coupling nut of MS connectors is safetied, by wire or other mechanical locking means, as required by applicable aircraft instructional manuals.

g. Ensure that moisture-absorbent material is not used as "fill" for MS3057 clamps or adapters.

h. Ensure that there is no evidence of deterioration such as cracking, missing, or disintegration of the potting material.

i. Identical connectors in adjacent locations can lead to incorrect connections. When such installations are unavoidable, the attached wiring must be clearly identified and must be routed and clamped so that it cannot be mismatched.

j. Connectors in unpressurized areas should be positioned so that moisture will drain out of them when unmated. Wires exiting connectors must be routed so that moisture drains away from them.

11-104. CIRCUIT BREAKERS. Note those circuit breakers which have a tendency to open circuits frequently, require resetting more than normal, or are subject to nuisance tripping. Before considering their replacement, investigate the reason.

11-105. SYSTEM SEPARATION. Wires of redundant aircraft systems should be routed in separate bundles and through separate connectors to prevent a single fault from disabling multiple systems. Wires not protected by a circuit-protective device, such as a circuit breaker or fuse, should be routed separately from all other wiring. Power feeders from separate sources should be routed in separate bundles from each other and from other aircraft wiring, in order to prevent a single fault from disabling more than one power source. The ground wires from aircraft power sources should be attached to the airframe at separate points so that a single failure will not disable multiple sources. Wiring that is part of electro-explosive subsystems, such as cartridge-actuated fire extinguishers, rescue hoist shear, and emergency jettison devices, should be routed in shielded and jacketed twisted-pair cables, shielded without discontinuities, and kept separate from other wiring at connectors. To facilitate identification of specific separated system bundles, use of colored plastic cable ties or lacing tape is allowed. During aircraft maintenance, colored plastic cable straps or lacing tape should be replaced with the same type and color of tying materials.

11-106. ELECTROMAGNETIC INTERFERENCE (EMI). Wiring of sensitive circuits that may be affected by EMI must be routed away from other wiring interference, or provided with sufficient shielding to avoid system malfunctions under operating conditions. EMI between susceptible wiring and wiring which is a source of EMI increases in proportion to the length of parallel runs and decreases with greater separation. EMI should be limited to negligible levels in wiring related to critical systems, that is, the function of the critical system should not be affected by the EMI generated by the adjacent wire. Use of shielding with 85 percent coverage or greater is recommended. Coaxial, triaxial, twinaxial, or quadraxial cables should be used, wherever appropriate, with their shields connected to ground at a single point or multiple points, depending upon the purpose of the shielding. The airframe grounded structure may also be used as an EMI shield.

11-107. INTERFERENCE TESTS. Perform an interference test for installed equipment and electrical connections as follow:

a. The equipment must be installed in accordance with manufacturer's installation instructions. Visually inspect all the installed equipment to determine that industry standard workmanship and engineering practices were used. Verify that all mechanical and electrical connections have been properly made and that the equipment has been located and installed in accordance with the manufacturer's recommendations. The wire insulation temperature rating should also be considered.

b. Power input tests must be conducted with the equipment powered by the airplane's electrical power generating system, unless otherwise specified.

c. All associated electrically operated equipment and systems on the airplane must be on and operating before conducting interference tests, unless otherwise specified.

d. The effects on interference must be evaluated as follows:

(1) The equipment shall not be the source of harmful conducted or radiated interference or adversely affect other equipment or systems installed in the airplane.

SECTION 9. ENVIRONMENTAL PROTECTION AND INSPECTION

11-115. MAINTENANCE AND OPERATIONS. Wire bundles must be routed in accessible areas that are protected from damage from personnel, cargo, and maintenance activity. They should not be routed in areas in where they are likely to be used as handholds or as support for personal equipment or where they could become damaged during removal of aircraft equipment. Wiring must be clamped so that contact with equipment and structure is avoided. Where this cannot be accomplished, extra protection, in the form of grommets, chafe strips, etc., should be provided. Protective grommets must be used, wherever wires cannot be clamped, in a way that ensures at least a 3/8-inch clearance from structure at penetrations. Wire must not have a preload against the corners or edges of chafing strips or grommets. Wiring must be routed away from high-temperature equipment and lines to prevent deterioration of insulation. Protective flexible conduits should be made of a material and design that eliminates the potential of chafing between their internal wiring and the conduit internal walls. Wiring that must be routed across hinged panels, must be routed and clamped so that the bundle will twist, rather than bend, when the panel is moved.

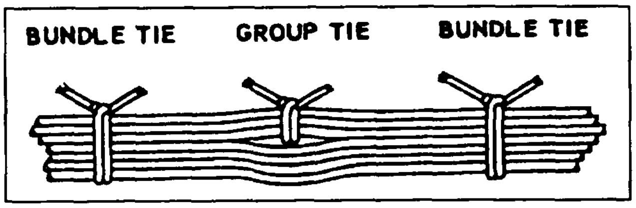


FIGURE 11-7. Group and bundle ties.

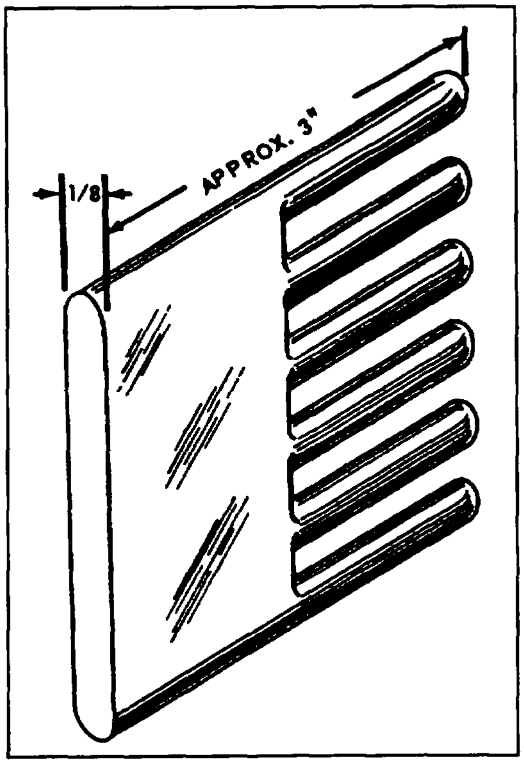


FIGURE 11-8. Comb for straightening wires in bundles.

11-116. GROUP AND BUNDLE TIES. A wire bundle consists of a quantity of wires fastened or secured together and all traveling in the same direction. Wire bundles may consist of two or more groups of wires. It is often advantageous to have a number of wire groups individually tied within the wire bundle for ease of identification at a later date. (See figure 11-7.) Comb the wire groups and bundles so that the wires will lie parallel to each other and minimize the possibility of insulation abrasion. A combing tool, similar to that shown in figure 11-8, may be made from any suitable insulating material, taking care to ensure all edges are rounded to protect the wire insulation.

11-117. MINIMUM WIRE BEND RADII. The minimum radii for bends in wire groups or bundles must not be less than 10 times the outside diameter of their largest wire; or they may be bent at 6 times their outside diameters at breakouts or where they must reverse direction in a bundle, provided that they are suitably supported.

a. RF cables should not bend on a radius of less than 6 times the outside diameter of the cable.

b. Care should be taken to avoid sharp bends in wires that have been marked with the hot stamping process.

11-118. SLACK. Wiring should be installed with sufficient slack so that bundles and individual wires are not under tension. Wires connected to movable or shock-mounted equipment should have sufficient length to allow full travel without tension on the bundle. Wiring at terminal lugs or connectors should have sufficient slack to allow two reterminations without replacement of wires. This slack should be in addition to the drip loop and the allowance for movable equipment. Normally, wire groups or bundles should not exceed 1/2-inch deflection between support points, as shown in figure 11-9. This measurement may be exceeded provided there is no possibility of the wire group or bundle touching a surface that may cause abrasion. Sufficient slack should be provided at each end to:

a. **Permit** replacement of terminals.

b. **Prevent** mechanical strain on wires.

c. **Permit** shifting of equipment for maintenance purposes.

11-119. POWER FEEDERS. The power feeder wires should be routed so that they can be easily inspected or replaced. They must be given special protection to prevent potential chafing against other wiring, aircraft structure, or components.

11-120. RF CABLE. All wiring needs to be protected from damage. However, coaxial and triaxial cables are particularly vulnerable to certain types of damage. Personnel should exercise care while handling or working around coaxial. Coaxial damage can occur when clamped too tightly, or when they are bent sharply (normally at or near connectors). Damage can also be incurred during unrelated maintenance actions around the coaxial cable. Coaxial can be severely damaged on the inside without any evidence of damage on the outside. Coaxial cables with solid center conductors should not be used. Stranded center coaxial cables can be used as a direct replacement for solid center coaxial.

11-121. PRECAUTIONS.

a. **Never kink** coaxial cable.

b. **Never drop** anything on coaxial cable.

c. **Never step** on coaxial cable.

d. **Never bend** coaxial cable sharply.

e. **Never loop** coaxial cable tighter than the allowable bend radius.

f. **Never pull** on coaxial cable except in a straight line.

g. **Never use** coaxial cable for a handle, lean on it, or hang things on it (or any other wire).

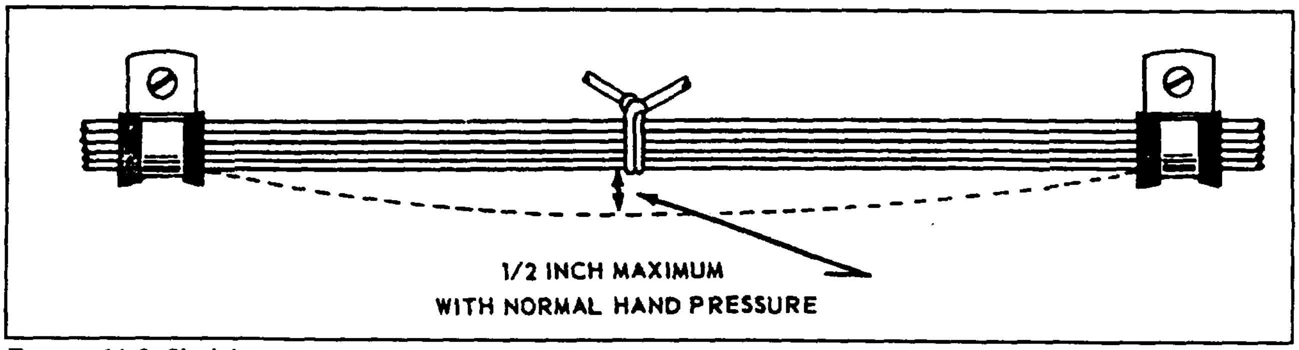


FIGURE 11-9. Slack between supports.

11-122. MOISTURE PROTECTION, WHEEL WELLS, AND LANDING GEAR AREAS.

a. Wires located on landing gear and in the wheel well area can be exposed to many hazardous conditions if not suitably protected. Where wire bundles pass flex points, there must not be any strain on attachments or excessive slack when parts are fully extended or retracted. The wiring and protective tubing must be inspected frequently and replaced at the first sign of wear.

b. Wires should be routed so that fluids drain away from the connectors. When this is not practicable, connectors must be potted. Wiring which must be routed in wheel wells or other external areas must be given extra protection in the form of harness jacketing and connector strain relief. Conduits or flexible sleeving used to protect wiring must be equipped with drain holes to prevent entrapment of moisture.

11-123. PROTECTION AGAINST PERSONNEL AND CARGO. Wiring must be installed so the structure affords protection against its use as a handhold and damage from cargo. Where the structure does not afford adequate protection, conduit must be used, or a suitable mechanical guard must be provided.

11-124. HEAT PRECAUTIONS. Wiring must be routed away from high-temperature equipment and lines to prevent deterioration of insulation. Wires must be rated (reference paragraph 11-66 and 11-67) so that the conductor temperature remains within the wire specification maximum when the ambient temperature, and heat rise, related to current carrying capacity are taken into account. The residual heating effects caused by exposure to sunlight when aircraft are parked for extended periods should also be taken into account. Wires such as in fire detection, fire extinguishing, fuel shutoff, and fly-by-wire flight control systems that must operate during and after a fire, must be selected from types that are qualified to provide circuit integrity after exposure to fire for a specified period. Wire insulation deteriorates rapidly when subjected to high temperatures. Do not use wire with soft polyethylene insulation in areas subject to high temperatures. Use only wires or cables with heat resistance shielding or insulation.

11-125. MOVABLE CONTROLS WIRING PRECAUTIONS. Clamping of wires routed near movable flight controls must be attached with steel hardware and must be spaced so that failure of a single attachment point can not result in interference with controls. The minimum separation between wiring and movable controls must be at least 1/2 inch when the bundle is displaced by light hand pressure in the direction of the controls.

11-126. FLAMMABLE FLUIDS AND GASES. An arcing fault between an electrical wire and a metallic flammable fluid line may puncture the line and result in a fire. Every effort must be made to avoid this hazard by physical separation of the wire from lines and equipment containing oxygen, oil, fuel, hydraulic fluid, or alcohol. Wiring must be routed above these lines and equipment with a minimum separation of 6 inches or more whenever possible. When such an arrangement is not practicable, wiring must be routed so that it does not run parallel to the fluid lines. A minimum of 2 inches must be maintained between wiring and such lines and equipment, except when the wiring is positively clamped to maintain at least 1/2-inch separation, or when it must be connected directly to the fluid-carrying equipment. Install clamps as shown in figure 11-10. These clamps should not be used as a means of supporting the wire bundle. Additional clamps should be installed to support the wire bundle and the clamps fastened to the same structure used to support the fluid line(s) to prevent relative motion.

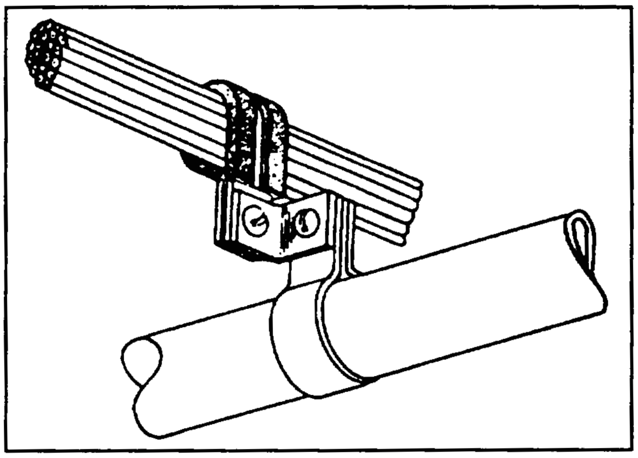


FIGURE 11-10. Separation of wires from plumbing lines.

11-127.—11-134. [RESERVED.]

SECTION 12. WIRE INSULATION AND LACING STRING TIE

11-155. GENERAL. Insulation of wires should be appropriately chosen in accordance with the environmental characteristics of wire routing areas. Routing of wires with dissimilar insulation, within the same bundle, is not recommended, particularly when relative motion and abrasion between wires having dissimilar insulation can occur. Soft insulating tubing (spaghetti) cannot be considered as mechanical protection against external abrasion of wire; since at best, it provides only a delaying action. Conduit or ducting should be used when mechanical protection is needed.

11-156. INSULATION MATERIALS. Insulating materials should be selected for the best combination of characteristics in the following categories:

a. Abrasion resistance.

b. Arc resistance (noncarbon tracking).

c. Corrosion resistance.

d. Cut-through strength.

e. Dielectric strength.

f. Flame resistance.

g. Heat distortion temperature.

h. Impact strength.

i. Mechanical strength.

j. Resistance to fluids.

k. Resistance to notch propagation.

l. Smoke emission.

m. Special properties unique to the aircraft.

n. For a more complete selection of insulated wires refer to SAE AS 4372 Aerospace Wire Performance Requirement and SAE AS 4373 Test Methods for Aerospace Wire.

11-157. STRIPPING INSULATION. Attachment of wire, to connectors or terminals, requires the removal of insulation to expose the conductors. This practice is commonly known as stripping. Stripping may be accomplished in many ways; however, the following basic principles should be practiced.

a. Make sure all cutting tools used for stripping are sharp.

b. When using special wire stripping tools, adjust the tool to avoid nicking, cutting, or otherwise damaging the strands.

c. Damage to wires should not exceed the limits specified in table 11-13.

d. When performing the stripping operation, remove no more insulation than is necessary.

11-158. LACING AND TIES. Ties, lacing, and straps are used to secure wire groups or bundles to provide ease of maintenance, inspection, and installation. Braided lacing tape per MIL-T-43435 is suitable for lacing and tying wires. In lieu of applying ties, straps meeting Specification MS17821 or MS17822 may be used in areas where the temperature does not exceed 120 °C. Straps may not be used in areas of SWAMP such as wheel wells, near wing flaps or wing folds. They may not be used in high vibration areas, where failure

SECTION 16. WIRE MARKING

11-205. GENERAL. The proper identification of electrical wires and cables with their circuits and voltages is necessary to provide safety of operation, safety to maintenance personnel, and ease of maintenance.

a. Each wire and cable should be marked with a part number. It is common practice for wire manufacturers to follow the wire material part number with the five digit/letter C.A.G.E. code identifying the wire manufacturer. Existing installed wire that needs replacement can thereby be identified as to its performance capabilities, and the inadvertent use of a lower performance and unsuitable replacement wire avoided.

b. The method of identification should not impair the characteristics of the wiring.

CAUTION: Do not use metallic bands in place of insulating sleeves. Exercise care when marking coaxial or data bus cable, as deforming the cable may change its electrical characteristics.

11-206. WIRE IDENTIFICATION. To facilitate installation and maintenance, original wire-marking identification is to be retained. The wire identification marks should consist of a combination of letters and numbers that identify the wire, the circuit it belongs to, its gauge size, and any other information to relate the wire to a wiring diagram. All markings should be legible in size, type, and color.

11-207. IDENTIFICATION AND INFORMATION RELATED TO THE WIRE AND WIRING DIAGRAMS. The wire identification marking should consist of similar information to relate the wire to a wiring diagram.

11-208. PLACEMENT OF IDENTIFICATION MARKINGS. Identification markings should be placed at each end of the wire and at 15-inch maximum intervals along the length of the wire. Wires less than 3 inches long need not be identified. Wires 3 to 7 inches in length should be identified approximately at the center. Added identification marker sleeves should be so located that ties, clamps, or supporting devices need not be removed in order to read the identification.

The wire identification code must be printed to read horizontally (from left to right) or vertically (from top to bottom). The two methods of marking wire or cable are as follows:

a. Direct marking is accomplished by printing the cable's outer covering. (See figure 11-23.)

b. Indirect marking is accomplished by printing a heat-shrinkable sleeve and installing the printed sleeve on the wire or cables outer covering. Indirect-marked wire or cable should be identified with printed sleeves at each end and at intervals not longer than 6 feet. The individual wires inside a cable should be identified within 3 inches of their termination. (See figure 11-24.)

11-209. TYPES OF WIRE MARKINGS. The preferred method is to mark directly on the wire. Teflon coated wires, shielded wiring, multiconductor cable, and thermocouple wires usually require special sleeves to carry identification marks. Whatever method of marking is used, the marking should be legible and the color should contrast with the wire insulation or sleeve.

a. Extreme care must, therefore, be taken during circuit identification by a hot stamp machine on insulation wall 10 mils or thinner.

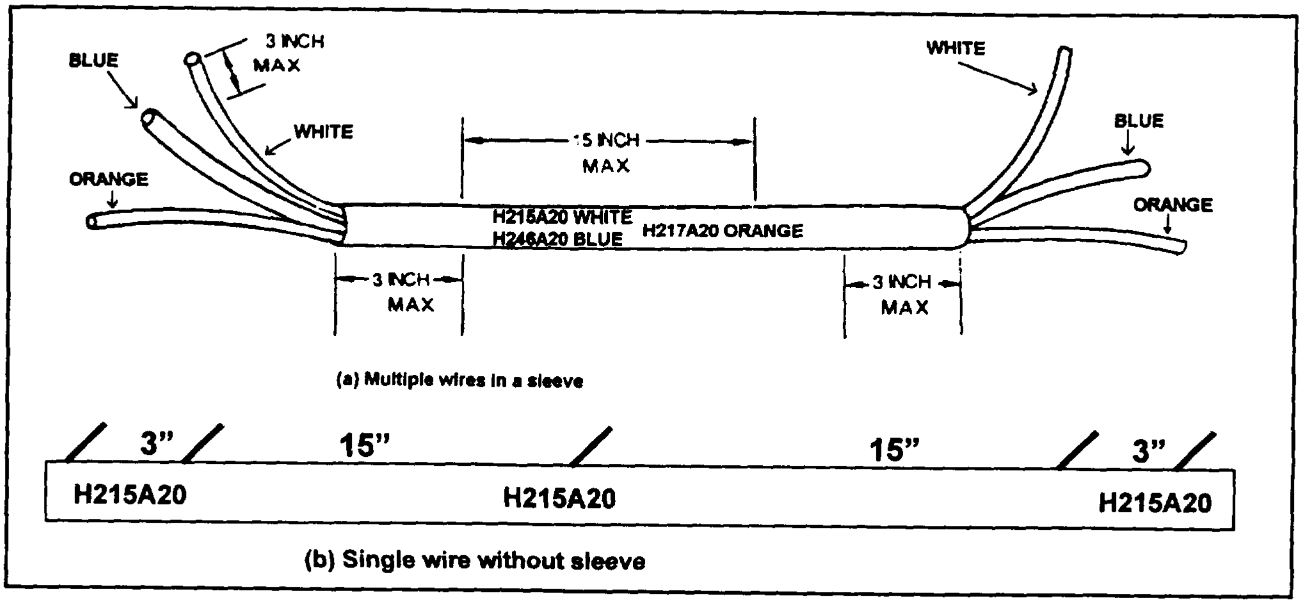


FIGURE 11-23. Spacing of printed identification marks (direct marking).

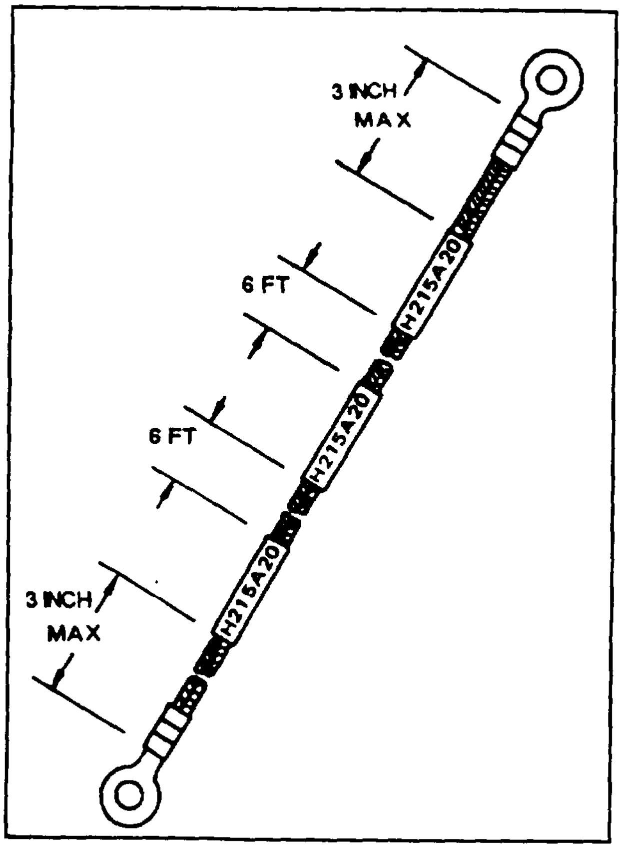


FIGURE 11-24. Spacing of printed identification marks (indirect marking).

b. Alternative identification methods such as "Laser Printing", "Ink Jet", and "Dot Matrix" are preferred. When such modern equipment is not available, the use of stamped identification sleeving should be considered on insulation wall thickness of 10 mils or less.

11-210. HOT STAMP MARKING. This method imprints hot ink marks onto the wire. Caution must be exercised when using this method, as it has been shown to damage insulation when incorrectly applied. Type set characters, similar to that used in printing presses but shaped to the contour of the wire, are heated to the desired temperature. Wire is pulled through a channel directly underneath the characters. The heat, of the type set characters, transfers the ink from the marking foil onto the wire.

a. Good marking is obtained only by the proper combination of temperature, pressure, and dwelling. Hot stamp will mark wire with an outside diameter of 0.038 to 0.25-inch.

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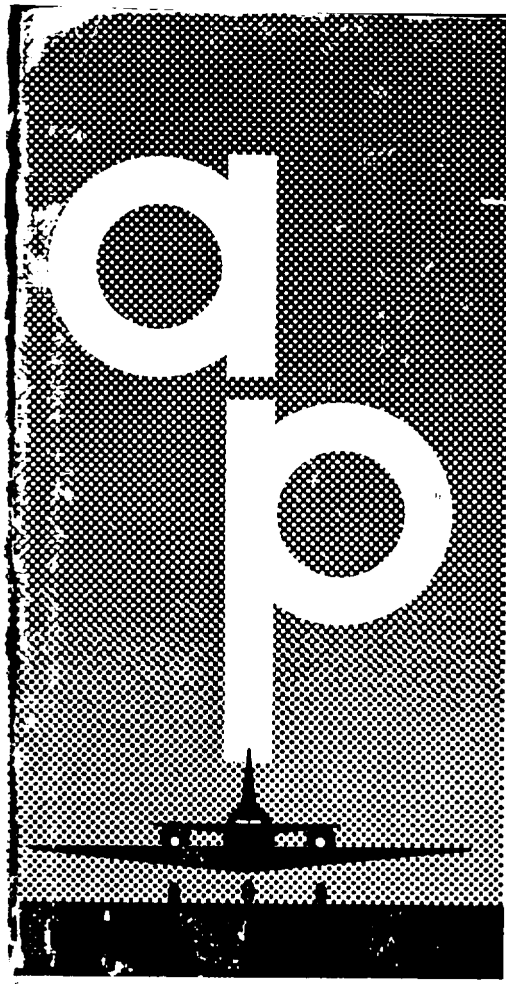

Airframe & Powerplant MECHANICS

Airframe Handbook

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

(1) The conductor length in feet.
(2) The number of amperes of current to be carried.
(3) The amount of voltage drop permitted.
(4) Whether the current to be carried will be intermittent or continuous, and if continuous, whether it is a single conductor in free air, in a conduit, or in a bundle.

Assume that it is desired to install a 50-ft. conductor from the aircraft bus to the equipment in a 28-volt system. For this length, a 1-volt drop is permissible for continuous operation. By referring to the chart in figure 11–5, the maximum number of feet a conductor may be run carrying a specified current with a 1–volt drop can be determined. In this example the number 50 is selected.

Assuming the current required by the equipment is 20 amperes, the line indicating the value of 20 amperes should be selected from the diagonal lines. Follow this diagonal line downward until it intersects the horizontal line number 50. From this point, drop straight downward to the bottom of the chart to find that a conductor between size No. 8 and No. 10 is required to prevent a greater drop than 1 volt. Since the indicated value is between two numbers, the larger size, No. 8, should be selected. This is the smallest size conductor which should be used to avoid an excessive voltage drop.

To determine that the conductor size is sufficient to preclude overheating, disregard both the numbers along the left side of the chart and the horizontal lines. Assume that the conductor is to be a single wire in free air carrying continuous current. Place a pointer at the top of the chart on the diagonal line numbered 20 amperes. Follow this line until the pointer intersects the diagonal line marked "curve 2." Drop the pointer straight downward to the bottom of the chart. This point is between numbers 16 and 18. The larger size, No. 16, should be selected. This is the smallest size conductor acceptable for carrying 20-ampere current in a single wire in free air without overheating.

In many cases the permissible voltage drop is more or less than 1 volt. Since the chart in figure 11–5 is based on only a 1-volt drop, it is necessary to use a correction formula when selecting a conductor which requires other than a 1-volt drop. This is accomplished by dividing the length of the actual conductor run by the permissible voltage drop. For example, assume that a 14-volt system requires a 50-ft. conductor in a bundle between the bus and the equipment. This would permit an allowable voltage drop of 0.5 volt for equipment operated continuously. To use the chart, divide 50 ft. by 0.5 volt.

$$\frac{50 \text{ ft.}}{0.5 \text{ v.}} = 100$$

In this case, when the conductor chart is used to select the wire size, the value of 100 is used instead of the 50-ft. conductor length to determine the size wire to be used.

Conductor Insulation

Two fundamental properties of insulation materials (for example, rubber, glass, asbestos, or plastic) are insulation resistance and dielectric strength. These are entirely different and distinct properties.

Insulation resistance is the resistance to current leakage through and over the surface of insulation materials. Insulation resistance can be measured with a megger without damaging the insulation, and data so obtained serves as a useful guide in determining the general condition of the insulation. However, the data obtained in this manner may not give a true picture of the condition of the insulation. Clean, dry insulation having cracks or other faults might show a high value of insulation resistance but would not be suitable for use.

Dielectric strength is the ability of the insulator to withstand potential difference and is usually expressed in terms of the voltage at which the insulation fails because of the electrostatic stress. Maximum dielectric strength values can be measured by raising the voltage of a test sample until the insulation breaks down.

Because of the expense of insulation and its stiffening effect, together with the great variety of physical and electrical conditions under which the conductors are operated, only the necessary minimum insulation is applied for any particular type of cable designed to do a specific job.

The type of conductor insulation material varies with the type of installation. Such types of insulation as rubber, silk, and paper are no longer used extensively in aircraft systems. More common today are such materials as vinyl, cotton, nylon, Teflon, and Rockbestos.

Identifying Wire and Cable

Aircraft electrical system wiring and cable may be marked with a combination of letters and numbers to identify the wire, the circuit it belongs to, the gage number, and other information necessary to relate the wire or cable to a wiring diagram. Such markings are called the identification code.

a marked sleeve tied in place; the other uses a pressure-sensitive tape.

Electrical Wiring Installation

The following recommended procedures for installing aircraft electrical wiring are typical of those used on most aircraft. For purposes of this discussion, the following definitions are applicable:

(1) Open wiring—any wire, wire group, or wire bundle not enclosed in conduit.

(2) Wire group—two or more wires going to the same location tied together to retain identity of the group.

(3) Wire bundle—two or more wire groups tied together because they are going in the same direction at the point where the tie is located.

(4) Electrically protected wiring—wires which include (in the circuit) protection against overloading, such as fuses, circuit breakers, or other limiting devices.

(5) Electrically unprotected wiring—wires (generally from generators to main bus distribution points) which do not have protection, such as fuses, circuit breakers, or other current-limiting devices.

Wire Groups and Bundles

Grouping or bundling certain wires, such as electrically unprotected power wiring and wiring going to duplicate vital equipment, should be avoided.

Wire bundles should generally be less than 75 wires, or 1-1/2 to 2 in. in diameter where practicable. When several wires are grouped at junction boxes, terminal blocks, panels, etc., identity of the group within a bundle (figure 11-9) can be retained.

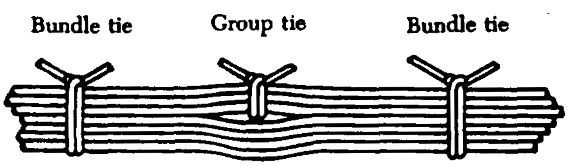

FIGURE 11-9. Group and bundle ties.

Twisting Wires

When specified on the engineering drawing, or when accomplished as a local practice, parallel wires must sometimes be twisted. The following are the most common examples:

(1) Wiring in the vicinity of magnetic compass or flux valve.

(2) Three-phase distribution wiring.

(3) Certain other wires (usually radio wiring) as specified on engineering drawings.

Twist the wires so that they will lie snugly against each other, making approximately the number of twists per foot as shown in table 11-3. Always check wire insulation for damage after twisting. If the insulation is torn or frayed, replace the wire.

TABLE 11-3. Recommended number of twists per foot.

	Wire Size									
	#22	#20	#18	#16	#14	#12	#10	#8	#6	#4
2 Wires	10	10	9	8	7½	7	6½	6	5	4
3 Wires	10	10	8½	7	6½	6	5½	5	4	3

Spliced Connections in Wire Bundles

Spliced connections in wire groups or bundles should be located so that they can be easily inspected. Splices should also be staggered (figure 11-10) so that the bundle does not become excessively enlarged. All noninsulated splices should be covered with plastic, securely tied at both ends.

Slack in Wiring Bundles

Single wires or wire bundles should not be installed with excessive slack. Slack between supports should normally not exceed a maximum of 1/2 in. deflection with normal hand force (figure 11-11). However, this may be exceeded if the wire bundle is thin and the clamps are far apart. Slack should never be so great that the wire bundle could abrade against any surface. A sufficient amount of slack should be allowed near each end of a bundle to:

(1) Permit easy maintenance.

(2) Allow replacement of terminals.

(3) Prevent mechanical strain on the wires, wire junctions, and supports.

(4) Permit free movement of shock and vibration-mounted equipment.

(5) Permit shifting of equipment for purposes of maintenance.

Bend Radii

Bends in wire groups or bundles should be not less than 10 times the outside diameter of the wire group or bundle. However, at terminal strips, where wire is suitably supported at each end of the bend, a minimum radius of three times the outside diameter of the wire, or wire bundle, is normally acceptable. There are, of course, exceptions to these guidelines in the case of certain types of cable; for

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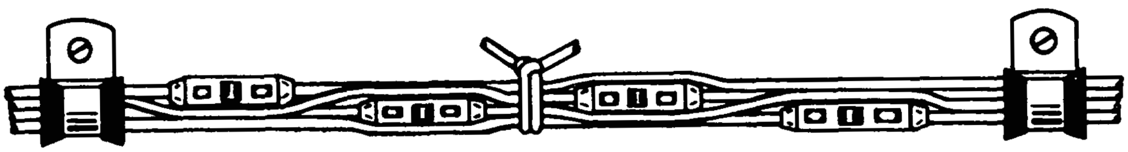

FIGURE 11-10. Staggered splices in a wire bundle.

example, coaxial cable should never be bent to a smaller radius than six times the outside diameter.

Routing and Installations

All wiring should be installed so that it is mechanically and electrically sound and neat in appearance. Whenever practicable, wires and bundles should be routed parallel with, or at right angles to, the stringers or ribs of the area involved. An exception to this general rule is coaxial cable, which is routed as directly as possible.

The wiring must be adequately supported throughout its length. A sufficient number of supports must be provided to prevent undue vibration of the unsupported lengths. All wires and wire groups should be routed and installed to protect them from:

(1) Chafing or abrasion.
(2) High temperature.
(3) Being used as handholds, or as support for personal belongings and equipment.
(4) Damage by personnel moving within the aircraft.
(5) Damage from cargo stowage or shifting.
(6) Damage from battery acid fumes, spray, or spillage.
(7) Damage from solvents and fluids.

Protection Against Chafing

Wires and wire groups should be protected against chafing or abrasion in those locations where contact with sharp surfaces or other wires would damage the insulation. Damage to the insulation can cause short circuits, malfunction, or inadvertent operation of equipment. Cable clamps should be used to support wire bundles at each hole through a bulkhead (figure 11-12). If wires come closer than 1/4 in. to the edge of the hole, a suitable grommet is used in the hole as shown in figure 11-13.

Sometimes it is necessary to cut nylon or rubber grommets to facilitate installation. In these instances, after insertion, the grommet can be secured in place with general-purpose cement. The cut should be at the top of the hole, and made at an angle of 45° to the axis of the wire bundle hole.

Protection against High Temperature

To prevent insulation deterioration, wires should be kept separate from high-temperature equipment, such as resistors, exhaust stacks, or heating ducts. The amount of separation is normally specified by engineering drawings. Some wires must invariably be run through hot areas. These wires must be insulated with high-temperature material such as asbestos, fiber glass, or Teflon. Additional protection is also often requred in the form of conduits. A low-temperature insulation wire should never be used to replace a high-temperature insulation wire.

Many coaxial cables have soft plastic insulation, such as polyethylene, which is especially subject to deformation and deterioration at elevated temperatures. All high-temperature areas should be avoided when installing these cables insulated with plastic or polyethylene.

Additional abrasion protection should be given to asbestos wires enclosed in conduit. Either conduit with a high-temperature rubber liner should be used, or asbestos wires can be enclosed individually in high-temperature plastic tubes before being installed in the conduit.

Protection Against Solvents and Fluids

Wires should not be installed in areas where they will be subjected to damage from fluids or in the lowest 4 in. of an aircraft fuselage, except those that must terminate in that area. If there is a possibility that wire may be soaked with fluids, plastic tubing should be used to protect the wire. This tubing should extend past the exposure area in both directions and should be tied at each end. If the wire has a low point between the tubing ends, provide a 1/8-in. drain hole, as shown in figure 11-14. This hole should be punched into the tubing after the installation is complete and the low point definitely established by using a hole punch to cut a half circle. Care should be taken not to damage any wires inside the tubing when using the punch.

Wire should never be routed below an aircraft

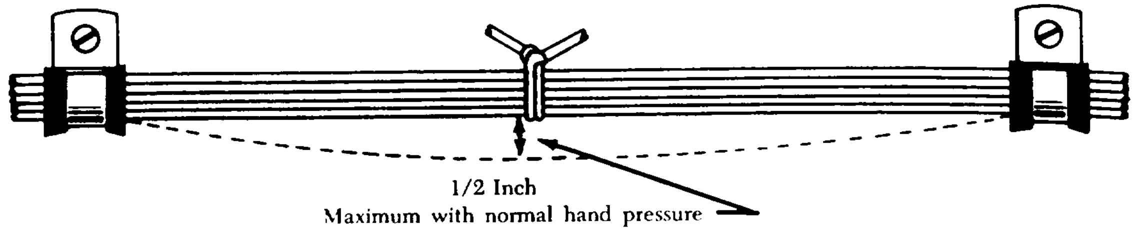

FIGURE 11–11. Slack in wire bundle between supports.

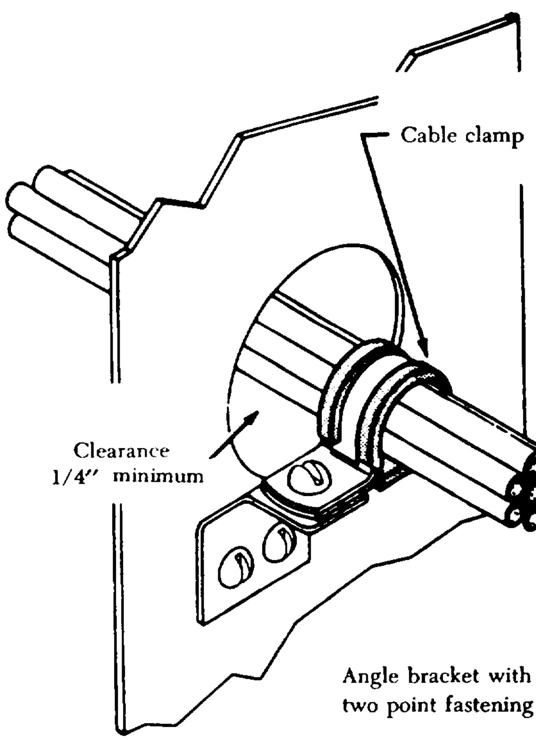

FIGURE 11–12. Cable clamp at bulkhead hole.

Routing Precautions

When wiring must be routed parallel to combustible fluid or oxygen lines for short distances, as much fixed separation as possible should be maintained. The wires should be on a level with, or above, the plumbing lines. Clamps should be spaced so that if a wire is broken at a clamp it will not contact the line. Where a 6-in. separation is not possible, both the wire bundle and the plumbing line can be clamped to the same structure to prevent any relative motion. If the separation is less than 2 in. but more than 1/2 in., a polyethylene sleeve may be used over the wire bundle to give further protection. Also two cable clamps back-to-back, as shown in figure 11–15, can be used to maintain a rigid separation only, and not for support of the bundle. No wire should be routed so that it is located nearer than 1/2 in. to a plumbing line. Neither should a wire or wire bundle be supported from a battery. All wires in the vicinity of an aircraft battery should be inspected frequently and wires discolored by battery fumes should be replaced.

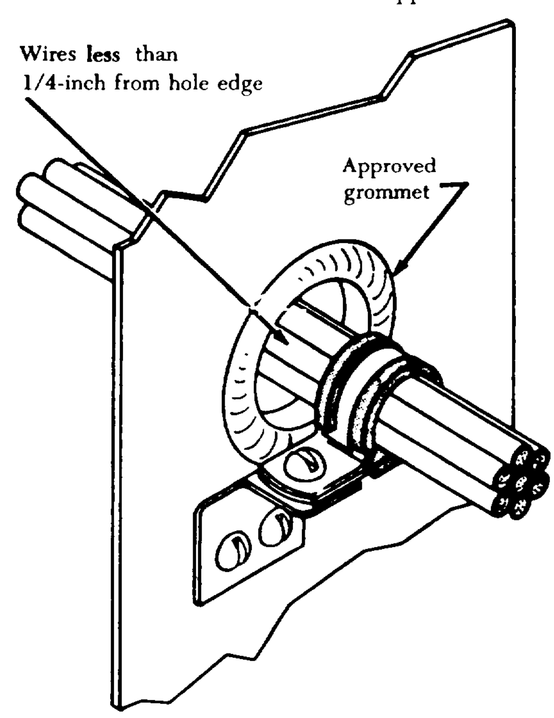

FIGURE 11–13. Cable clamp and grommet at bulkhead hole.

Protection of Wires in Wheel Well Area

Wires located in wheel wells are subject to many additional hazards, such as exposure to fluids, pinching, and severe flexing in service. All wire bundles should be protected by sleeves of flexible tubing securely held at each end, and there should be no relative movement at points where flexible tubing is secured. These wires and the insulating tubing should be inspected carefully at frequent intervals, and wires or tubing should be replaced at the first sign of wear. There should be no strain on attachments when parts are fully extended, but slack should not be excessive.

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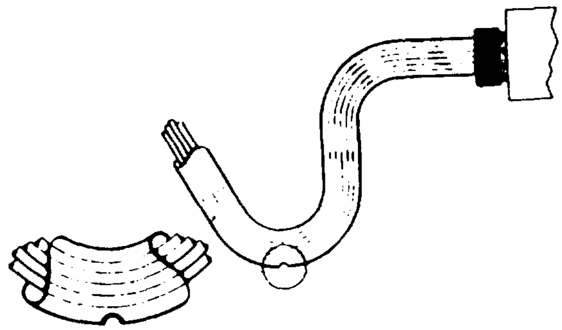

FIGURE 11–14. Drain hole in low point of tubing.

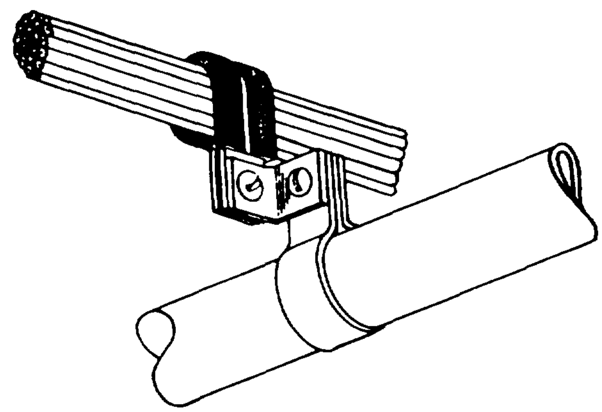

FIGURE 11–15. Separation of wires from plumbing lines.

plumbing line that carries flammable fluids or oxygen.

Wiring should be routed to maintain a minimum clearance of at least 3 in. from control cables. If this cannot be accomplished, mechanical guards should be installed to prevent contact between wiring and control cables.

Installation of Cable Clamps

Cable clamps should be installed with regard to the proper angle, as shown in figure 11–16. The mounting screw should be above the wire bundle. It is also desirable that the back of the cable clamp rest against a structural member where practicable.

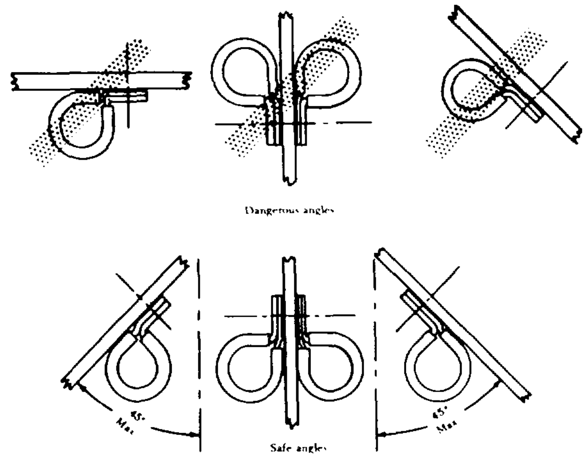

FIGURE 11–16. Proper mounting angles for cable clamps.

Figure 11–17 shows some typical mounting hardware used in installing cable clamps.

Care should be taken that wires are not pinched in cable clamps. Where possible, mount the cables directly to structural members, as shown in figure 11–18.

Clamps can be used with rubber cushions to secure wire bundles to tubular structures as shown in figure 11–19. Such clamps must fit tightly, but should not be deformed when locked in place.

LACING AND TYING WIRE BUNDLES

Wire groups and bundles are laced or tied with cord to provide ease of installation, maintenance, and inspection. This section describes and illustrates recommended procedures for lacing and tying wires with knots which will hold tightly under all conditions. For the purposes of this discussion, the following terms are defined:

(1) Tying is the securing together of a group or bundle of wires by individual pieces of cord tied around the group or bundle at regular intervals.

(2) Lacing is the securing together of a group or bundle of wires by a continuous piece of cord forming loops at regular intervals around the group or bundle.

(3) A wire group is two or more wires tied or laced together to give identity to an individual system.

(4) A wire bundle is two or more wires or groups tied or laced together to facilitate maintenance.

The material used for lacing and tying is either cotton or nylon cord. Nylon cord is moisture- and fungus-resistant, but cotton cord must be waxed before using to give it these necessary protective characteristics.

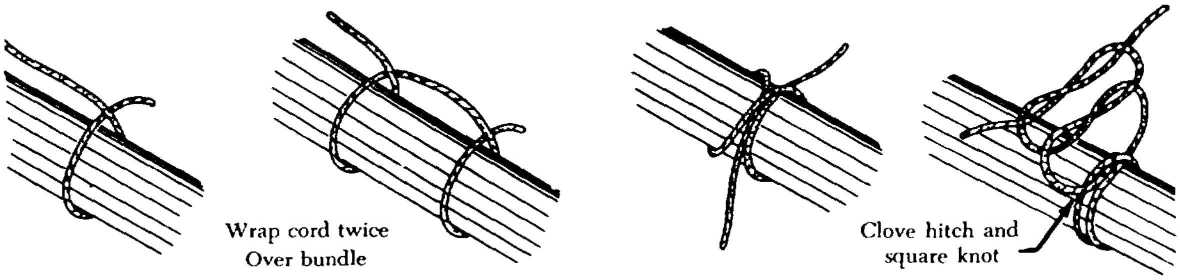

FIGURE 11–23. Tying a wire group or bundle.

fully; follow the manufacturer's instructions to avoid nicking, cutting, or otherwise damaging strands. This is especially important for aluminum wires and for copper wires smaller than No. 10. Examine stripped wires for damage. Cut off and re-strip (if length is sufficient), or reject and replace any wires having more than the allowable number of nicked or broken strands listed in the manufacturer's instructions.

(3) Make sure insulation is clean-cut with no frayed or ragged edges. Trim if necessary.

(4) Make sure all insulation is removed from stripped area. Some types of wires are supplied with a transparent layer of insulation between the conductor and the primary insulation. If this is present, remove it.

(5) When using hand-plier strippers to remove lengths of insulation longer than 3/4 in., it is easier to accomplish in two or more operations.

(6) Re-twist copper strands by hand or with pliers, if necessary, to restore natural lay and tightness of strands.

A pair of hand wire strippers is shown in figure 11–24. This tool is commonly used to strip most types of wire.

The following general procedures describe the steps for stripping wire with a hand stripper. (Refer to figure 11–25.)

(1) Insert wire into exact center of correct cutting slot for wire size to be stripped. Each slot is marked with wire size.

(2) Close handles together as far as they will go.

(3) Release handles, allowing wire holder to return to the "open" position.

(4) Remove stripped wire.

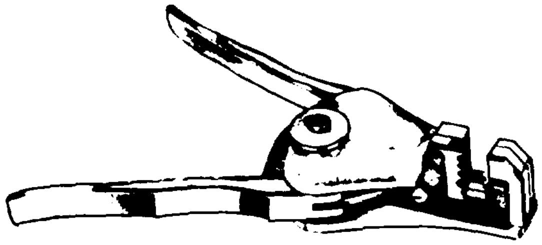

FIGURE 11–24. Light-duty hand wire strippers.

Solderless Terminals and Splices

Splicing of electrical cable should be kept to a minimum and avoided entirely in locations subject to extreme vibrations. Individual wires in a group or bundle can usually be spliced, provided the completed splice is located so that it can be inspected periodically. Splices should be staggered so that the bundle does not become excessively enlarged. Many types of aircraft splice connectors are available for splicing individual wires. Self-insulated splice connectors are usually preferred; however, a noninsulated splice connector can be used if the splice is covered with plastic sleeving secured at both ends. Solder splices may be used, but they are particularly brittle and not recommended.

Electric wires are terminated with solderless terminal lugs to permit easy and efficient connection to and disconnection from terminal blocks, bus bars, or other electrical equipment. Solderless splices join electric wires to form permanent continuous runs. Solderless terminal lugs and splices are made of copper or aluminum and are preinsulated or uninsulated, depending on the desired application.

Terminal lugs are generally available in three types for use in different space conditions. These are the flag, straight, and right-angle lugs. Terminal lugs are "crimped" (sometimes called "staked" or "swaged") to the wires by means of hand or power crimping tools.

The following discussion describes recommended

Hardware material and finish should be selected on the basis of the material of the structure to which attachment is made and on the material of the jumper and terminal specified for the bonding or grounding connection. Either a screw or bolt of the proper size for the specified jumper terminal should be used. When repairing or replacing existing bonding or grounding connections, the same type of hardware used in the original connection should always be used.

Testing Grounds and Bonds

The resistance of all bond and ground connections should be tested after connections are made before re-finishing. The resistance of each connection should normally not exceed 0.003 ohm. Resistance measurements need to be of limited nature only for verification of the existence of a bond, but should not be considered as the sole proof of satisfactory bonding. The length of jumpers, methods, and materials used, and the possibility of loosening the connections in service should also be considered.

CONNECTORS

Connectors (plugs and receptacles) facilitate maintenance when frequent disconnection is required. Since the cable is soldered to the connector inserts, the joints should be individually installed and the cable bundle firmly supported to avoid damage by vibration. Connectors have been particularly vulnerable to corrosion in the past, due to condensation within the shell. Special connectors with waterproof features have been developed which may replace non-waterproof plugs in areas where mositure causes a problem. A connector of the same basic type and design should be used when replacing a connector. Connectors susceptible to corrosion difficulties may be treated with a chemically inert waterproof jelly. When replacing connector assemblies, the socket-type insert should be used on the half which is "live" or "hot" after the connector is disconnected, to prevent unintentional grounding.

Types of Connectors

Connectors are identified by AN numbers and are divided into classes with the manufacturer's variations in each class. The manufacturer's variations are differences in appearance and in the method of meeting a specification. Some commonly used connectors are shown in figure 11–37. There are five basic classes of AN connectors used in most aircraft. Each class of connector has slightly different construction characteristics. Classes A, B, C, and D are made of aluminum, and class K is made of steel.

(1) Class A—Solid, one-piece back shell, general-purpose connector.

(2) Class B—Connector back shell separates into two parts lengthwise. Used primarily where it is important that the soldered connectors be readily accessible. The back shell is held together by a threaded ring or by screws.

(3) Class C—A pressurized connector with inserts that are not removable. Similar to a class A connector in appearance, but the inside sealing arrangement is sometimes different. It is used on walls of bulkheads of pressurized equipment.

(4) Class D—Moisture- and vibration-resistant connector which has a sealing grommet in the back shell. Wires are threaded through tight-fitting holes in the grommet, thus sealing against moisture.

(5) Class K—A fireproof connector used in areas where it is vital that the electric current is not interrupted, even though the connector may be exposed to continuous open flame. Wires are crimped to the pin or socket contacts and the shells are made of steel. This class of connector is normally longer than other classes of connectors.

Connector Identification

Code letters and numbers are marked on the coupling ring or shell to identify a connector. This code (figure 11–38) provides all the information necessary to obtain the correct replacement for a defective or damaged part.

Many special-purpose connectors have been designed for use in aircraft applications. These include subminiature and rectangular shell connectors, and connectors with short body shells or split-shell construction.

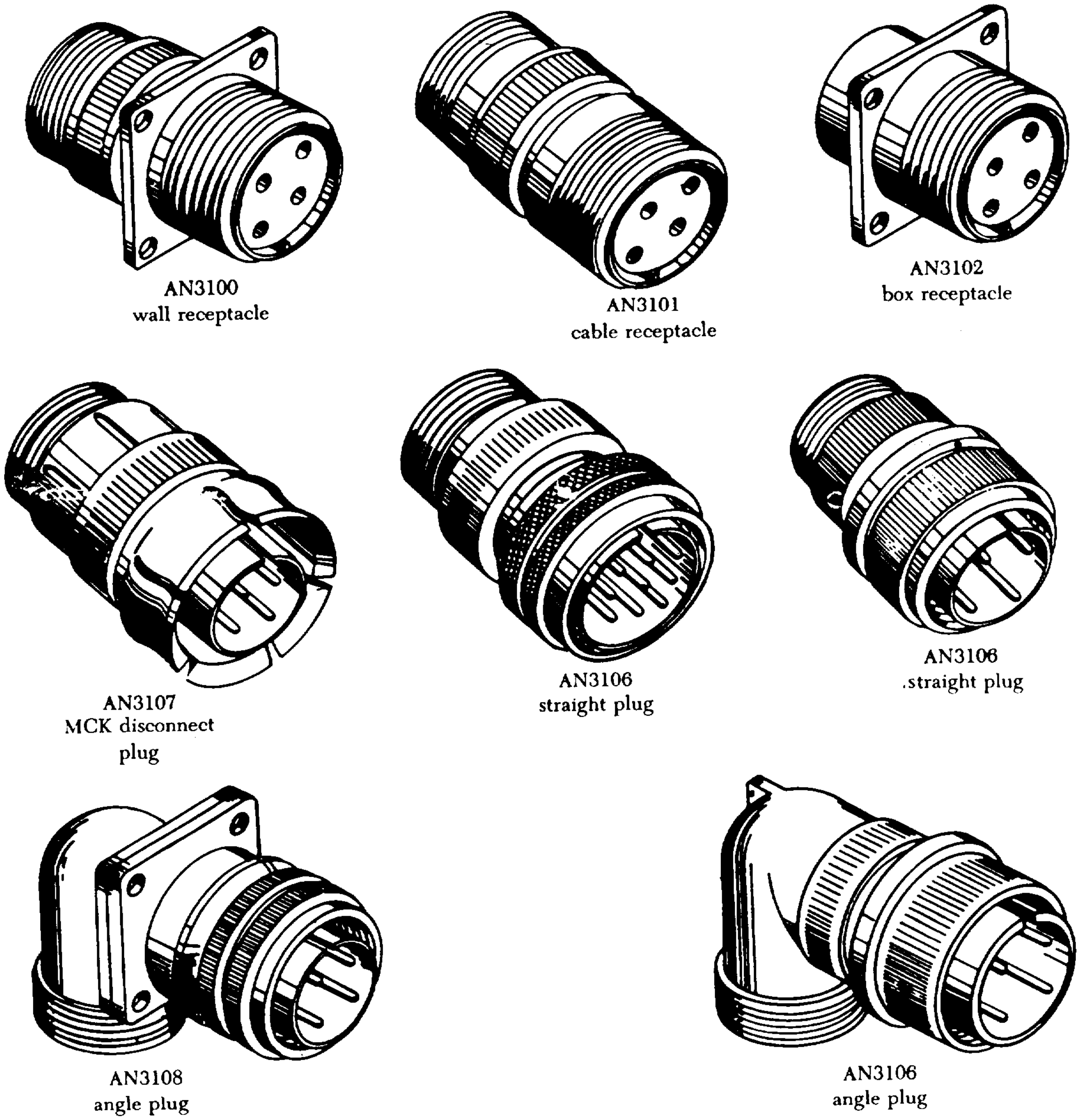

Figure 11–37. AN connectors.

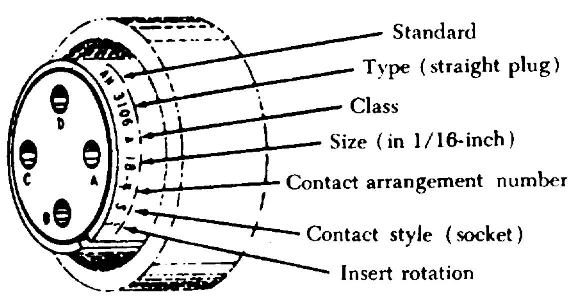

Figure 11–38. AN connector marking.

Installation of Connectors

The following procedures outline one recommended method of assembling connectors to receptacles.

(1) Locate the proper position of the plug in relation to the receptable by aligning the key of one part with the groove or keyway of the other part.

(2) Start the plug into the receptacle with a light forward pressure and engage the

threads of the coupling ring and receptacle.

(3) Alternately push in the plug and tighten the coupling ring until the plug is completely seated.

(4) Use connector pliers to tighten coupling rings one sixteenth to one eighth turn beyond fingertight if space around the connector is too small to obtain a good finger grip.

(5) Never use force to mate connectors to receptacles. Do not hammer a plug into its receptacle; and never use a torque wrench or pliers to lock coupling rings.

A connector is generally disassembled from a receptacle in the following manner:

(1) Use connector pliers to loosen coupling rings which are too tight to be loosened by hand.

(2) Alternately pull on the plug body and unscrew the coupling ring until the connector is separated.

(3) Protect disconnected plugs and receptacles with caps or plastic bags to keep debris from entering and causing faults.

(4) Do not use excessive force, and do not pull on attached wires.

CONDUIT

Conduit is used in aircraft installations for the mechanical protection of wires and cables. It is available in metallic and nonmetallic materials in both rigid and flexible form.

When selecting conduit size for a specific cable bundle application, it is common practice to allow for ease in maintenance and possible future circuit expansion by specifying the conduit inner diameter about 25% larger than the maximum diameter of the conductor bundle. The nominal diameter of a rigid metallic conduit is the outside diameter. Therefore, to obtain the inside diameter, subtract twice the tube wall thickness.

From the abrasion standpoint, the conductor is vulnerable at the conduit ends. Suitable fittings are affixed to the conduit ends in such a manner that a smooth surface comes in contact with the conductor within the conduit. When fittings are not used, the conduit end should be flared to prevent wire insulation damage. The conduit is supported by clamps along the conduit run.

Many of the common conduit installation problems can be avoided by proper attention to the following details:

(1) Do not locate conduit where it can be used as a handhold or footstep.

(2) Provide drain holes at the lowest point in a conduit run. Drilling burrs should be carefully removed from the drain holes.

(3) Support the conduit to prevent chafing against the structure and to avoid stressing its end fittings.

Damaged conduit sections should be repaired to prevent damage to the wires or wire bundle. The minimum acceptable tube bend radii for rigid conduit as prescribed by the manufacturer's instructions should be followed carefully. Kinked or wrinkled bends in a rigid conduit are normally not acceptable.

Flexible aluminum conduit is widely available in two types: (1) Bare flexible and (2) rubber-covered conduit. Flexible brass conduit is normally used instead of flexible aluminum conduit, where necessary to minimize radio interference. Flexible conduit may be used where it is impractical to use rigid conduit, such as areas that have motion between conduit ends or where complex bends are necessary. Transparent adhesive tape is recommended when cutting flexible tubing with a hacksaw to minimize fraying of the braid.

ELECTRICAL EQUIPMENT INSTALLATION

This section provides general procedures and safety precautions for installation of commonly used aircraft electrical equipment and components. Electrical load limits, acceptable means of controlling or monitoring electrical loads, and circuit protection devices are subjects with which mechanics must be familiar to properly install and maintain aircraft electrical systems.

Electrical Load Limits

When installing additional electrical equipment that consumes electrical power in an aircraft, the total electrical load must be safely controlled or managed within the rated limits of the affected components of the aircraft's power-supply system.

Before any aircraft electrical load is increased, the associated wires, cables, and circuit protection devices (fuses or circuit breakers) should be checked to determine that the new electrical load (previous maximum load plus added load) does not exceed the rated limits of the existing wires, cables, or protection devices.

The generator or alternator output ratings prescribed by the manufacturer should be compared with the electrical loads which can be imposed on the affected generator or alternator by installed equipment. When the comparison shows that the probable total connected electrical load can exceed the output load limits of the generator(s) or alternator(s), the load should be reduced so that an overload cannot occur. When a storage battery is part of the electrical power system, ensure that the battery is continuously charged in flight, except when short, intermittent loads are connected such as a radio transmitter, a landing-gear motor, or other similar devices which may place short-time demand loads on the battery.

Controlling or Monitoring the Electrical Load

Placards are recommended to inform crewmembers of an aircraft about the combination of electrical loads that can safely be connected to the power source.

In installations where the ammeter is in the battery lead, and the regulator system limits the maximum current that the generator or alternator can deliver, a voltmeter can be installed on the system bus. As long as the ammeter does not read "discharge" (except for short, intermittent loads such as operating the gear and flaps) and the voltmeter remains at "system voltage," the generator or alternator will not be overloaded.

In installations where the ammeter is in the generator or alternator lead, and the regulator system does not limit the maximum current that the generator or alternator can deliver, the ammeter can be redlined at 100% of the generator or alternator rating. If the ammeter reading is never allowed to exceed the red line, except for short, inermittent loads, the generator or alternator will not be overloaded.

Where the use of placards or monitoring devices is not practicable or desired, and where assurance is needed that the battery in a typical small aircraft generator/battery power source will be charged in flight, the total continuous connected electrical load may be held to approximately 80% of the total rated generator output capacity. (When more than one generator is used in parallel, the total rated output is the combined output of the installed generators.)

When two or more generators are operated in parallel and the total connected system load can exceed the rated output of one generator, means must be provided for quickly coping with the sudden overloads which can be caused by generator or engine failure. A quick load reduction system, or a specified procedure whereby the total load can be reduced to a quantity which is within the rated capacity of the remaining operable generator(s), can be employed.

Electrical loads should be connected to inverters, alternators, or similar aircraft electrical power sources in such a manner that the rated limits of the power source are not exceeded, unless some type of effective monitoring means is provided to keep the load within prescribed limits.

Circuit Protection Devices

Conductors should be protected with circuit breakers or fuses located as close as possible to the electrical power source bus. Normally, the manufacturer of the electrical equipment specifies the fuse or circuit breaker to be used when installing equipment.

The circuit breaker or fuse should open the circuit before the conductor emits smoke. To accomplish this, the time current characteristic of the protection device must fall below that of the associated conductor. Circuit protector characteristics should be matched to obtain the maximum utilization of the connected equipment.

Figure 11–39 shows an example of the chart used in selecting the circuit breaker and fuse protection for copper conductors. This limited chart is applicable to a specific set of ambient temperatures and wire bundle sizes, and is presented as a typical example only. It is important to consult such guides before selecting a conductor for a specific purpose. For example, a wire run individually in the open air may be protected by the circuit breaker of the next higher rating to that shown on the chart.

Wire AN gage copper	Circuit breaker amperage	Fuse amp.
22	5	5
20	7.5	5
18	10	10
16	15	10
14	20	15
12	30	20
10	40	30
8	50	50
6	80	70
4	100	70
2	125	100
1		150
0		150

FIGURE 11–39. Wire and circuit protector chart.

FAA AC 65-15

All re-settable circuit breakers should open the circuit in which they are installed regardless of the position of the operating control when an overload or circuit fault exists. Such circuit breakers are referred to as "trip-free." Automatic re-set circuit breakers automatically re-set themselves. They should not be used as circuit protection devices in aircraft.

Switches

A specifically designed switch should be used in all circuits where a switch malfunction would be hazardous. Such switches are of rugged construction and have sufficient contact capacity to break, make, and carry continuously the connected load current. Snap-action design is generally preferred to obtain rapid opening and closing of contacts regardless of the speed of the operating toggle or plunger, thereby minimizing contact arcing.

The nominal current rating of the conventional aircraft switch is usually stamped on the switch housing. This rating represents the continuous current rating with the contacts closed. Switches should be derated from their nominal current rating for the following types of circuits:

(1) High rush-in circuits—Circuits containing incandescent lamps can draw an initial current which is 15 times greater than the continuous current. Contact burning or welding may occur when the switch is closed.

(2) Inductive circuits—Magnetic energy stored in solenoid coils or relays is released and appears as an arc when the control switch is opened.

(3) Motors—Direct-current motors will draw several times their rated current during starting, and magnetic energy stored in their armature and field coils is released when the control switch is opened.

The chart in figure 11–40 is typical of those available for selecting the proper nominal switch rating when the continuous load current is known. This selection is essentially a derating to obtain reasonable switch efficiency and service life.

Hazardous errors in switch operation can be avoided by logical and consistent installation. Two-position "on-off" switches should be mounted so that the "on" position is reached by an upward or forward movement of the toggle. When the switch controls movable aircraft elements, such as landing gear or flaps, the toggle should move in the same direction as the desired motion. Inadvertent operation of a switch can be prevented by mounting a suitable guard over the switch.

Nominal system voltage	Type of load	Derating factor
24 v. d.c.	Lamp	8
24 v. d.c.	Inductive (Relay-Solenoid)	4
24 v. d.c.	Resistive (Heater)	2
24 v. d.c.	Motor	3
12 v. d.c.	Lamp	5
12 v. d.c.	Inductive (Relay-Solenoid)	2
12 v. d.c.	Resistive (Heater)	1
12 v. d.c.	Motor	2

FIGURE 11–40. Switch derating factors.

Relays

Relays are used as switching devices where a weight reduction can be achieved or electrical controls can be simplified. A relay is an electrically operated switch and is therefore subject to dropout under low system voltage conditions. The foregoing discussion of switch ratings is generally applicable to relay contact ratings.

AIRCRAFT LIGHTING SYSTEMS

Aircraft lighting systems provide illumination for both exterior and interior use. Lights on the exterior provide illumination for such operations as landing at night, inspection of icing conditions, and safety from midair collision. Interior lighting provides illumination for instruments, cockpits, cabins, and other sections occupied by crewmembers and passengers. Certain special ights, such as indicator and warning lights, indicate the operational status of equipment.

Exterior Lights

Position, anti-collision, landing, and taxi lights are common examples of aircraft exterior lights. Some lights, such as position lights and anti-collision lights, are required for night operations. Other types of exterior lights, such as wing inspection lights, are of great benefit for specialized flying operations.

Position Lights

Aircraft operating at night must be equipped with position lights that meet the minimum requirements specified by the Federal Aviation Regulations. A set of position lights consist of one red, one

INSPECTION TECHNIQUES

TWA LEVELS OF INSPECTION

LECTROMEC INSPECTION METHOD

GRCI/ECLYPSE WIRE TEST

ECAD INFO

DIT-MCO WIRE TESTER

UNIVERSAL SYNAPTICS

INSPECTION POLICY – SPECIFIC INSPECTIONS

5. Levels of Inspection

A. Visual Inspection

Visual airframe and power plant inspection constitutes a check of visible or exposed areas, usually external, as specified on the appropriate inspection forms. A visual inspection may include those items which are partially hidden, plus those that might be readily accessible through quick access panels.

B. Detailed Inspection

A detailed inspection is covered by two complimentary inspection concepts – the area concept and the specific item concept.

(1) Area Concept

The area inspection concept constitutes a very detailed inspection of the designated area, including, but not limited to structures, tubing, cables, wiring and any units exposed or visible through routine open up. Normal assistance to visual inspection will be used as required and may consist of mirrors, magnifying glasses, dye penetrant checks or specialized non–destructive test equipment where applicable.

(2) Specific Item Concept

The specific item concept is a very detailed inspection of a specific item as detailed on the work forms or by inspection supervision. It is limited to the defined item(s) and does not cover the associated area.

C. Final Inspection

Upon completion of all maintenance and service work at Check "C" and higher maintenance as outlined on the appropriate maintenance work forms, the aircraft and power plant shall be given a final check by an inspector. When a Check "C" is accomplished in conjunction with a higher maintenance, the sign–out procedures of the higher maintenance shall prevail. If the aircraft is found to be satisfactory for service, the inspector shall so indicate by initialing in the space provided under "Plane OK For Return to Service" on the Maintenance work "Final Inspection" form.

(1) Airframe

This inspection is intended as a visual safety check to assure all access covers, inspection doors, panels and "J" box covers are installed; that tools, rags, loose hardware, etc., have been removed from cabin, cockpit, cargo compartments, wheel wells and engine inlets; that all loose equipment and furnishings have been properly stowed.

(2) Powerplant

This inspection is intended as a visual safety check to assure all access covers, inspection doors and panels are installed. Visually check inlet and exhaust that tools, rags, loose hardware, etc., have been removed.

TWA LEVELS OF INSPECTION

Visual Wiring Insulation Inspection
vs.
Advanced Inspection Techniques & Emerging Technologies

This is a summary of findings derived from Lectromec's Report N193-RPT14MY9, an inspection project completed in May 1999 by Lectromec. The scope of work involved testing the wiring in one zone, on each of five military aircraft. The Lectromec DelTest™ (see attached description) was conducted in parallel to independent, professional visual inspections.

Exhibit A, to follow, outlines the total number of wire insulation breaches (fractures) found by each inspection method. The comparative data are quite telling and suggest an inadequacy in the most widely used wire inspection technique. Visual inspection has difficulty detecting hidden breaks which are behind harnesses, contained in the middle of harnesses, microscopic in size, under clamps & ties, covered in Nomex, etc. In fact, most visual inspection practices do not untie bundles, separate wires, loosen clamps or inspect wire in tight locations.

FINDINGS:

*The DelTest™ detected 67 total breaches within the zones tested

vs.

26 breaches that were found during the Professional Visual Inspection.

This means that 61% of the breaches were NOT detected by Visual Inspection

CONCLUSION:

These tests confirm the trend that Lectromec has witnessed for years: "*Visual inspection alone is NOT an adequate means for determining the condition of wire or finding the majority of breaches in wire insulation.*" Proper visual inspection does however play a complementary role in the testing process. The DelTest™, Lectromec WIDAS Aging Test and other similar technologies (DITMCO, Eclypse, etc.) should be implemented in any effective, proactive preventative maintenance program.

***The 26 breaches found by visual inspection may be a high estimate. Please see footnote.*

LECTROMEC INSPECTION METHOD

Exhibit A

Lectromec DelTest™ Findings:

	Aircraft 1	Aircraft 2	Aircraft 3	Aircraft 4	Aircraft 5	Total
Total # of Breaches Detected	11	11	7	13	25	67

AIR-4.4.4. - Visual Inspection Findings:

	Aircraft 1	Aircraft 2	Aircraft 3	Aircraft 4	Aircraft 5	Total
Total # of Breaches Detected	3	7	5	6	5	26

LECTROMEC INSPECTION METHOD

**Footnotes

There were several variables during the inspections which lead Lectromec to further conclude that the Visual Inspection detected less that 25 percent of the total insulation breaks (Opposed to the reported 39%)

- Ten percent of the trailing edge wires were solely checked by visual inspection and were not part of the Lectromec test schedule. This resulted in an unequal sampling between test methods, therefore falsely increasing an already low "hit rate" for the Visual Inspector.
- A second factor which skewed the visual inspection count tally was the fact that, on occasion, the Visual practice recorded multiple fractures in close proximity to one another, as one breach, whereas Lectromec's staff recorded each breach separately.
- Because the DelTest preempted the Visual Inspection at times, hidden breaches were uncovered which otherwise would not have been discovered by the Visual Inspectors. Breaks under clamps or in the middle of bundles are not areas studied during a traditional visual inspection. Several of these may have been falsely recorded in the visual inspection counts.

Regardless of whether the exact percentage was 39%, 25% or somewhere in between, the figure remains unacceptably low. This is especially the case when considering that the purpose of the inspection is to detect and rectify any potential problem sources aboard active aircraft.

*In controlled, blind laboratory experiments, the Lectromec DelTest™ has proven to be effective in detecting nearly 100% of breaches in wiring insulation.

Prepared for:

Christopher D. Smith, Ph.D.
Federal Aviation Administration
June 17, 1999

By:

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LECTROMEC INSPECTION METHOD

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TO:	Bob Swaim
FAX:	202.314.6349
FROM:	Vincent Press
DATE:	7 July 1999
SUBJECT:	Visual Inspection Vs. DelTest
PAGES:	4 in Total

Bob,

As per your request, following please find the summary which was a product of our recent work with the Navy. The five aircraft referred to in the findings were Naval P-3 planes. We have been given permission to discuss this work. Feel free to use these findings as you see fit. Please note that the following report is a culmination of what Dr. Bruning has witnessed for years, and our recent work has afforded us some hard numbers to back up our long time assumptions. Please call anytime with questions. Dan Kasture can address any detailed questions you may have regarding the actual test methods or other technical issues.

Best regards,

Vince Press
Marketing / Sales Manager

LECTROMEC INSPECTION METHOD

DelTest™

The Description

The aim of the DelTest™ is to provide the customer with scientific data as to the current conditon (level of insulation breach) of aircraft wiring. This test is effective for both exposed and laced or Nomex covered bundles. The DelTest™ is a proprietary, non-destructive test developed & administered by Lectromec Design Co. to assist aircraft operators with wire management and preventative maintenance programs. The test result data can be used as a management tool to determine rectification, schedule and prioritize maintenance and target specific problem areas for wire husbandry education.

We recommend that the DelTest™ is preformed by Lectromec personnel in conjunction with a maintenance or electrical representative provided by the customer. The DelTest™ is often carried out during scheduled aircraft maintenance checks when many of the test areas are already exposed. The DelTest™ is a extremely complete check of wiring including wire contained in the center and hidden sides of bundles. It is for this reason that the DelTest™ is far superior than traditional visual inspection methods. In fact, Lectromec has found that more than 75% of total breaks in insulation are not detectable by traditional visual methods. Visual inspection still plays a valuable role in selecting test zones and serves as a supplemental practice to the DelTest™, to document for instance improper maintenance practices (wires, clamps, splices, ties, etc).

The DelTest™ is a relatively inexpensive method to effectively determine or verify the condition of wire insulation in suspected trouble zones within the aircraft. The DelTest™ has a proven success record in helping operators discover both potential problems as well as wire which remains in good condition. Lectromec can conduct tests using other available equipment including DITMCO and Eclypse if the customer wishes to supplement the DelTest™.

The Need

On active aircraft there are breaches or cracks in wiring insulation. These breaches are especially prevalent in older aircraft. Insulation deterioration occurs for several reasons including exposure to temperature, strain, water or physical damage. The aircraft may continue to operate normally with these breaches however, under certain circumstances not uncommon to active aircraft, these breaches can lead to spurious signals, noise and electrical arcing which in turn may result in avionics and equipment malfunctions, damage to the aircraft or personnel, in-flight fires or an incident or accident. The risk of these negative effects may be eliminated by repair or rewire of the harness.

DelTest cont'd™

The Procedure

Lectromec personnel conduct a preliminary analysis of the aircraft to determine the most vulnerable locations. Three criteria are used in this process: 1) Density of power wires in a location, 2) historical trouble areas and 3) accessibility to the location. Pre-Test preparation involves analyzing the circuits and determining which connectors/terminal boards have to be disconnected and what panels need to be removed to allow access. We then determine how long the testing will take.

After the completion of pre-test preparation, we run the test as follows: 1) A conducting fluid applied to a wire bundle. 2) a small voltage is applied to the wire. 3) A meter measures any electric current leakage into the conductive fluid. If current is evident, there may be a crack in the insulation. The location of the insulation breech can easily be ascertained based upon where the leakage registers. Further, heuristics of background noise compensation determine if there is a crack and investigative probing thereafter pinpoint its location.

Following are recommended actions in response to DelTest™ findings. In several past instances the problems were tended to immediately resulting in very little down time for the aircraft.

- Replace faulty or suspect wire as breaches are discovered
- Completely re-wire section determined to be a problem area
- Retire aircraft
- The customer uses data to develop in-house solutions or alternatives

GRC
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3 September 1999

Robert L. Swaim, AS-40
TWA Systems Group Chairman
National Transportation Safety Board
490 L'Enfant Plaza, E, SW
Washington, DC 20594

Dear Bob,

Thank you for the kind comments regarding our presentations on Automated System Quality Assurance (ASQA) and Intelligent Wire Testing (IWT). Both GRC International and Eclypse International are proud of what we have accomplished so far and continue to be quite optimistic about the potential for this technology in our industry.

You are free to include this information in the NTSB public docket. We hope this information will be of assistance to others working in this area and ultimately result in a better product for the traveling public.

Please call if there are any questions or if additional information is desired.

Sincerely,

GRC INTERNATIONAL

Mark Brown

Mark N. Brown
Decision Technologies Division

GRCI/ECLYPSE WIRE TEST

Intelligent Wire Testing

An Eclypse International and GRC International Joint Project

Mark Brown

Chris Teal

July 1999

ECLYPSE INTERNATIONAL

GRC INTERNATIONAL INC

GRCI / ECLYPSE WIRE TEST

Introduction

Automated System Quality Assurance (ASQA) is a general term that describes a systems engineering approach to vehicle design, development, manufacturing, testing and operational support. The core of this approach is a master database that uniquely captures the vehicle information, down to the part level, as "Integrated System Schematics" (ISS). The ISS captures the vehicle architecture as intended by the initial designers. This database includes details on the power, data, and cooling connectivity, linking each part in a subsystem, system, or vehicle together. This vehicle design can then be verified, controlled, assessed, manufactured and tested using the same master database to drive all of these activities. This approach forces all participants in the process to operate from the same information, thus eliminating errors, misunderstandings, and costly mistakes. When a vehicle has completed manufacturing, the ISS, which would also now include testing data, can be delivered to the buyer providing the "as built" master data source to use for maintenance, upgrades, and trending as vehicles age. ASQA is a true cradle-to-grave approach to vehicle design and manufacturing.

GRCI/ECLYPSE WIRE TEST

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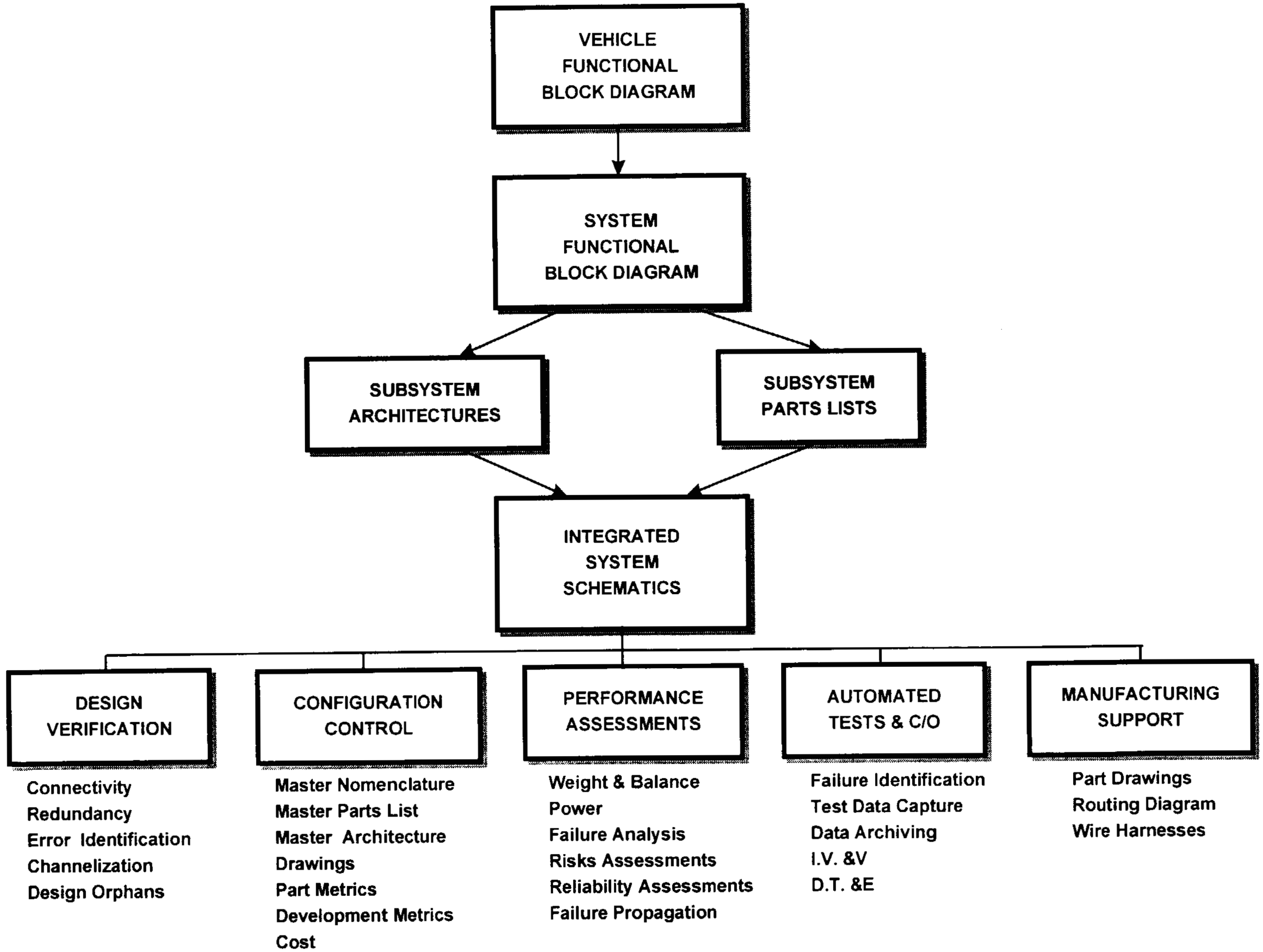
Automated System Quality Assurance



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GRCI/ECLYPSE WIRE TEST

How does ASQA Apply to Wire Testing?

- Automated System Quality Assurance (ASQA) is the efficient analysis of a subsystem, system, or vehicle to verify electrical integrity
- System verification activities

Electrical continuity	Insulation Integrity	Wire Chafing
Wire harness integrity	DC Hipot testing	Capacitance
Pin-to-pin connectivity	4 wire-Kelvin measurements	Stimulus

- ASQA provides definition of the real-world state of a system or vehicle in these areas to include architecture capture, fault detection, failure analysis, risk assessment, and trend development
- ASQA is the automation of what was previously a manual process through a system engineering approach
- ASQA can support DT&E and IV&V on new systems as well as operations, utilization, and logistics
- Although these techniques were developed with aircraft in mind, they apply equally to spacecraft, ships, tanks, and other complex electrical equipment

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GRCI / ECLYPSE WIRE TEST

Why is ASQA Needed?

- Today, the bulk of DT&E and IV&V is performed manually
- These activities are labor intensive, time consuming, and expensive!
- Many abnormalities are going undetected today due to the difficulties involved in performing this type of testing (visual methods, limited access)
- Even when testing is performed as part of a maintenance program, little is done to track system integrity with over time (no trending)
- Numerous aircraft events associated with electrical malfunctions have occurred:
  - 1/9/98, United Airlines 767-200, electrical fire
  - 7/5/97, Northwest Airlines DC-9-15, electrical fire
  - 6/17/97, Sun Country Airlines, DC-10-10, smoke in aircraft
  - 2/20/97, Northwest Airlines DC-9-15, electrical fire
  - 12/11/96, US Air 757-225, in-flight fire
  - 9/5/96, Federal Express DC-10-10, smoke in cabin
  - 6/6/96, Continental Express Beech 1900, in-flight fire
  - 6/5/96, Delta Airlines 767-225, electrical fire
  - 1/11/96, Colombian DC-9-14, in-flight fire, fatal accident
  - 7/96, TWA 800, fatal accident
  - 9/98, SwissAir Flight 111, fatal accident

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GRCI/ECLYPSE WIRE TEST

The Boeing 737 Fuel Tank Wiring as an Example

- The FAA has ordered an inspection of all Boeing-737 fuel tank wiring
- Results as of 6/16/98:

A/C Flt Hrs	A/C Inspected	>50% Insulation Gone	Bare Wire
70k+	19	6	3
60-70k	37	7	3
50-60k	73	11	3
40-50k	135	3	0
30-40k	194	2	1
Totals	**458**	**29**	**10**

- There appears to be a near linear relationship between aircraft age and the degradation of wiring due to chafing
- Bare wiring does not automatically lead to catastrophic failure
-

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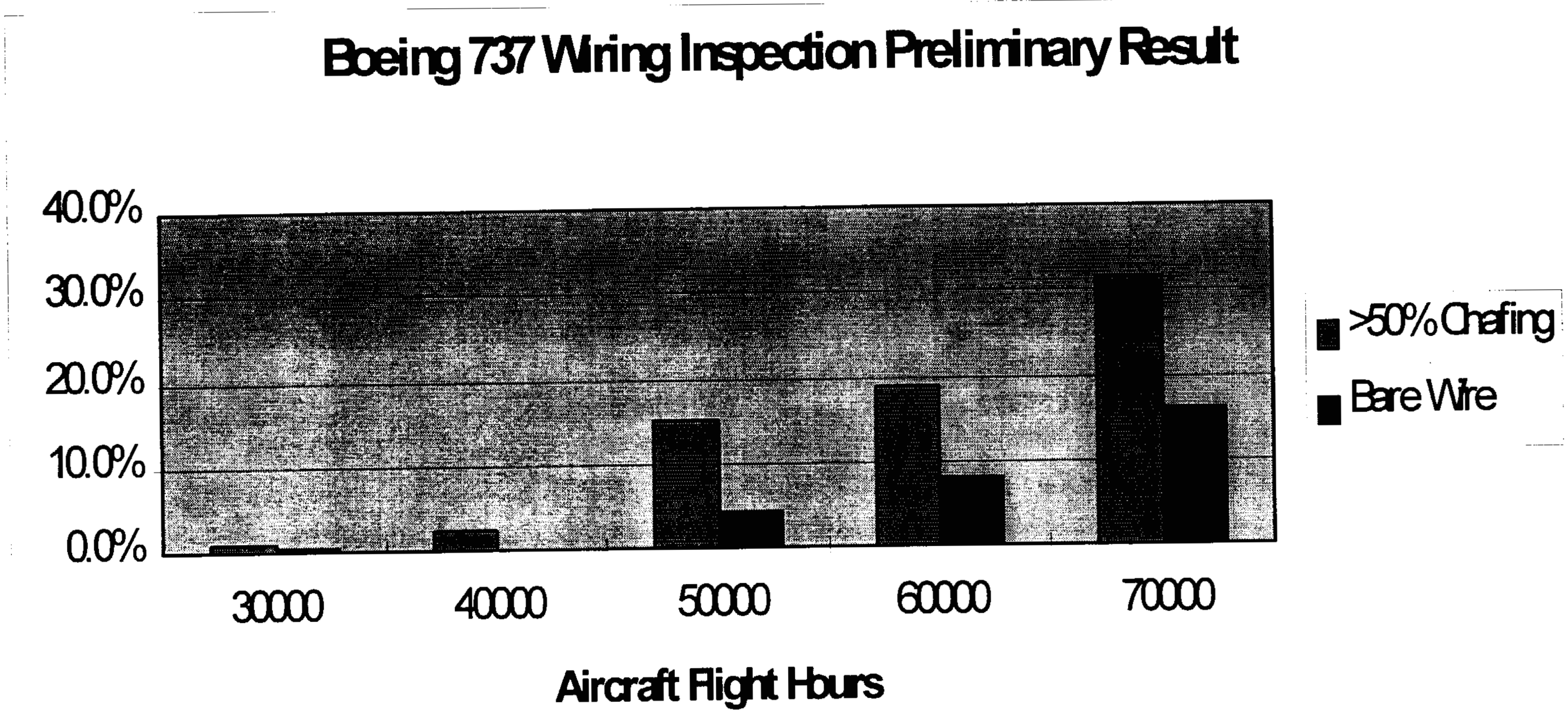
GRCI/ECLYPSE WIRE TEST

Significance of Early Inspections



16 June 1998

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Significance of Early Data

- The data shown applies only to the B-737 and does not address even older aircraft (DC-9, B-727,…)
- The same safety issue can be expected to exist in all military aircraft
- Although current efforts center on fuel tank wiring, the need exists to examine the entire aircraft
- This phenomenon mandates the examination of all commercial and military aircraft for wiring integrity and degradation with periodic inspections thereafter
- 207 Airlines in operation world wide
- Over 7300 commercial aircraft in use in the US alone
- Over 4400 aircraft in use by the US Air Force with another 400 in use by reserve units
- A typical wide body jetliner contains up to 5,000 flight critical and up to 30,000 total wires
- How many bare wires are in the air today?
- How many are on your aircraft?

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AN ASQA Program

- Eclypse and GRCI have developed an integrated ASQA program for the electrical testing of subsystems, systems, and vehicles called Intelligent Wire Testing
- This program can follow a system or aircraft from initial design through retirement from service or be applied to equipment already in service
- The system architecture is captured in a database and used to drive automated test and checkout with all resulting data being captured for analysis
- The services that are recommended include:

System/Vehicle Architecture Capture	Time-Based Architecture Changes
Component Connectivity Analysis and Testing	Design Verification
Failure Propagation and Assessment	Data Archiving
Wire and Component Testing	Trouble Shooting/Failure Analysis
Insulation Integrity	Wire Chafing Assessments
Formatted Reporting	Trend Analysis
System Design Visualization	Schematics/Blueprints

- ASQA provides real insight into system health

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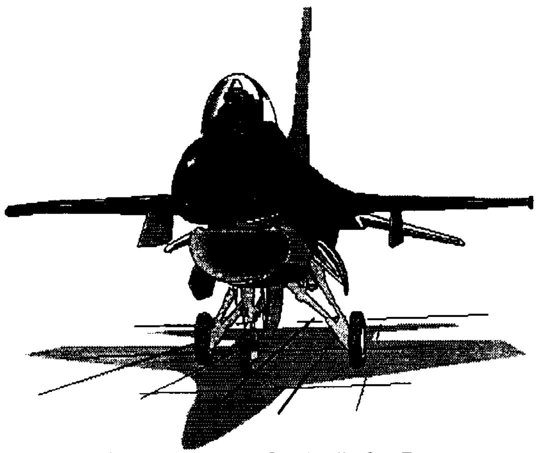
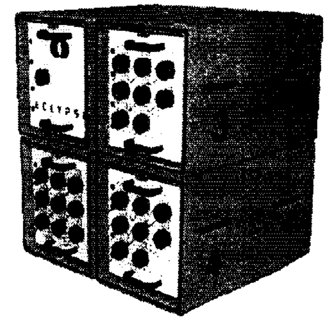
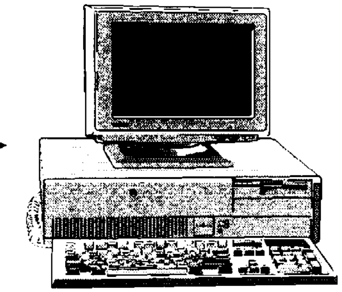
ASQA Overview



System/Vehicle



Automated Test Equipment



Data Archiving and Analysis

Automated System Quality Assurance (ASQA) using MultiLinx ™ software and Eclypse ™ test hardware places historical trending information in the hands of decision makers in a timely and cost efficient way

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ASQA Program Overview

	Component	Sub Assembly	System	Vehicle	Type	Fleet

End Items	• Wire Harnesses
	• Black Boxes
	• E/M Mechanisms
		• Power, Data, and Cooling Connected to an E/M Mechanism	• Power
			• Flight Control
			• Comm/Nav
			• Guidance
				• Aircraft
				• Spacecraft
				• Ships
				• Tanks
				• Missiles
					• Unique Series
					  • B-737
					  • F-106
					  • Space Shuttle
						• Group of Types
						  • 10 DC-9
						  • 8 B-727
						  • 3 DC-10

Activities	• Architecture Capture
	• Continuity Checks
	• Performance Metrics
	• Insulation Integrity
	• Assisted Trouble Shooting
	• Data Capture
	• Data Presentation
	• Formatted Reporting
	• Schematics/ Blueprints
		• Architecture Capture
		• Test & Eval
		  • Manual
		  • Automated
		• Assisted Trouble Shooting
		• Data Capture
		• Data Presentation
		• Data Analysis
		• Formatted Reporting
		• Schematics/Bl ueprints
			• Architecture Capture
			• Automated Test & Check Out
			• Integrated Verification & Validation
			• Assisted Trouble Shooting
			• Data Capture
			• Data Presentation
			• Data Analysis
			• Formatted Reporting
			• Schematics/ Blueprints
				• Architecture Capture
				• Automated Verification & Validation
				• Assisted Trouble Shooting
				• Data Capture
				• Data Presentation
				• Data Analysis
				• Trend Analysis
				• Formatted Reporting
				• Schematics/ Blueprints
					• Data Presentation
					• Data Analysis
					• Trend Analysis
					• Formatted Reporting
						• Data Presentation
						• Data Analysis
						• Trend Analysis
						• Formatted Reporting

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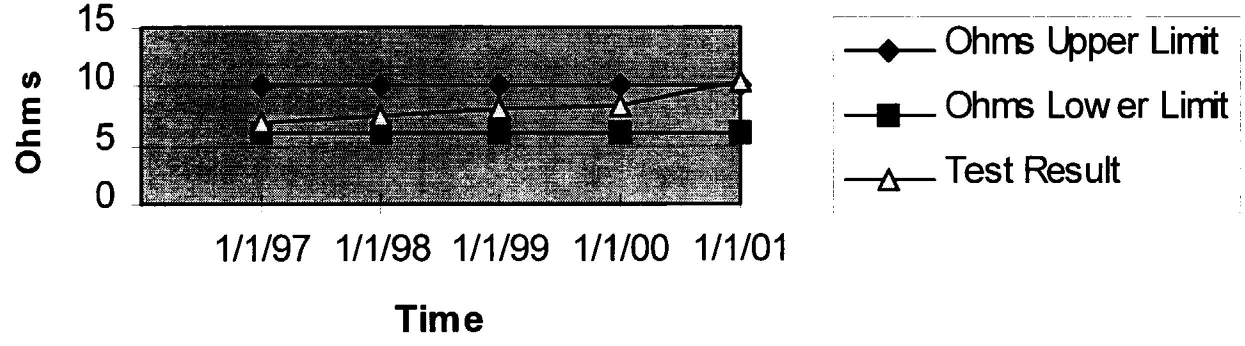
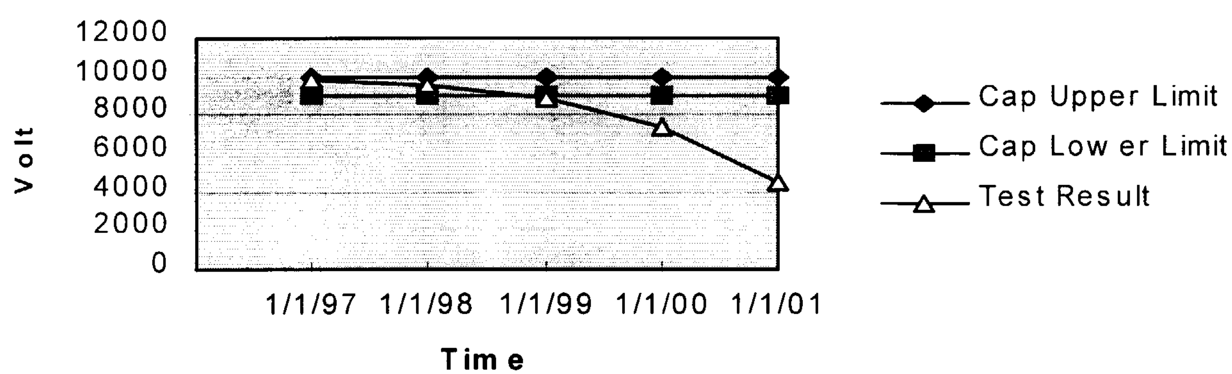
Graphical Representations of Potential Results

Resistance Test: Wire F-16/98123/ARMT23456



Capacitance Test: Wire F-16/98123/ARMT 23456



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Summary

- Automated System Quality Assurance (ASQA), when applied to Intelligent Wire Testing, offers the opportunity to convert an expensive, man-hour intensive, human error prone, marginally effective process into an efficient, quality, automated one
- For the first time, visibility will be gained into the actual status of the wiring architectures in systems and vehicles
  - Insulation Integrity
  - Wire Chafing Analysis
  - Risk Assessments
  - Recommended Corrective Actions
- System and vehicle test, verification, integration, and trouble shooting will move into the 21st Century!

GRCI/ECLYPSE WIRE TEST

Demonstration

- Component to be tested: P&W 4000 engine wire harness
- Design Architecture: Captured into database
- Design Verification: Comparison of design architecture to design requirements (design connectivity)
- Schematics: Viewable real-time, hardcopy output to printer, or save to disk
- Automated component testing:
  - Resistance (continuity)
  - Simulated Failure (wire chafing degradation over time)
- Data Capture: Testing data captured in architecture database
- Data Analysis: Performance/Quality assessment (failure identification)
- Data Archived: Retain for trend analysis
- Data Presentation: Graphical display of test results
- Formatted Reporting: Test results output in hard copy report

GRCI/ECLYPSE WIRE TEST

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Company Qualifications

Eclypse International

Eclypse International is a leading manufacturer of Automated Test Equipment (ATE). They specialize in circuit analyzers for use in both controlled and severe environments. Their equipment is currently in operation through out the United States and abroad with both military and commercial organizations.

GRC International

As a leader in knowledge-based services and high-quality technical solutions, GRCI has gained prominence for innovation in complex information systems, advanced technology development, space experiments and operations, telecommunications, materials testing and other decision-support and productivity enhancement products and services.

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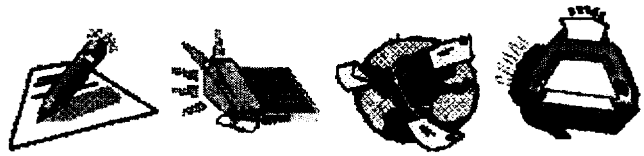
Contact Information



Our Products

ECAD Family of Condition Monitoring Systems (Electronic Characterization And Diagnostics)

ECAD represents the state-of-the-art in automated testing for a wide variety of circuits and components.Our ECAD systems contain computer directed instruments that provide you with intimate details of your electrical circuits. As a troubleshooting tool, our ECAD systems can identify and locate failures in instrumentation, control and power circuits. As a condition monitoring tool, our ECAD systems provide valuable trending information which can be used as an input to predictive maintenance, life extension and license renewal programs.

There are two generations of the ECAD system, the ECAD System 1000 and the second generation ECAD System 1100. The ECAD system 1000 is configured using laboratory-grade instruments mounted in a rugged equipment enclosure. The ECAD System 1100 is implemented as a collection of PC-based instrument cards and is packaged in a light-weight, but rugged package. Both Systems are compatible with each other.You can see them both side by side here.

Our Mission

We have been supplying ECAD diagnostic systems and services on a continuous basis since 1986. Our client base includes many major domestic and international electric utilities and industrial complexes. These systems and services represent our sole focus and our only business. We are dedicated to the support of our technology to the benefit of our clients and the industries they lead.
As the pioneer of ECAD diagnostic technology, we have engineered our data acquisition system hardware and software to provide precision, repeatability, and reliability into our products and services that you will find nowhere else. After nearly 11 years of use in the field, our products are mature, and our software is guaranteed to run bug-free! Further, our corporate commitment is to ensure that all future hardware and software improvements are downwardly compatible to existing owners and users for purposes of maintaining data integrity and to advance our clients long-term commitment to condition monitoring, predictive maintenance, and life-extension programs.

Our World Wide Associations

CM Technologies has been providing ECAD systems and services around the world since 1986. Their value has been recognized many times over. Take a look and see who uses the ECAD for what in your neighborhood.

Our Employees

Our field service representatives have over 30 years combined experience in using ECAD data to analyze electrical circuit condition. The ECAD Division of CM Technologies serves their clients from 3 regional offices in the United States.

Our Product Information

The second generation ECAD system, the ECAD 1100, is a highly portable test and data acquisition system. The first generation system, ECAD 1000, is still in wide-spread use around the world. Take a look at the systems side by side.

Our Technical Support and Services

The ECAD Division of CM Technologies provides a 24-hour emergency service Hot-line. You can contact a member of the ECAD service team by calling:

Emergency Hotline:(1) 412-645-2775

Consulting and analysis services are provided to our clients and owners of ECAD.

CM Technologies Corporation

1026 Fourth Ave.

Coraopolis, PA 15108

Voice:

1 (412) 262 0734

Fax:

1 (412) 262 2250

ECAD® SYSTEM 1100

The ECAD System 1100 consists of a suite of test instruments that acquire data under the direction of an IBM® or compatible PC. Once data is acquired, it is stored on hard disk for later retrieval and analysis. Data can be transferred to the ECAD System2000 software tool for detailed analysis and report generation. The ECAD System1100 is compact and designed to operate in industrial environments.

Shown here is the ECAD System 1100 with a source measurement unit and the IBM controller option. The System 1100 weighs in at only 12 kg. The ECAD unit alone is compact enough to travel in the overhead of an airliner.

The ECAD System 1100 measures and calculates lumped electrical parameters. The distributed character of the circuit under test is acquired and displayed on the time domain reflectometer signature. The ECAD System 1100 can also characterize voltage vs. current action of an ionization or fission neutron detector. The ECAD System 1100 will measure and calculate factors relating to insulation quality including Polarization Ratio, Dissipation factor, Quality Factor, and Insulation Resistance.

Under the direction of a PC, each test is performed in the same manner each time the component under test is characterized. This takes test set-up and human variability out of the results of the test.

ECAD System 1100 test lead parameters are measured and stored prior to a testing session. The test lead factors are taken

out of the collected circuit data. This results in "pure" circuit data for display and analysis. This means that very accurate and repeatable testing can be done in order to closely trend component performance. This is the key to effective condition monitoring.

The ECAD System 1100 is built around a collection of printed circuit instruments, each residing in a full size 16 bit ISA slot.

PCI-3100 is the first smart metallic time domain reflectometer on a PC-ISA bus card. The PCI-3100 competes well with other brand name TDRs in both ability and price (Take a look at the numbers).

Impedance and Phase Angle measurements are taken with the PCI-3200 LCR card.

Voltage, current and resistance measurements are taken with the PCI-3400 Multimeter Card.

The PCI-3300 Instrument can switch up to 2500 VDC.

Depending on test options selected, the time required to acquire data that completely characterizes the circuit is between 3 to 15 minutes. The longer time period is required for the calculation of a 10 minute IEEE polarization index. Options for testing are user selected in the 1100 software where device under test information is stored. Fields on the ECAD System 1100 software insure the device under test is connected the same way on subsequent tests.

Here is a sample screen into which the user will input test data.

```
ECAD SYSTEM
                    Device Circuit Entry

Circuit Identification                          Test History
Device Code   : IRM A SIG FROM DET              First Tested : 05/30/97
Description   : SIGNAL CABLE FROM DETECTOR      Last Tested  : 05/30/97
Device Type   : NI                              Last MO      : 311725
Configuration: A                                Tests to Date:     1

Test Area     : CONTROL ROOM          Unit: 1
Termination   : IRM A              ID Code: J1

High Test Pt  : PNL P669           ID Code:                  Pin:
Low Test Pt   : SHIELD             ID Code:                  Pin:
Comments      : DETECTOR JUMPERED TO SIGNAL CABLE AT PREAMP
IR Test Volts:      VDC

Drawing Ref #:
Sheet #       :  0
Comments      : TESTED AT POWER WITHDRAWN

                 Current File Set:  C:\ECAD
[A]dd [F]ind [N]ext [P]rev [R]evise Delete<[T]est [C]ircuit> [Esc] Exit
```

This test file remains resident in the ECAD System 1100 controller and is ready for future testing when the system is powered up. The test file provides information for connection to the device when the device was first tested. Selectable options such as Insulation Resistance test voltage and time and information comments are entered on the test configuration.

When the data is collected it can be loaded into the ECAD System 2000 analysis software. for detailed analysis. For details about the ECAD System testing, see ECAD Testing Methodology.

The ECAD System 1100 can be custom built to your needs.

Back to ECAD Homepage

PCI-3100 TDR Card

PCI-3400 Multimeter Card

PCI-3200 LCR Card

(Page 5 blank. R/ Swain)

Swaim Bob

From: Francis Scullion [franditmco@sprintmail.com]
Sent: Wednesday, December 15, 1999 1:54 PM
To: Swaim Bob
Subject: DIT-MCO INFO

ntsb_tdinfo.doc

Bob

Thanks for help in getting the word out.

If you have any questions please call or e-mail

856-222-1796

Thanks much
Fran

DIT-MCO

DIT-MCO International

5612 Brighton Terrace, Kansas City, MO 64130
Tele: 816-444-9700 Fax: 816-444-9737

Maintenance and Depot Level Wire Inspections

The Commercial Aviation Industry has achieved two mile stones, Routine Acceptance and Maturity. The trip to Grandma's house is no longer in the back of the family station wagon but on a Boeing 777. American businesses have met the global marketing challenge by taking to the air in ever increasing numbers. This high demand for on-time air travel has put a strain on the companies and people who maintain the commercial aviation fleet.

DIT-MCO ATE (Automatic Test Equipment) has played an important roll in the production of both military and commercial aircraft for more than 50 years. DIT-MCO ATE is, and has been, testing wire harness integrity and control panel functions for the space shuttle, satellites, KC-135 to the B-2B, V-22 to H-60 and AH-64D, Boeing 727 to 777 and all regional jets manufacturers.

DIT-MCO ATE has been in use in maintenance shops like, Military depots. Northwest Airlines Electrical Shop, TWA Overhaul Center, American Airlines, and Rolls Royce engine shop for several years. The RB-211E engine harness, fire wire and solenoids can be tested from the pylon connectors in 20 minutes or less.

DIT-MCO has addressed the need for flexible Automatic Test Equipment with the inception of the model 20/20 portable 50 to 1000 point test system. The model 20/20, can be carried in two small cases, and is packaged to meet the varied needs of field military and flight line support services. The DIT-MCO Model 2115 benchtop test system (50 to 5000 test points) is adaptable to flight line maintenance, depot test stations or new product manufacturing environments. The DIT-MCO model 2508 system (1000 to 100K test points) is packaged to maximize space and flexibility in a large system. The 2508 can be trailer mounted or a fixed station and is used to test large production harness before and after installation into the airframe. The DIT-MCO 2500MBA system enables the testing of panels or harness with active components. The 2500MBA eliminates the need for custom interface harness for each revision of a product. If the test cable connectors mate with the product, then it can be used to test and power the product active components.

The DIT-MCO systems present in most aviation manufacturing facilities use the same test programs as the equipment list above. This means the test program and interface harness for your engine harness or airframe harness is most likely already written.

The continuity and insulation tests performed by the DIT-MCO can detect harness fatigue and abrasion failures without removing the harness from the aircraft or engine.

To learn more about DIT-MCO Automatic Test Equipment please read on or visit our Web Site at **http://www.ditmco.com/**

DIT-MCO

DIT-MCO Test Systems

Once you determine your test specifications, you define the instrumentation required to meet the test specification. In a DIT-MCO test system, the basic instrument is the comparator that functions as both a stimulus generator and a measurement device.

DIT-MCO takes testing one step beyond simple comparison-to-limit, GO/NO-GO resistance testing. Positioned for today's complex products, the instrumentation provides testing flexibility.

Each system comes complete with the capability to test:

- •Circuit continuity tests for open circuits
- •Insulation resistance verification for short circuits
- •Dielectric breakdown (hipot) tests
- •Resistor tests
- •Relay tests
- •Diode tests
- •Capacitor tests
- •Switch and circuit breaker tests

You can program measurements in high-resolution steps from 0.01 ohm to 1000 megohms, program voltage stimuli as well from .225 volt through 2000 volts and current from 5 milliamps through 2 amp.

Product Adaptation

Once you determine the testing requirements, you need to connect the test system to your Unit Under Test (UUT). Product adaptation takes many different forms from simple cables to complex fixtures. DIT-MCO's experience in adaptation means users can start testing upon installation of their test system. Our engineers have designed fixtures to contact backpanels, wired assemblies and circuit boards as well as the facility tooling required to accommodate the testing. DIT-MCO's Special Products Group can provide a complete turnkey installation including all design, development and manufacturing required to test your product.

Test Programming

Creation and maintenance of your test program is simple and straightforward using a personal computer.

DIT-MCO offers several ways to create test programs so you have the flexibility to choose the method that best fits your current application. You can generate test programs by:

- •Using engineering design data; from-to wire lists
- •Manual entry by a test programmer
- •Self learning using a known good product
- •Computer download of test data

Test Programming Flexibility

TestExecutive®, a real-time control program, drives the DIT-MCO wiring analyzer using an extensive library of instructions created cooperatively with our customers over many years. Although you can complete many tests using only two commands (one for insulation, the other for continuity), you have 26 different switching system commands and 24 parameter sets. With over 90 directives and modes to control testing, contingency actions, report formatting, etc., the software will meet your test requirements.

DIT-MCO

Error Reporting and Data Logging

DIT-MCO allows you to capture product errors found during the test process printed in the form of an error log. You can have errors identified in either DIT-MCO addressing, your product terminology, or both. You will find the error logs easy to format to meet your particular needs. Use the error log as a process control tool to improve manufacturing processes, product design, and speed up repair.

Fault Diagnostics and Repair Support

Nobody but DIT-MCO gives you the features that help you debug and rework your product.

- •DIT-MCO includes Write Error Program (WEP) which builds a test file containing only those tests that produced errors. Using this file allows you to repair the product as you go, repeating the fault-causing instruction until the fault clears.
- •You can also use the Manual Mode of operation to help find and diagnose product faults. Manual Mode operation gives you complete functional control of the system without first building a test file.
- •The optional Fault Locator pinpoints the location of shorts and opens within the circuit so that you do not need to sort through intermediate connections in search of the fault.

Customer Support

Once you own a DIT-MCO system, you receive on-going technical advice and repair support. DIT-MCO's success in the automatic test business over the past 50 years is due to setting high priorities for customer support. With service technicians in the USA and UK, we support thousands of installations worldwide.

Experienced service technicians are ready to install systems, provide training, or solve customer problems at any location. They can provide all the help needed either by the telephone or at your facility, to minimize downtime.

Need to replace a board or component in your test system? DIT-MCO ships them overnight using air express. Our centralized repair service location provides those repairs or exchange services at a minimum cost.

Training and Documentation

DIT-MCO offers training of maintenance, operation, and programming personnel at our centrally located headquarters. Choose from standard training or work with our staff to develop training customized for your application. You also have the option of receiving training at a location you specify.

Your DIT-MCO test system comes with a complete set of documentation including OEM supplied manuals as well as software manuals and complete on-line help.

DIT-MCO

Testing Components

- The drawing to the right is an example of a common diode/relay configuration that cannot be fully tested with a ground reference instrument.

- In this case, the diode cannot be tested in the forward bias condition unless the instrument is floating.

- Another case where a fully floating instrument would be required is testing resistor networks that are connected to ground. In the example shown, if R5 and R6 are 100 ohms, the measured value would be 50 ohms.

- With the polarity reversed, the test would be 100 ohms.

With a fully floating instrument you do not have to be concerned with ground circuits. With the example shown, a floating instrument would test R5 at 100 ohms (with either polarity) and R6 would have to be tested by connecting a switching point to ground. It would also be tested at 100 ohms.

Which instrument is right for you?

Even though a ground reference instrument can be more accurate due to lower circuit noise, it is important to understand which configuration is appropriate for your testing. If your products are simple cables or harnesses, which will be tested on a bench or form board, you probably do not need the floating instrument. If, on the other hand, your product contains components, active power, or must be grounded for safety considerations, then you will require a floating instrument. DIT-MCO is committed to providing advanced instrumentation utilizing floating designs.

Single Board Comparator (SBC, HVC)

DIT-MCO

The SBC is a single printed circuit assembly capable of generating the test stimulus for measuring voltage, resistance, and capacitance while comparing these measured values to programmable limits.

In systems with the high voltage Series 41 switching, the high voltage version of the SBC is used to supply up to 2000 VDC. This instrument is referred to as the HVC. The functionality for the HVC is the same as for the SBC except for the high voltage capability.

With the Single Board Comparator, you have the flexibility to program test stimuli as a constant voltage from 0.225 volt to 1500 volts (2000 volts with HVC) or as a constant current from 0.005 to 2.0 amps.

The instrument utilizes an analog comparison to provide fast continuity and isolation testing. The analog comparison is enabled only for single "high" limit continuity tests with current stimulus and single "low" limit isolation tests with voltage stimulus. If the analog measured value is within approximately 15% of the programmed limit, the comparator will shift to the digital mode and calculate the value for comparison to the limit. All measurements can be
digitized with the appropriate test program commands.

The SBC is available as both a ground reference and floating (ground isolated) instrument in the Model 2115. The 2500 Models with the SBC and HVC all use the floating instrument.

Test Stimulus

The SBC offers an exceptionally broad range of stimulus. It can provide constant voltage from a high or low voltage source, or constant current stimulus in the following ranges:

- •Low voltage 0.225 VDC to 29.75 VDC
- •High voltage 30 VDC to 2000 VDC
- •Current 5mA to 2A

Resistance Measurement

The SBC can measure resistance in a range from 0.01 ohm to 1,000 megohms, digitizing the value at the applied stimulus.

DC Voltage Measurement

The SBC measures DC voltages from 0.01 volt to 1500 volts with the SBC or 2000 volts with HVC. Voltages greater than -4.5V will cause a pass test decision if the test instruction does not contain a low limit, allowing testing for "zero" volts.

AC Voltage Measurement

The SBC measures AC voltages from 1.0 volt to 500 volts RMS within the frequency range of 50Hz to 400Hz. Non-sine wave functions can be measured including DC voltages. The AC voltage measurement capability can thus be used to measure DC voltages where the polarity is unknown.

DC Dielectric (Hipot) Testing

The SBC can detect momentary (10 microseconds or longer) breakdowns or arcs in the Unit Under Test (UUT). The SBC monitors the current through the UUT while the stimulus is applied. If the current exceeds a programmed limit of 0.5mA, 1mA, 1.5mA, 2mA, or 2.5mA, the hipot test fails even though the current may return to normal prior to the completion of the test. Valid stimulus voltage is from 250 VDC through 1500 VDC. The SBC has a maximum short circuit current of 5.0mA during hipot tests.

Capacitance Measurements

The SBC is capable of measuring capacitors which may be found in your product from 10nf to 1000mf. These measurements use time domain techniques and a low voltage constant current source. A constant current generator with a compliance voltage up to 30 VDC is connected and used to determine the time to charge the unknown capacitance. Charging currents vary from 0.25mA to 200mA.

Programmable Dwell Times

You can control the minimum and maximum time the stimulus will be applied to the circuit under test (called dwell time). These are programmable over the range of 0.001 to 1638 seconds. With the dwell time bypass mode enabled, the test is completed as soon as a pass condition is true and the minimum dwell has elapsed, allowing you to achieve the maximum test rate.

Discharge Wait Circuit

The SBC incorporates a "discharge wait" circuit that monitors to ensure the test stimulus has been discharged after the test is complete. This keeps the system from opening the switch relays while any charge is present, therefore protecting the switching devices from being switched "hot", preserving the switch life, and saving on maintenance costs.

Compensated Continuity Resistance

The DIT-MCO tester provides a method to make low resistance measurements without using four wire access to the product. The compensated continuity resistance measurement mode eliminates the series "tare" resistance from the two wire measurement.

Simultaneous Hipot IR

Many applications require both insulation resistance and hipot testing. With the SBC you can simultaneously run the insulation resistance measurements and hipot testing, significantly reducing test times.

Company Information

When you buy a wire analyzer, you buy not only the analyzer but also the company behind it.

DIT-MCO International Corporation, the first name in testing equipment, has over 50 years of experience manufacturing and supporting wiring test systems. DIT-MCO provides a complete line of test systems capable of meeting your ATE needs.

Headquartered in Kansas City, Missouri, DIT-MCO has a sales and service office in the UK as well as agents and distributors in 17 other countries.

The company relies on its considerable engineering strengths and manufacturing expertise to produce an evolving series of products that continue to lead the ATE industry.

Market Leader

DIT-MCO has been responsible for a number of important "firsts" including:

- •First supplier of fully automatic self-programming
- •First Random Access fully programmable circuit analyzers

DIT-MCO

- •First computer controlled standard product analyzer
- •First solid state system to test at 10,000 tests per second
- •First digital comparator

Recent innovations include:
- •1553 bus testing
- •Accurate capacitance measure with full tare compensation
- •Distributed bus switching systems for in-aircraft testing
- •Remote wireless test stations
- •True random access, multi-bus architecture analyzer

About the Service

DIT-MCO's success in the automatic test equipment industry comes from setting high priorities for customer support. DIT-MCO now has over 2,000 major installations worldwide and a Customer Support Service department to match. The services they offer include:
- •Free telephone consultation on any matter pertaining to your analyzer
- •Remote diagnostics
- •Low cost parts exchange and repair
- •Express service for maintenance parts
- •Fully trained service technicians for field service work and product installation
- •Training offered at DIT-MCO's Kansas City corporate headquarters or on-site at your location

Contacting Us

Your local representative can give you additional information on the company, products, or available services. In the USA, call toll free at (800) 821-3487. Or the WEB at http://www.ditmco.com/

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Israel
Italy
Japan
Singapore
Spain
South Africa
South Korea
Taiwan

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Appendix I – Configurations

Configuration	Model 2115	Series 2500	Model 2500.MBA	Model 2500.HVA	Model 2600
	Benchtop with optional rack mounted consoles	Rack mount control console with separate 10K switching cabinets	Cabinet mounted switching modules with internal or external control	Cabinet mounted switching modules with internal or external control	Distributed Switching in Suitcase Assembly or Line Replaceable Units (LRU)
Max Test Points	15,000	100,000+ (Models 2503, 2505)	100,000+	100,888+	100,000+
Expansion	50 Point Boards 1000 Point Chassis	100 Point Boards 500 Point Modules 10K Cabinets	100 Point Boards 100 Point Random Access Relay Control Boards 1K Point Master Modules with up to 1000 test point plus two Random Buses 1K Point Slave Modules with up to four Random Buses	20 Point Boards 250 Point Modules and 500 Point Modules	150 Point 1200 Point Suitcase LRU per requirement
Switching	Series 17B	Series 17A	Series 42	Series 41	Series 19
Max Test Voltage	1500VDC, 1000VAC	1500VDC, 1000VAC	1000VDC, 750VAC	2000VDC, 2000VAC	1000VDC, 750VAC
Standard Instrumentation Optional	Floating SBC	Floating SBC	Floating SBC	Floating SBC with AC Breakdown	Floating SBC
	grounded SBC	DCS-III	DCS-III	CCS Capacitance	DCS-III
	Floating SBC with AC Breakdown	Floating SBC with AC Breakdown	Floating SBC with AC Breakdown		Floating SBC with AC Breakdown
		CCS Capacitance	CCS Capacitance		CCS Capacitance
		DD AC Dielectric – 1000VAC	DD AC Dielectric – 1000VAC	DD AC Dielectric – 1000VAC	DD AC Dielectric – 1000VAC
External Power	LM Card-10 points each, up to 200 points in LMU	EE 50 or 100 point chassis LM 50 or 100 point chassis	10 LM in each Switching Module Standard	EE 50 or 100 point chassis LM 50 or 100 point chassis	10 LM in each suitcase or LRU
External Power Supplies	28 VDC mounted internal to ESU or LM Other supplies can be connected externally	28 VDC 115 VAC 400 Hz Others per requirement	28VDC 115 VAC 400 Hz Others per requirement	28 VDC 115 VAC 400 Hz Others per requirement	28 VDC 115 VAC 400 Hz Others per requirement

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Continuity Probe	CTP-4	CTP-1 for DCS CTS-2 for DCS with retest capability CTP-3 for SBC	CTP-1 for DCS CTS-2 for DCS with retest capability CTP-3 for SBC	CTP-3	CTP-1 for DCS CTS-2 for DCS with retest capability CTP-3 for SBC

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Switching System	
Heavy Duty Electro-Mechanical	Standard
Set-up Complete Circuit	Standard
Capacitance Discharge Tested	Standard

Hardware Options	
Latching Matrix	Yes
Continuity Probe	Yes
Spares Kit	Yes
Wireless Remote Control	Yes
Bar Code Reader	Yes
Fixturing for PCB, MCM, Backpanels	Yes

Software	
TestExecutive® Real-Time Control Software	Standard
TestLink® Environment	Standard
TestEdit® with ACT file display	Standard
Checksum Generator	Optional
Syntax Checker	Standard
Customer Formatted Error Logs	Standard
64 Character UUT Names	Standard
Diagnostic Software	Standard
TestAssistant® for Program Development	Optional
Auto Program Generator (APG)	Optional
Wiresort	Optional

Services	
Current Installations	Over 2,500 Worldwide
Programmer Training	Training class available at DIT-MCO
On-Site Training	Available per your schedule
Customized Training	To customer specifications
Customer Engineering Department	Installation and field support
On-Site Service	Available
Defective Board Exchange Policy	Overnight delivery
Interface Cable Manufacturing	To customer specifications
Test Program Generation	Available

Appendix II – Standard Instrumentation

	Model 2115	Series 2503	Model 2500 MBA	Model 2500 HVA	Model 2600
Reference	Floating Reference Standard	Fully Floating Comparator & Supplies Standard	Fully Floating Comparator & Supplies Standard	Fully Floating Comparator & Supplies Standard	Fully Floating Comparator & Supplies Standard
Programmable Voltage Stimulus	0-1500VDC 2VDC Steps	0-1500VDC 2VDC Steps	0-1000VDC 2VDC Steps	0-2000VDC 2VDC Steps	0-1000VDC 2VDC Steps
Programmable Current Stimulus	5mA – 2 Amp 2.5mA Steps	5mA – 2 Amp 2.5mA Steps	5mA – 2 Amp 2.5mA Steps	5mA – 2 Amp 2.5mA Steps	5mA – 2 Amp 2.5mA Steps
Programmable Resistance	.010 ohms – 99.9 Kohms	.010 ohms – 99.9 Kohms	.010 ohms – 99.9 Kohms	.010 ohms – 99.9 Kohms	.010 ohms – 99.9 Kohms
Insulation Resistance	1000Mohms	1000Mohms	1000Mohms	1000Mohms	1000Mohms
DC Voltage Measurements	10mV – 1000VDC	10mV – 1000VDC	10mV – 1000VDC	10mV – 1000VDC	10mV – 1000VDC
AC Voltage Measurements	1 VRMS – 500 VRMS	1 VRMS – 500 VRMS	1 VRMS – 500 VRMS	1 VRMS – 500 VRMS	1 VRMS – 500 VRMS
Programmable DC Hipot	Up to 1500VDC .5mA-2.5mA	Up to 1500VDC .5mA-2.5mA	Up to 1000VDC .5mA-2.5mA	Up to 2000VDC .5mA-2.5mA	Up to 1000VDC .5mA-2.5mA
Programmable Capacitance	0.01 - 1000µf	0.01 - 1000µf	0.01 – 1000µf	0.01 - 1000µf	0.01 - 1000µf
4-Wire Kelvin	Standard	Standard	Standard	Standard	Standard
Set-up Complete	Standard	Standard	Standard	Standard	Standard
Discharge Wait	Standard	Standard	Standard	Standard	Standard
Simultaneous IR/Hipot	Standard	Standard	Standard	Standard	Standard
Diode Testing	Standard	Standard	Standard	Standard	Standard
Digitized Measurements	Standard	Standard	Standard	Standard	Standard
Dual Limit Testing	Standard	Standard	Standard	Standard	Standard
Programmable Dwell	1 msec – 1638 sec	1 msec – 1638 sec	1 msec – 1638 sec	1 msec – 1638 sec	1 msec – 1638 sec

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Polling	Standard	Standard	Standard	Standard	Standard

Appendix III – Instrumentation Options

	SBC-3	SBC-4	SBC-BP	HVC	DCS-III	CGS	DD
Standard	Resistance Capacitance AC and DC Voltage DC Hipot Current	Resistance Capacitance AC and DC Voltage DC Hipot Current	Resistance Capacitance AC and DC Voltage DC Hipot Current	Resistance Capacitance AC and DC Voltage DC Hipot Current	Resistance Capacitance AC and DC Voltage DC Hipot Current	*High Resolution* Capacitance for Twisted Pairs and Shields	*AC Dielectric* Breakdown Currents
Optional	AC Breakdown		AC Breakdown	AC Breakdown	Transformer Pulse		
Reference	Floating	Ground	Floating	Floating	Floating	Floating	Floating
Test Speed	5000 Cont. 3000 Ins.	5000 Cont. 3000 Ins.	7000 Cont. 4500 Ins.				
Stimulus	0.25 – 1500VDC 5mA – 2A	0.25 – 1500VDC 5mA – 2A	0.25 – 1500VDC 5mA – 2A	0.25 – 2000VDC 5mA – 2A	0.25 – 2000VDC 5mA – 2A	0 – 10V	500 – 1500-VAC
Optional Stimulus	250-1000VAC		250-1000VAC	250-2000VAC			
Ranges	.010Ω - 99.9KΩ 100KΩ - 1000MΩ 10mV – 1000VDC 1 – 1000 VRMS 0.5 – 2.5 mA hipot 0.01 - 1000µf 1 msec – 1638 sec	.010Ω - 99.9KΩ 100KΩ - 1000MΩ 10mV – 1000VDC 1 – 1000 VRMS 0.5 – 2.5 mA hipot 0.01 - 1000µf 1 msec – 1638 sec	.010Ω - 99.9KΩ 100KΩ - 1000MΩ 10mV – 1000VDC 1 – 1000 VRMS 0.5 – 2.5 mA hipot 0.01 - 1000µf 1 msec – 1638 sec	.010Ω - 99.9KΩ 100KΩ - 1000MΩ 10mV – 1000VDC 1 – 1000 VRMS 0.5 – 2.5 mA hipot 0.01 - 1000µf 1 msec – 1638 sec	.010Ω - 99.9KΩ 100KΩ - 1000MΩ 10mV – 1000VDC 1 – 1000 VRMS 0.5 – 2.5 mA hipot 0.01 - 1000µf 1 msec – 1638 sec	100ρf – 999.9ρf 1ηf – 9.999ηf 0.01µf – 999µf	1mA detector

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David A. Marcontell
Director - Engineering, Airborne Express
FAA/DoD/NASA Conference on Aging Aircraft
September 22, 1999

ATA ASTF

- Background
  - Air Transport Association (ATA) formed the Aging Systems Task Force (ASTF) in June, 1998
  - Key objectives included:
    - Define current airline best practices and share industry wide
    - Prepare/implement a specialized sample inspection of aircraft systems wiring over 20 years old
    - Collect data on inspection findings and in-service reports, share the data, and devise actions as required

ATA ASTF

- Background (continued)
  - Aging Transport Systems Rulemaking Advisory Committee (ATSRAC) chartered January, 1999, in response to the FAA Aging Transport Non-Structural Systems Plan
  - Following tasks were assigned to ASTF:
    - Task 1A - Electrical Systems Inspections
    - Task 1B - Non-electrical Systems Inspections
    - Task 2B - Non-electrical Service History Review
    - Task 2D - Electrical Service History Review

ATA ASTF

- ASTF Structure
  - ASTF 40+ general members comprised of representatives from 14 airlines, FAA, OEM's, DoD, SAE, NADA and others
  - Created 8 Working Groups for the following models (all certificated >20 years ago): 727, 737, 747, DC-8, DC-9, DC-10, L-1011, A-300
  - Working Group members comprised of airline, FAA, and OEM specialists highly knowledgeable of a specific aircraft model

ATA ASTF

- Current Airline Best Practices
  - ATA Specification 117 - Wiring Maintenance Practices/Guidelines was released July 31, 1998, and made available to the general public via the ATA website or through ATA Publications
  - Spec 117 Video completed incorporating key principles from the written specification
    - Available through ATA for $550 per copy with unlimited duplication rights within company/agency
  - Survey of ATA member airlines reveals widespread adoption of Spec 117 guidelines

ATA ASTF

- Fleet Inspection Programs
  - ASTF developed guidelines for Working Groups to follow in preparing their inspection programs
    - Zone-by-zone review of potential or unforeseen problem areas, paying particular attention to:
      - Wiring and associated hardware only
      - Flight critical areas
      - Areas normally hidden from view
      - Areas in close proximity to flammable liquids and gases

ATA ASTF

- Fleet Inspection Programs (continued)
  - High electric current draw areas
  - Aging caused by:
    - High vibration areas
    - Areas with harsh environments
    - Corrosion-prone areas
    - High maintenance traffic areas
  - Past service findings and inspection results

ATA ASTF

- Fleet Inspection Programs (continued)
  - Inspection documents produced for each of the subject models except the A-300
  - All inspections are Detailed Visual (vs. General Visual from routine maintenance programs)
  - Aircraft undergoing routine heavy maintenance targeted for inspection
  - Working Group members nearly always present during inspections
  - All results reported on common form

ATA ASTF

ATA ASTE

- Fleet Inspection Programs (continued)
  - 71 aircraft inspected to date:
    - 8 727's completed, program ongoing
    - 4 737's completed, program ongoing
    - 7 747's completed, *program done*
    - 15 DC-8's completed, *program done*
    - 15 DC-9's completed, *program done*
    - 13 DC-10's completed, *program done*
    - 0 L-1011's completed, program ongoing
    - 9 A-300's completed, *program done*

ATA ASTF

- Fleet Inspection Programs (continued)
  - Preliminary results:
    - Averaged 30-40 manhours per aircraft for inspections (does not include open or close up time)
    - Averaged 4-5 discrepancies per model type which require further investigation
      - Airworthiness Concerns Coordination process will be used as appropriate
      - All discrepancies investigated will be reported to ASTF for oversight by August 1, 1999

ATA ASTF

- Fleet Inspection Programs (continued)
    - *No immediate airworthiness issues or concerns found*
  - Summary conclusions and recommendations will be available by October ATSRAC meeting

ATA ASTF

- Service History Review
  - OEM's requested to perform keyword search of service information to identify documents which describe potential aging systems problems
  - Keywords included:
    - arc, arced, arcing, arcs, black, blackened, burn, burned, burns, burnt, burndy, cannon, chafe, chafed, chafes, chafing, connector, electric, electrical, electronic, fire, flash, flashed, ground, intermittent, intermittently, open, resistance, shield, shielded, shielding, shields, short, shorted, shorting, smoke, smoked, smoking, spark, sparked, sparking, sparks, splice, strip, terminal, thermal, track, wire

ATA ASTF

- Service History Review (continued)
  - Documents satisfying keyword search are reviewed by applicable Working Group for possible service action (including Service Bulletin issuance or upgrade of status)
  - ECD November 30, 1999

ATA ASTF

- Follow-on Activities (continued)
  - Created an Intrusive Inspection Subcommittee
    - Determine if there is damage in electrical systems that is going undetected by even detailed visual inspections
    - Application or wire type specific inspections, rather than model specific inspections
    - Substantial effort being made to cover major wire types (including Kapton polyimide)

ATA ASTF

- Follow-on Actions (continued)
  - ASTF looking at airline failure reporting methodology
  - Deferred non-electrical systems inspections until conclusion of electrical systems inspections and service history review (ECD December 31, 1999)

ATA ASTF

- Conclusions
  - Fleet survey revealed no immediate airworthiness issues
  - Significant improvements in training and knowledge sharing have been made
  - More intrusive inspections and further research required to resolve nagging questions regarding wire service life, latent failures, and airline failure reporting programs

ATA ASTF

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Air Transport Association
America's leading airlines

What is the ATA?

Current ATA Members

ATA Membership

Councils and Committees

ATA Headquarters - General Information

How to Contact ATA

Job Openings

Web Site Notes

What is the ATA?

The ATA is the Air Transport Association of America. Founded by a group of 14 airlines meeting in Chicago in 1936, it was the first, and today remains, the only trade organization for the principal U.S. airlines. In that capacity it has played a major role in all the major government decisions regarding aviation since its founding, including the creation of the Civil Aeronautics Board, the creation of the air traffic control system, and airline deregulation.

The purpose of the ATA is to support and assist its members by promoting the air transport industry and the safety, cost effectiveness, and technological advancement of its operations; advocating common industry positions before state and local governments; conducting designated industry-wide programs; and assuring governmental and public understanding of all aspects of air transport.

The ATA has represented the needs and promoted the interests of the commercial airline industry for almost 60 years. During its history, ATA has seen the airline industry and its members evolve from the small, pioneering companies of the 1930s into key players in the global transportation market. The industry continues to evolve with the addition of new carriers, which are playing a major role in shaping the future of air transportation.

As airlines continue to look for ways to reduce costs and maximize efficiencies while maintaining the safest transportation system in the world, ATA offers carriers that very opportunity. ATA is respected by Congress, state legislatures, the Department of Transportation, the Federal Aviation Administration, the press and the public for its professional and accomplished representation of the industry. As its members chart their futures in this changing market, ATA provides invaluable expertise, guidance and assistance.

ATA's structure is similar to most airlines and provides an interface between the carriers and various government and private sector organizations. Key departments within the association deal with operations and safety, engineering, maintenance and materiel, airport operations, air traffic management, cargo, electronic data interchange, facilitation,

ATA DESCRIPTION

federal and state government affairs, international affairs, legal affairs, passenger service, public relations, and security. Working with these established functions are a variety of ATA councils, committees, subcommittees and task forces, composed of experts from member airlines, formed to address industry issues.

Today, the ATA continues to represent the industry on major aviation issues before Congress, federal agencies, state legislatures, and other governmental bodies. It continues to promote safety by coordinating industry and government safety programs, and it serves as a focal point for industry efforts to standardize practices and enhance the efficiency of the air transport system.

Feedback

What is the ATA? - 5-10-99 -

Survey of Electrical Failures in Aircraft Mishaps

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Abstract

Topic: Aging Airframes, Subsystems, Avionics

Ten years ago, a study was commissioned by the US Air Force to compile and analyze data on the various electrical and electronic components contributing to aircraft mishaps from 1986 to the date of request in 1989. Mishaps are classified by severity of injury and material damage. Class A mishaps have $1,000,000 in damage or a fatality; class B - $200,000 to $1,000,000 or a disabling injury; class C - $10,000 to $200,000; class HAP - High Accident Potential. The report recorded the basic electric system of the failed individual component and each component. Results indicated that connectors and wiring were the largest contributors to electrical failures. As aircraft age, it becomes necessary to determine what effect time has on the integrity of the systems and which systems demand the most attention.

Electronic failure was identified as the primary cause in approximately 2% of Air Force mishaps. There are a much higher percentage of situations where electric failures are a contributor to a mishap. We have recently initiated a study to update the earlier analysis and incorporate other factors such as aircraft age and how the electronic failure contributed to the mishap. The analysis of primary and secondary electrical failures, and the aircraft systems they affect, will come closer to the true impact of electric systems on an aging aircraft fleet.

Mishap data will be collected from the Air Force mishap database, which is maintained by the Air Force Safety Center, Kirtland Air Force Base, New Mexico. Information will be categorized by aircraft type and age, impact of the failure, failed component, function of this component and the system first affected by this failure.

Introduction

In 1989, a report was released in an effort to analyze the contribution of electrical and electronic components to aircraft mishaps. The survey included all mishaps for US Air Force aircraft from 1986 to the date of request. Approximately 650 reports were reviewed and organized by type of aircraft. A sample of reports was selected and a total of 326 reports were evaluated in detail. Findings included aircraft type and failed components. The paper covered those reports where some type of electrical failure was included in the findings. An effort was made in this new survey to include only

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those mishaps where electrical/electronic failures were cited as the primary or secondary cause of the mishap. This partition provides more confidence that the electrical failure initiated or was a major contributor in the mishap, instead of being the result of some other failure. We also selected ten years of data to determine if aging trends may exist in the collected data. The information was collected in a database format that can be readily updated for future studies. This preliminary effort will serve as a model for a more thorough research process.

Mishap Report format

Each mishap report included a brief summary of the event from the pilot for any conditions that affect the safety of the aircraft. Following this summary is a list of findings – one to several of these findings are identified as causes. Each report is submitted to the Air Force Safety Center, Kirtland Air Force Base, New Mexico. Reports are cataloged in a database and categorized by the primary and secondary causes contributing to the mishap. The identifying category may be a single word or short phrase. Collecting these reports requires a list of any words that might be in the list of possible categories and related to some function of subject system.
In this case, a list of descriptors for electrical systems and components was submitted for a search. This selection narrowed the number of mishap reports to 271 for mishaps occurring between 1989 and March 1999 where the primary or secondary failure was an electrical system and/or component.

Each summary and list of findings was reviewed for significant artifacts to be included in the final analysis. These details were recorded in a simple database via a form with pull-down menus to make it easier to record additional details. Those details are listed and defined below.

Collected details

- *Age of Aircraft*
- *Mishap Class* – A US Air Force mishap is defines as an unplanned event, or series of events, resulting in:
    - Injury to Air Force military personnel.
    - Injury to on-duty DAF civilian personnel.
    - Injury to non-Air Force personnel resulting from Air Force operations.
    - Occupational illness of Air Force military or DAF civilian personnel. The medical staff reports occupational illnesses through its reporting system.
    - Illness of non-Air Force personnel caused by Air Force operations.
    - Damage to Air Force property.
    - Damage to non-Air Force property resulting from Air Force operations.
    - Degradation of nuclear or radiological safety.
- Mishaps included here are flight mishaps involving Air Force aircraft when intent for flight is established and there is reportable damage to the aircraft.
    A – more than $1,000,000;fatality or permanent disability

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B - $200,000 to $1,000,000; permanent partial disability; inpatient hospitalization of 3 or more personnel
C - $10,000 to $200,000; Injury resulting in a lost workday involving 8 hours or more away from work beyond the day or shift on which it occurred
H – High Accident Potential (HAP), observed during maintenance or pre-flight checks

- *Aircraft Type* – Describes the mission of the involved aircraft. For concise recording, some categories have been consolidated. In particular, Electronic Counter Measure aircraft have been included with Avionics/Reconnaissance. Other categories include Bomber/Attack, Cargo, Fighter, Helicopter, and Trainer.
- *Components* – The primary cause of a mishap is usually attributed to one component. In some cases, two components (or no components) were listed in the report. Those components that could not be determined or did not fit within the range of the surveyed components were included in the avionics group. Other components include batteries, capacitors, circuit breakers, conductors (wiring), connectors, electric panels (contains switches, lights and in some cases printed wiring boards), fuel probes, generators, lights, motors, relays (or contactors), resistors, switches, and transformers.
- *Function* – These categories describe the function of the components.
  - Electronic components operate without moving parts – capacitors, circuit, breakers, conductors, connectors, electric panels, fuel probes, lights, resistors.
  - Failed components with moving parts are included in the electromechanical category – generators, batteries, switches, relays, and motors. A failure in one of these components can involve smaller electronic parts or interconnections. Generators in particular were often cited as failed components but for an undetermined reason – could be internal wiring, moving parts or connections from another system to the generator.
  - Interconnections include wiring, connectors, and in some cases printed wiring boards
- *Systems* – The system affected by the component was recorded when the information was available. Some components can be a part of several systems (connectors, conductors, capacitors, and relays). Where a system was not specifically mentioned or discussed the failure was added to the avionics category. This category also included areas that supported other systems indirectly (general avionics commonly referred to as a "black box") Other categories included flight control, fuel systems, instrument (indicators, panel lights, radios, landing gear, etc.), power systems, and total electrical failure – system unknown

Findings

Most mishap incidents resulted in minor damage to an aircraft or were actually situations that could have potentially caused the loss or serious damage to an aircraft. The distribution of mishap class as defined in the above paragraph is given below in figure 1. There are a much higher percentage of situations where electronic failures are a contributor to a mishap. Most mishap investigations we have conducted are the result of several independent events. The combination of these events can result in the loss

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of one or more critical systems that can ultimately lead to the loss or serious damage to an aircraft.

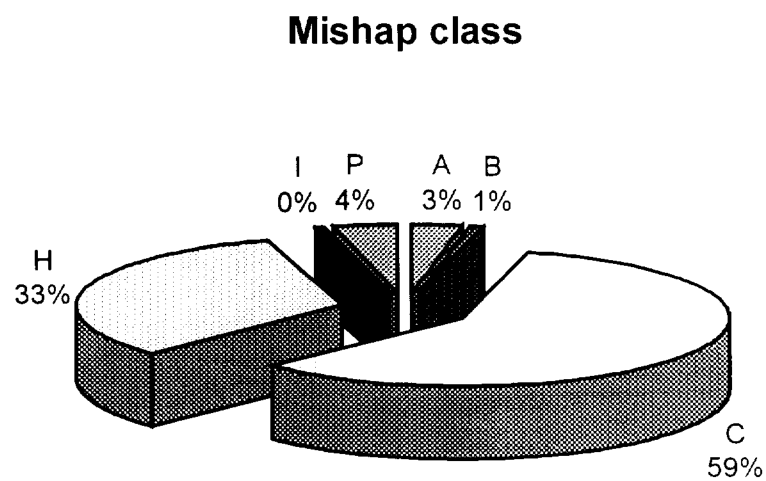

Figure 1.

As can be seen from figure 1 relatively few mishaps result in the loss or major injuries. Most mishaps fall into the class C category or below. Next to class C mishaps, High Accident Potential mishaps were reported far more than mishaps in the remaining classes. These are mishaps that were discovered in routine maintenance or pre-flight checks. Had these failures not been repaired they could have caused a more serious mishap in flight. These findings indicate that some failures can be avoided by preventive maintenance, others may be unavoidable. Improvements in this area can avert mishaps that are more serious and maintain or reduce the number of class C mishaps.

Recently, there has been considerable interest in the aging of electronics and its impact on overall aircraft reliability and safety. The data that was provided in the mishap summaries included the age of the mishap aircraft. A distribution of the aircraft age is given below in figure 2.

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Age Groups of Mishap Aircraft

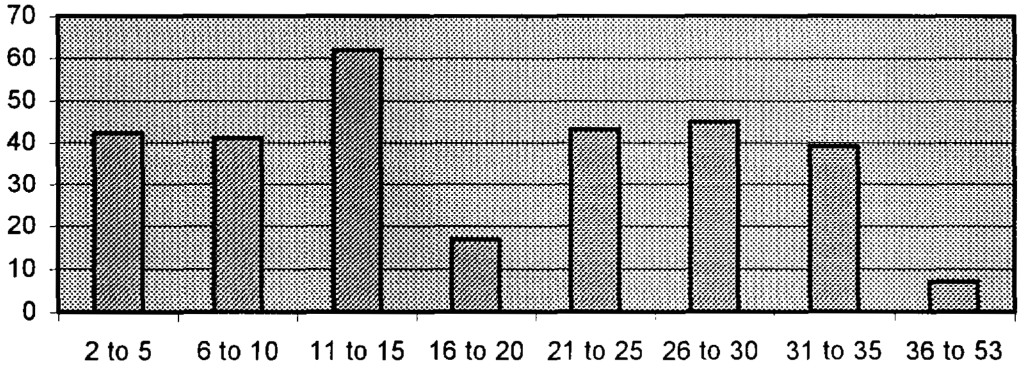

Figure 2.

While this summary implies aircraft in the 11 to 15 year experience more mishaps caution must be used in forming any conclusions. There are several factors that must be considered before reaching any conclusions. This would include factors such as quantity of aircraft, aircraft type, and number of flight hours. Additional analysis will be required and correlation of several factors will be needed to normalize the data in figure 2. Once the data is normalized for several factors, an aging trend may be apparent.

Aircraft were categorized into several types to look at the kinds of failures that might be specific to one type. In most cases, the component failures were independent of the type of aircraft. That is to say that components failed in the same way regardless of the aircraft in which they failed. The percentage of mishaps with respect to aircraft type is shown in figure 3.

Aircraft Type

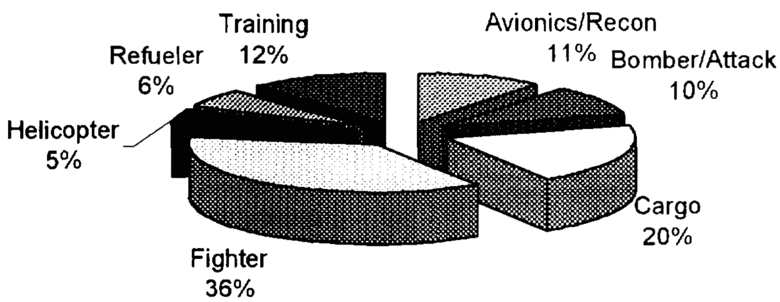

Figure 3.

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Insulation degradation is a significant, if not primary, contributor to the aging problems attacking the entire aircraft fleet. The experience in this laboratory indicates that fighters may be more susceptible to aging damage, with 42% of fighter mishaps resulting from wiring and connector failures. Fighter aircraft typically have more complex avionics in a relatively small space compared to cargo and bomber aircraft. Wiring must be fitted into tight spaces, making it difficult to repair and increasing the chances for chafing. Fighter avionics are also typically subjected to higher operating temperatures. For comparison, nearly half of the mishaps in the Cargo and Bomber/Attack groups were the result of electronic failures. Again, additional analysis needs to be done to normalize this data with respect to aircraft population, flight hours, and stresses of the mission. The systems affected by these failures are analyzed in figure 4 below.

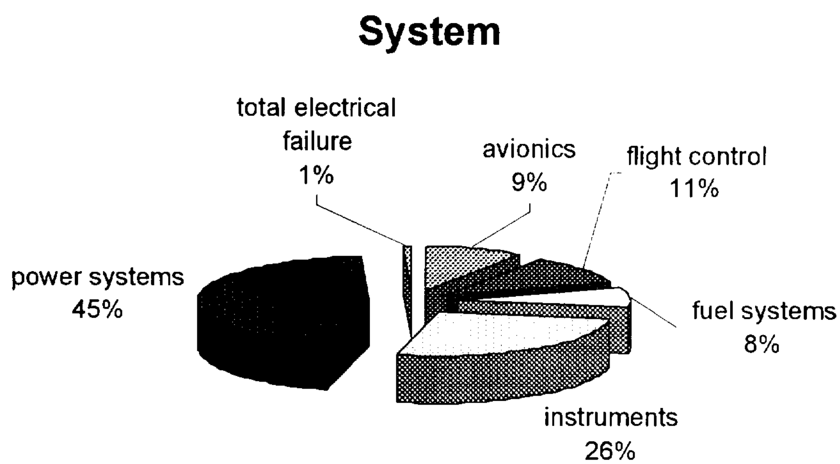

Figure 4.

Electronic and electrical systems perform many types of functions. This can range from supplying electrical power to controlling flight surfaces to analyzing and displaying aircraft performance characteristics. The graph in figure 4 shows mishap distribution by system function. By this illustration, electrical power and instrumentation are the largest categories. Electrical power has become a flight critical system since for many systems, electric power is required to maintain stabilized flight. Many aircraft are now completely dependent on electronics and no longer have mechanical back-up systems. Aircraft also rely on electronics to manage and control entire systems. These critical systems are typically controlled in the cockpit and can not be easily overridden in the event of a catastrophic failure.

Each failed component was part of a system. Many components can be included in several systems, for example relays, connectors or electric panels. Mishaps where a system could not be determined were included with avionics systems; this was usually in cases where one of these common components was cited without a system or location. The system reported with the most failures was the power system, making up

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nearly half of all system failures. Power systems endure the most stress - they also have components of every function. In comparison, fuel systems and instruments had most failures in the electronics and interconnection components. Within these systems each component performed one of three functions – electronic, electromechanical, or interconnecting. The graph below in figure 5 illustrates the breakup across all of the recorded mishaps.

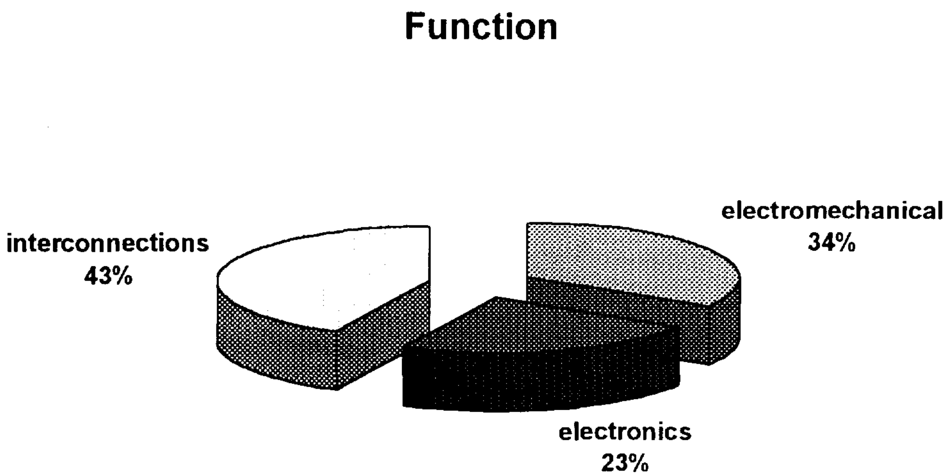

Figure 5.

Laboratory investigation experience in AFRL/MLSA failure analysis and the previous study on electronic mishaps suggested most mishaps are related interconnections or electromechanical functions. These types of functions can typically experience mechanical movement, wear, or direct exposure to the surrounding aircraft environment. The result can be mechancial or physical degradation, with both being time dependent. This functions are excellent candidates for further aging studies.

Components functioning as interconnections make up the largest part of failures. This category generally consists of wiring and connectors. The other categories cover a much larger range of components – an indication that interconnective components deserve a higher priority in understanding the affects of aging and developing preventive maintenance procedures. A closer look at the distribution of functional failures in a sample of the aircraft popullation is illustrated below in figure 6.

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Function of Failed Component by Aircraft Type

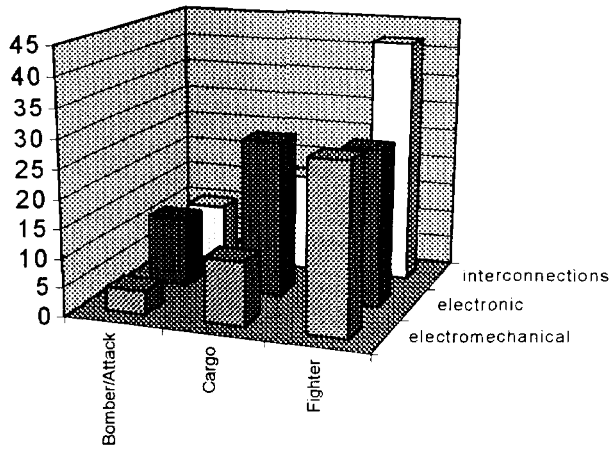

Figure 6.

As mentioned earlier drawing conclusions from one factor can be misleading. Data analysis also needs to be correlated with actual field experience and system knowledge. To illustrate, figure 6 shows the three functions plotted against the number of fighter, cargo, and bomber mishaps. Bomber and cargo aircraft typically have many more miles of wiring (an interconnection) compared to a fighter aircraft. Yet interconnections appear to only dominant other function categories with respect to fighters. Based on AFRL/MLSA laboratory experience one explanation is that fighter aircraft have a higher density of wiring, and therefore, more opportunities for chafing. A detailed breakdown of mishap failures by component function is given below in figure 7

Components

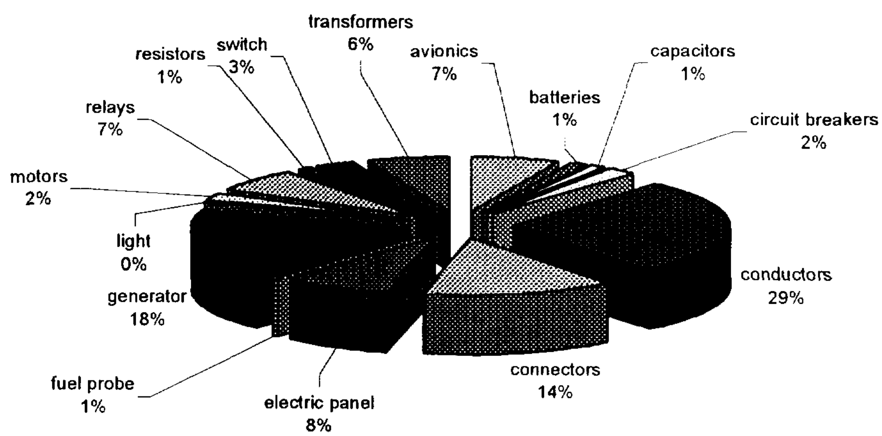

Figure 7.

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Wiring and connector failures make up just over 40% of failed components. This agrees with our experience in conducting mishap investigations. An electrical arc that may be due to a chafed wire or an internal short in a connector often initiates aircraft fires. In some cases the wire or connector failure causes the loss of a flight critical system or compromises another system causing it to malfunction. Conductors and connectors are often nexus points and can become single point failure sites. A single site failure can quickly cascade into other systems, comprising the aircraft integrity. Generators make up the second largest segment of failed components. These components have rotating parts that experience wear and can de damaged by other electrical components that are drawing power from the generator. The remaining components listed are also of interest. In many cases, these failures are related to an interconnection issue. As noted in the 1989 study, there were very few, if any mishaps, that could be attributed to an active electronic component such as an integrated circuit or other type of solid state device. This may be due to cataloging of failures and will be further investigated.

Conclusions

The objective of this survey was to characterize these trends in aircraft mishaps and identify the types of components contributing to mishaps. This survey has initiated an effort to record more precise detail both in past records and in future mishaps as they occur.. The objective of this study was met in that it revealed areas that need further investigation and helped refine our data collection and analysis tools. Mishap databases appear to be an excellent resource for identifying the systems mostvulnerable to the effects of aging – a tool that will directly impact the reliability and safety of U S Air Force aircraft.

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Acknowledgements

Air Force Safety Center, Kirtland AFB, NM

References

a. Safety and Investigations Reports, Air Force Instruction 91-204, 20 February 1998

b. Mishap reports, Air Force Safety Center, Oct 89 to Nov 98.

c. Causes of Aircraft Electrical Failures, National Aerospace and Electronics Convention, George Slenski and Don Galler, 21 May 1990

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IMPLEMENTATION OF FUNCTIONAL SYSTEMS INTEGRITY PROGRAMS: AN ALC AND MAJCOM PERSPECTIVE

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ABSTRACT

Historically, military aircraft failure prevention has been predominately focused on structural issues. In the US Air Force, this has been accomplished through the Aircraft Structural Integrity Program (ASIP). Functional systems have long avoided scrutiny unless implicated in a mishap, supportability becomes problematic, or as a peripheral issue in the course of an

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operational enhancement. The prevailing philosophy remains "fly to failure" for these systems. While this extracts the maximum usage out of each component, it fails to recognize the impacts associated with lost mission capability and lost revenues due to unscheduled maintenance downtime. It also does not recognize the costs associated with recovering an aircraft that may have become inoperable at a remote location. As the total number of military aircraft declines, the availability of these weapon systems becomes increasingly important. Additionally, the resources available to maintain aircraft fleets are shrinking. Consequently, reduction of total ownership costs becomes increasingly important. The Functional Systems Integrity Program (FSIP) is designed to implement the same reliability principles that have served aircraft structures so well through the ASIP to predict and prevent failure of systems components. FSIP will reduce weapon system operating costs, maintain aircraft availability through reliability improvements and reduce unscheduled downtime by performing aggressive preventative maintenance during scheduled downtimes. FSIP will provide a structured method based on available metrics and proactive management to focus on preventing in-service systems failures, thereby ensuring aircrew safety and mission completion. Together with the ASIP, as part of an overall aircraft fleet integrity and reliability management program, FSIP will provide the warfighter with a safe, economical, reliable, and fully mission capable aircraft.

INTRODUCTION

What Is FSIP?

FSIP is a regimen of proactive maintenance actions designed to reduce or eliminate functional systems failures. In so many words, it is a common-sense approach to keeping aircraft flying more reliably, modeled after the extremely successful Aircraft Structural Integrity Program (ASIP). The basic idea of any integrity program is to determine the impact if something breaks, and whether or not you can tolerate that occurrence. If you can't, then you try to determine or predict when it is going to break, and then do what it takes to keep it from breaking, whether that be inspection, repair, or replacement. In the case of functional systems, there is usually not a catastrophic event associated with failures. It more often results in the aircraft being out of service for repair. When this happens out of cycle, or unscheduled, it creates many problems. FSIP is something our friends in the airline industry have known and done for a long time, albeit not by that name, because when their aircraft are out of service they are losing money. Unfortunately, most USAF aircraft are not revenue generating, so we have been slow to adopt this process for purely economic gains. Yet, if we can prevent failures by doing maintenance when the aircraft is already down, then we can better ensure aircraft safety. We can also minimize our unscheduled downtime, which is extremely costly in terms of lost mission capability, aircraft availability, and ever shrinking available dollars.

Why FSIP?

Why do we want to implement FSIP? In the US Air Force, there has been an "artificial" separation of an aircraft into two components: structure and systems. Since it takes both the structure and the functional systems to fly an aircraft, we need to move toward an overall aircraft integrity program. There has been a significant effort since 1958 to predict and prevent failures in

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the structure. The Aircraft Structural Integrity Program (ASIP) was implemented in 1958 with that purpose in mind. Using analysis, test and inspection, the integrity principles used by the ASIP have performed admirably, with few aircraft losses due to structural failure. The functional systems, on the other hand, have avoided examination unless they were determined to be causal in a mishap or the supply status became unsupportable. Then and only then were they subjected to the scrutiny of the engineering staff. The predominant philosophy for functional systems, at least in the US Air Force, remains "fly to failure." Once the component has failed, it is then replaced with a new or refurbished component, and the aircraft returned to service. While this extracts the maximum usage, and therefore economy, from each component part, it fails to recognize that there is a cost associated with the loss of mission capability and aircraft availability. This mode of operation was deemed adequate from a safety perspective because most systems have redundancy, meaning there are few single point failures that can have catastrophic consequences. When an aircraft that is scheduled for a mission has to be removed from service to fix or replace the part that broke, it causes a ripple effect throughout the organization. It is difficult to put a dollar figure on the cost of a strike package that cannot complete its mission because the tanker's boom won't unlock, or on the impact of an airdrop not getting through to a unit under fire because the airlifter's doors won't open! It is easier to place a cost on the repair of the aircraft itself, but the cost of the resources required to accomplish the repair are harder to capture, especially if the aircraft happens to be at some out-of-the-way location!

It's no secret that our aging aircraft have aging systems. In many cases, components of the functional systems are pushed far beyond their life expectancy without inspection or attention. Unless they fail, they are not afforded the same analysis that aging structure receives if it is to be used beyond its design life. Additionally, as the years pass, it becomes more and more difficult to support aging systems when they do fail. As the commercial aviation industry moves ahead technologically, the military aviation industry is often left holding the bag with regards to obtaining spares or finding contractors willing and able to overhaul "old" systems. The depots have in-house manufacturing capability, but are not always the best source for making very specialized assemblies and subassemblies. Often, though, they are the only source available and the lead times are not always in line with the actual need by dates. If you did not plan for the depot to be the manufacturing source (which is often the case), and you have parts that fail requiring overhaul or replacement, you're already too late!

FSIP - The ALC Perspective

Supply Issues

From an ALC perspective, there are many advantages in having an FSIP. One big plus is the more or less steady-state demand rate it will create. Currently, there is a fluctuating demand for components, or component parts, which is difficult if not impossible to predict. This makes it difficult to have sufficient parts or components available when needed. This often results in aircraft out of service for days or weeks awaiting the replacement component. When parts are changed at a scheduled time, rather than just when they break or fail, spares can be better planned. This in turn allows the depots that repair or overhaul those components to better schedule their workload and procure the parts necessary to repair or overhaul the components. It permits the

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depots to utilize the production principles that have proven effective in the industrial world, for example, "just in time delivery".

Maintenance Issues

FSIP is also beneficial to the organizations performing maintenance on the aircraft, particularly to the depot performing heavy maintenance, which the Air Force calls Programmed Depot Maintenance, or (PDM). It allows the workload of each maintenance entity to be better predicted, resulting in a more efficient use of ever diminishing manpower resources. It also helps in the functional test, or systems checkout, that is performed after PDM. As it currently stands, at least in the C-141 world, a lot of time is expended at functional test replacing components that break or malfunction. With the planned replacement of these components, before they break, the number of surprises encountered becomes much smaller. This translates to reduced PDM flowdays, reduced costs to the customer, and more available aircraft.

FSIP Approach

The basics of the approach to FSIP are the same for both the KC-135 and the C-141, although the focus may be a little different. The first task is a systematic review of all the functional systems. This may be looking for safety concerns, or "bad actors", or the components that require the most resources to maintain and/or overhaul. Next a process is developed that may entail several steps that lead to the decision of how to resolve or mitigate the problems/concerns discovered during the review. Then an execution plan is tailored for each system to correct the deficiencies found. This will also provide a systems engineering type approach to the questions that are asked nearly every day about the life expectancy of the aircraft.

FSIP Implementation on the KC-135

Purpose

The Functional Systems Integrity Program (FSIP) for the C/KC-135 has been developed as a pro-active process to ensure safety of flight and durability of the aircraft functional systems beyond the original intended period of usage. It is intended to integrate with the ASIP program to provide an overall aircraft integrity process. The specific focus for the KC-135 is on impending safety and durability concerns.

Approach

During the systematic review of each system, each component that has a reduced margin of safety is identified, whether the reduction is due to the age of the system, or a change in mission requirements. Each system is also reviewed to determine if there are any components that could, by their failure, endanger the aircraft and /or flight crew. The standard is measured in terms of functional systems safety. The C/KC-135 aircraft contains a number of functional systems, all at varying and different points in their respective life cycles, thus requiring a number of independent and unique FSIP investigations.

The C/KC-135 FSIP process is broken down into five steps, each using a series of checklists customized to fit the system under investigation. The tasks are System Health

Assessment and Monitoring, Condition Analysis, Solution Development, Planning and Implementation, and Solution Health Monitoring.

KC-135 Examples

The following systems have been subjected to the FSIP process, with the findings as noted.

GOx system

There were 23 findings in the gaseous oxygen system. These included the lack of an internal pressure relief valve, modification discrepancies during the conversion from liquid oxygen to gaseous oxygen, and the uncertainty of the capacity of the gaseous oxygen system.

Landing gear

There were 59 findings during the review of the landing gear system, ranging from outdated wear and rework limits to outdated technical orders to improper maintenance procedures both in the field and at PDM.

Fuel system

There were 15 findings in the fuel system review, ranging from component wear to bladder leaks to deteriorated hoses, couplings and valves.

Flight controls

There were nine findings during the flight control review. These ranged from lubrication problems to component wear.

FSIP Implementation on the C-141

Purpose

The focus on the C-141 is slightly different. Due to the redundancy of the C-141 systems, there are few instances where a single-point failure can cause loss of the aircraft. For this reason, the focus has been placed on elimination of unscheduled maintenance. This will ensure that each mission will be completed, and will ensure the capability to sustain two theatre contingencies with the minimum maintenance footprint possible. Just as with the KC-135, the intent is to integrate all applicable integrity programs into an overall aircraft integrity and reliability program.

Approach

The approach for the C-141 is to systematically examine each system in order to establish a life expectancy for each system or component of each system using historical failure data. If this were a new aircraft, the process would begin by analysis and test, but 30+ years of test data already exists! Once a life expectancy is established, then a failure preventative action is accomplished at a scheduled downtime just prior to the predicted failure. This action could be either a forced time change at a scheduled downtime prior to predicted failure, an overhaul of a complex mechanical system to "zero-time" it, or refurbishment of the original equipment. Each system is also examined for frequency of maintenance and cost associated with the maintenance.

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If either of these is excessive, actions that will reduce the amount and/or cost of maintenance are designed and implemented. Once these actions have been implemented, failure and maintenance data from both field and depot is monitored to detect any reduction in actual life for any component. Any reduction detected results in a more detailed analysis to determine what has changed to cause premature failures. If necessary, part/component redesign or maintenance procedure adjustment is accomplished. In addition, an effective means of communication between depot and Original Equipment Manufacturer (OEM) engineers and technicians both at depot and field level has been established via a bulletin board on the World Wide Web. This has already yielded dividends of information that had been previously lost. Again, the aim is, in the words of the Warner Robins Air Logistics Center Commander, "Combat ready aircraft… anytime, anywhere!"

C-141 Examples

The following systems have been examined using this approach.

Flight control system

As a result of the flight control systems review, the Power Control Units are now replaced at PDM, and the mechanical PCU input systems are overhauled to an "as new" condition. This has resulted in a reduction of maintenance required at functional test.

Flap system

The results of the flap system review are the time-change replacement of the flap actuator jackscrews, and the overhaul of the flap carriage system to "like new" condition.

Spoiler system

The spoiler system review resulted in the refurbishment of the wiring harness for the spoiler actuator, which was original equipment. Additional actions that would have been identified by FSIP have already been accomplished, for example, a redesign of the spoiler checkout procedure.

FSIP - The MAJCOM Perspective

One look at the Air Mobility /Command (AMC) mission and Logistics vision implies a lot of proactivity. Unfortunately, the mission is interrupted on a daily basis with aircraft in the mobility fleet breaking out in the system. This causes an unnecessary loss of aircraft availability, cost burden (to include lost revenue) and increased maintenance workload. AMC's mission is to provide airlift, air refueling, special air mission, and aeromedical evacuation for U.S. forces. If this mission cannot be performed due to "broken" aircraft, chances are the other military forces won't be able to complete their mission at all of for very long. From the MAJCOM perspective, the significance of an effective FSIP relates to three key areas: Availability, Recovery Costs of aircraft broken in the mobility system, and Total Ownership Cost.

Aircraft Availability

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With the retirement of the C-141, AMC has significantly fewer strategic airlift aircraft available for tasking. The 126 C-5s and currently planned 135 C-17s, supplemented from time to time by tankers, must completely shoulder the heavy burden when the last of the 275 C-141 Starlifters retires in FY06. So far the C-17 is operating at a very high mission capable rate, but the other airlift assets aren't doing quite so well. Although the aircraft (with the exception of the C-17) average over 30 years old, the systems, not the structure, present the greatest challenge to achieving a required mission capable rate. The functional systems are the main driver for the delayed and cancelled sorties and for the ever-increasing flow days for Programmed Depot Maintenance. Figure 1 is an aggregate of the mission capable rates for the C-5, KC-10, C-17, C-130, KC-135, and the C-141. The graph shows that the trend of the curve for AMC reliability is continuing downward. It is short of the 87% mission capable rate required to meet our wartime tasking as defined by the Mobility Requirements Study, Bottom Up Review Update, indicated by the goal line. Figure 2 is a representative aircraft. It is clearly seen that the majority of the time this aircraft is not mission capable is due not to structural problems or inspections, but to failures of the aircraft's subsystems. In fact, seven major systems account for 71% of the reliability problems of this aircraft. A structured and effective FSIP will reduce the instances of ailing functional systems. A huge penalty has already been paid, but the US cannot afford to continue to pay this cost. Not completing the FSIP implementation now will further degrade the mobility capability and significantly increase operating costs as the fleet continues to age.

Cost of Recovery

All of those systems failing costs something. Let's look at an example of a cost not normally associated with the broken system or component.

How much does it cost to replace ten $1000 parts? At depot, it costs the $1000 for the part plus the labor cost, which is probably less than the $1000 part each time. For simplicity, we'll double it and say $2000.

Now how much does it cost when the aircraft breaks out in the mobility system, for example at places like Rwanda, Madagascar, Ethiopia, Iceland, Guam, Panama, Antarctica, Argentina, Kuwait or Johnston Atoll in the Pacific?

When one of AMC's aircraft breaks while on a mission, a Maintenance Recovery Team (MRT) is dispatched to that location. It must carry the needed parts, tools and support equipment, plus anything else that might happen to break before the aircraft is returned to service. Often the MRT only has what it brings with it, because many of the places AMC services barely have a runway capable of supporting the aircraft, much less any maintenance capability. Here is where AMC differs greatly from the airlines or even Air Combat Command aircraft, which usually land at the same base from which they launched. At worst case, they land at a base where forward-deployed maintenance teams are waiting on them. The AMC mission requires flights to anywhere on the globe, which makes prepositioning unfeasible. Figure 3 shows the average number of times a month that MRTs are dispatched, with the overall average about 60 times a month! It is an enormous expense to fly the MRT, the parts, tools and support equipment to everywhere aircraft break. Many times, that $1000 part costs us hundreds of thousands of dollars as sometimes a dedicated C-5 or C-17 mission is required just to bring in the correct tooling, parts and support equipment needed to make the repair.

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Where does an MRT come from? The maintainers, their tools, and support equipment are taken from their jobs of performing routine maintenance on the aircraft at home station to deploy and support the MRT. So not only is there the unnecessary burden of deploying the MRT, you also have lost maintenance capability at home station, which delays other aircraft from becoming mission capable. What a vicious circle, and what an opportunity for reducing the Total Ownership Cost!

Total Ownership Cost

FSIP recognizes that there is a value associated with lost mission capability that far outweighs the cost of the individual parts or components. Unfortunately, the Air Force's current costing systems don't tie all of the costs of these part failures back to the part, to include cannibalization from one aircraft to another and MRT expenses. In addition to the cost of recovery, the Transportation Working Capital Fund (TWCF) aircraft lose the revenue they could earn from paying customers for transporting their equipment and personnel around, similar to an airline. Again, however, the cost associated with a fighter or bomber not being able to complete its mission is difficult to compute, therefore it is even more difficult to show the return on investment that FSIP could provide.

Fortunately, there is a serious effort to better capture and manage the costs of operating all of the Air Force's systems, be they aircraft or trucks. Reduction of Total Ownership Cost is the latest emphasis from Air Staff and the Pentagon. Every program office is scrambling to show how they will save valuable dollars doing everything from reducing support personnel to outsourcing every available task. Unfortunately, those quick fixes don't take care of the greatest need, which is the ability to monitor and effectively manage the aging systems and structure of our aircraft. On the contrary, fewer people and smaller budgets in the program make it even more difficult to be proactive. The FSIP concept requires manpower and funding to avoid significantly larger costs as the aircraft ages. However, without very accurate and detailed supporting data, programs like FSIP don't stand a chance at getting funded, as often, if done effectively, the "real" savings are difficult to identify and capture. The other reality, though, is that we cannot afford to wait until our aging systems issues become major problems before we take any action.

How Do We Get There?

In order get moving in the right direction, two key areas need significant attention. First, there must be an Air Force-wide improvement of aircraft information capture and management. Data capture must include more real-time data from the aircraft itself via automated health and monitoring systems, from the aircrew with regards to usage information, and from the maintainer, both blue suit, contractor, and civil servant. Also necessary is the means to automatically capture all of the cost associated with the repair of an aircraft. All of this data needs be correlated by Work Unit Code and supply stock number (NSN) so that valid data screening and analysis can be automatically done to determine the real problem systems and then take effective and proactive actions. Of course, any good FSIP program should validate the problems and priority with the users from the field through some kind of reality check. To make all of this really effective though, formal guidance in the form of Air Force Policy and Instruction is a must.

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Status

The good news is that many individuals and program offices haven't waited around for published guidance to take needed action. There are many fantastic FSIP tools and methods already in use. Unfortunately, most are very weapon system unique.

From the headquarters level, HQ AFMC/DR is funding a pilot Post Fielding Support Analysis (PFSA) project with the C-130 aimed at implementing a state of the art data warehousing system with automated screening and analysis capability. Based on Air Force Special Operations Command's (AFSOC) A400 Special Operations Forces Reliability and Maintainability System, SOFRAMS, the C-130 system will correlate data from all existing maintenance and supply mainframe systems, screen the data for anomalies, and run pre-set analysis algorithms to notify program managers, engineers, item managers and MAJCOM weapon system managers when supply and maintenance trends indicate that trouble is beginning for specific systems or components.

Within AMC, there are some very effective FSIP programs at various levels of maturity for the KC-135, C-141, C-5 and most recently, the C-130. Together we have formed a team that is drafting an Air Force Policy Directive (AFPD), Air Force Instruction (AFI) and a Military Handbook (perhaps a Military Standard?) to formalize FSIP. These efforts have been briefed to the Air Staff Aging Aircraft Integrated Process Team and will be championed by the IPT as policy upon completion.

The already in place Mechanical Systems Integrity Program (MECSIP) will be absorbed by FSIP. FSIP can be implemented on all aircraft, especially fielded aircraft, and not just with new aircraft coming on line, as MECSIP is intended.

The goal will be to have ASC/EN responsible for the FSIP and ASIP programs and in line with Bob Giese's vision, create a Whole Airplane/Fleet Integrity Manager responsible for both structures and systems health. This vision integrates nicely with the Operational Safety, Suitability, and Effectiveness (OSS&E) policy, which is being implemented. OSS&E designates a Chief Engineer for each weapon system, who is responsible for the entire aircraft.

Summary

In summary, an effective FSIP will reduce Total Ownership Costs; reduce unscheduled aircraft downtime due to systems problems; improve supportability in the supply arena; enhance the enroute mission reliability by reducing unscheduled maintenance actions and the need for frequent MRT deployments to repair aircraft broken in the system; and finally, an effective FSIP will increase aircraft operational safety by preventing systems failures.

Note: Figures contained on pages 10 & 11 would not print. R Swain

USAF FSIP

SERVICE CONDITIONS

ENVIRONMENT AND CHEMICAL EXPOSURE

BOEING AERO ARTICLE, JAN 1999

51-20-00

MM pages

- 51-21-01 (pages 701-702)
- 51-21-02 (page 701)
- 51-21-03 (page 701-702)
- 51-24-13

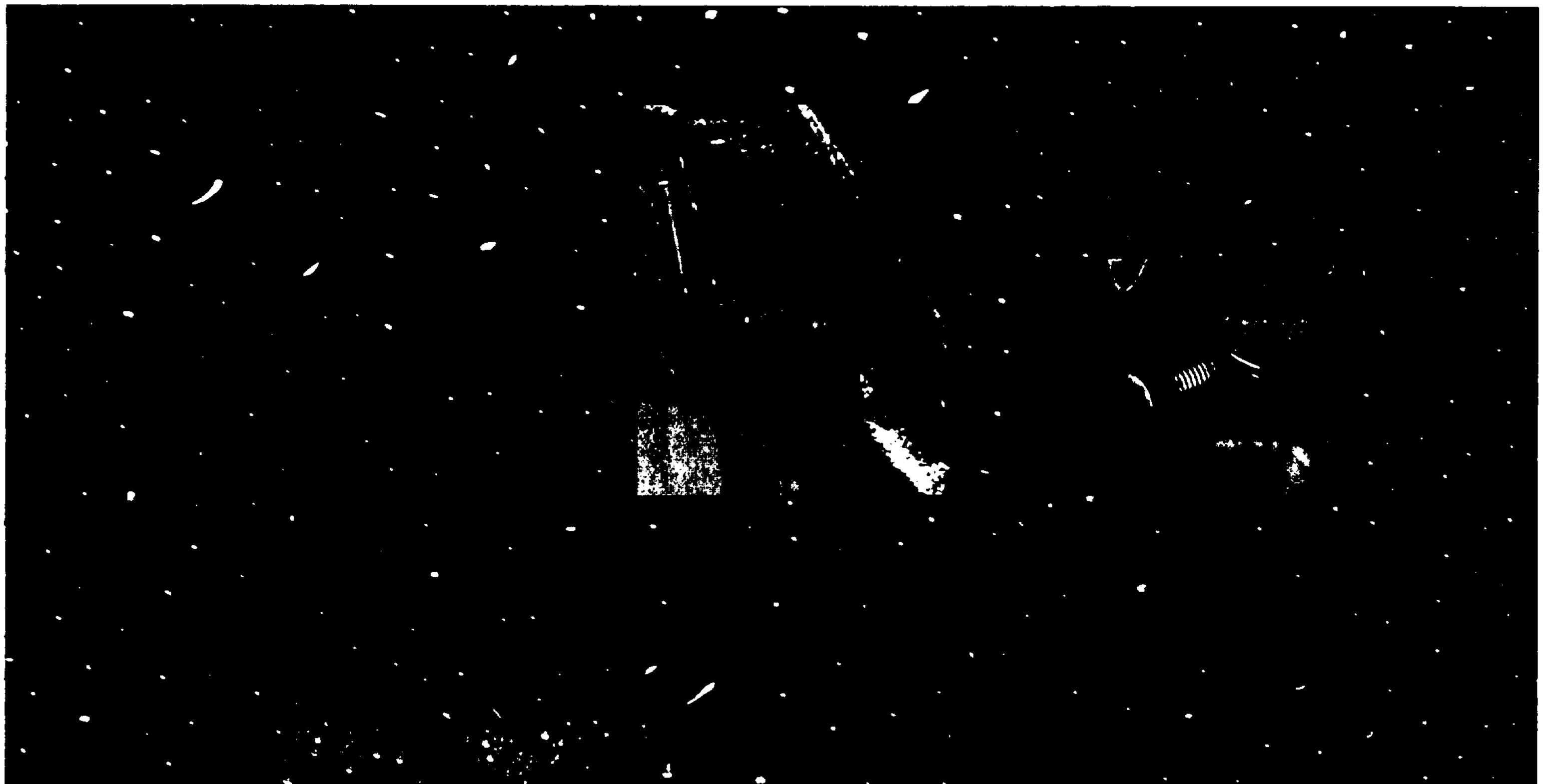
SRM 51-10-02, page 1, 6-10C

BOEING LETTER OF DEC 10, 1999

BOEING LETTER OF SEPT 13, 1999

BOEING LETTER OF AUGUST 4, 1998

BOEING S/B 747-28A2194



Moisture-related problems have been reported on commercial airplanes for the past 40 years. They include water dripping onto passengers, electrical equipment failures, and wet insulation blankets. All airplanes will experience moisture-related problems, but the extent of these problems will vary tremendously among operators and among individual airplanes depending on how they are used. Boeing has studied moisture-related problems extensively and has developed recommendations for minimizing moisture problems in its commercial airplanes.

BOEING AERO #5 ARTICLE, JAN 1999

ll commercial airplanes that carry passengers will experience moisture-related problems in service. The chief source of moisture inside these airplanes is passenger respiration and the resulting condensation on the airplane skin. After working with operators to evaluate existing and proposed moisture control methods, Boeing can now offer information to help mitigate the effects of moisture.

A Boeing team formed to address the moisture issue — known as "rain in the plane" — reviewed operator documentation on the subject and examined in-service airplanes with reported moisture problems. Operator reports identified where moisture problems were occurring and which operators were affected. The team then worked to develop cost-effective solutions for moisture control in all Boeing models, including out-of-production as well as current production and future models.

The team developed these solutions after examining the following issues:

1. Root causes of moisture problems.
2. Service experience with moisture problems.
3. Available moisture-control systems.

1 ROOT CAUSES OF MOISTURE PROBLEMS

When studying the origin of moisture problems, Boeing considered the following factors:

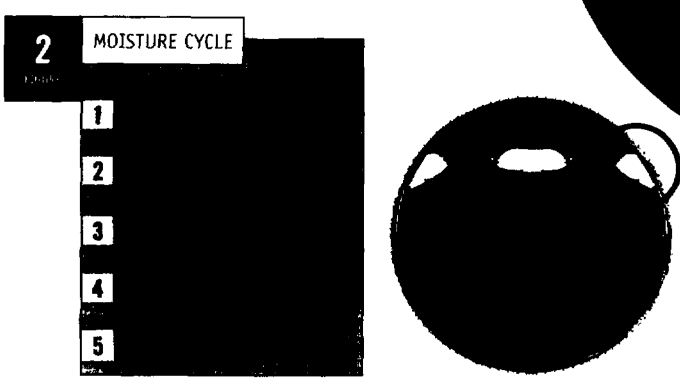
- Moisture sources and condensation.
- Drainage and dripping.
- Variables affecting condensation.
- Varying degrees of condensation and moisture problems across model fleets.

Moisture sources and condensation. Most condensation on airplane structure occurs during flight when the temperature of both the outside air and the structure are very cold. Structure temperatures are usually below the dew point of the cabin air, causing some amount of condensation to form during most flights. In addition, because structure temperatures are normally below the freezing point of water, most condensation forms as frost (fig. 1).

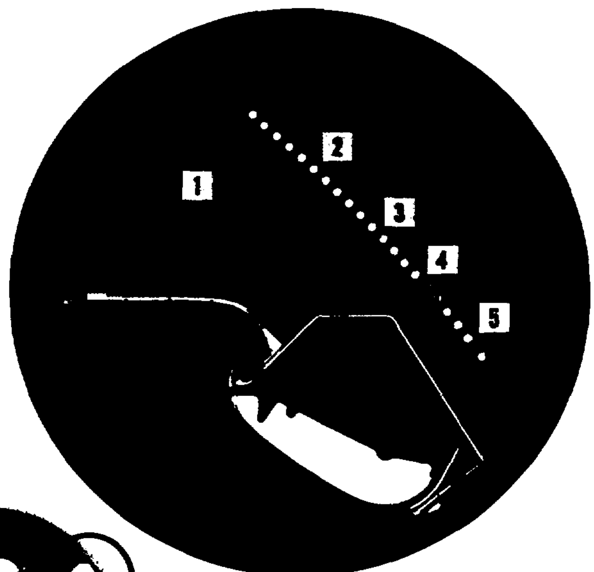
Condensation results when moist air moves to the cold structure (fig. 2). The cabin air passes through small gaps in the insulation coverage and cools rapidly. Buoyancy forces induce a continuous flow of air and continuous movement of moisture to the cold structure.

The rate of condensation depends on the rate of buoyancy-driven air movement to the structure as well as the cabin humidity level. In-flight cabin humidity levels are low from a standpoint of human comfort (usually less than 20 percent relative


1 EXTREME FROST ACCUMULATION



2 MOISTURE CYCLE



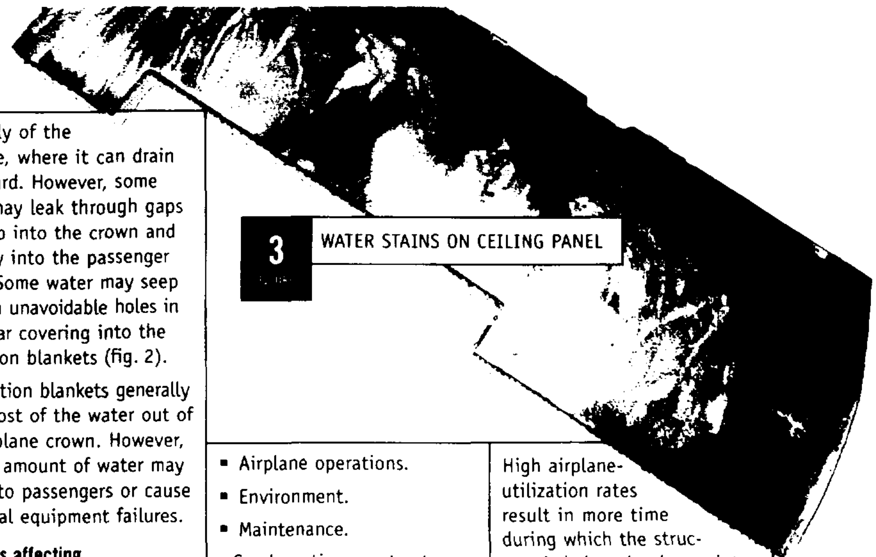
BOEING AERO ARTICLE, JAN 1999

humidity). However, the air is not completely dry, and any moisture it contains will condense as the air moves over the cold structure.

Drainage and dripping.
Frost melts rapidly during descent if conditions allow the airplane skin temperature to rise above freezing. This causes a sudden onset of drainage, which, if not managed completely, drips into the crown area (attic) of the airplane and possibly into the passenger cabin (fig. 3).

The insulation blankets that cover the structure typically are fiberglass batting covered with waterproof nonmetallic Mylar. This allows water to drain over the outboard Mylar surface similar to how rain drains over roof tiles or shingles. Ideally, all of the water flows to the bilge areas in the belly of the airplane, where it can drain overboard. However, some water may leak through gaps and drip into the crown and possibly into the passenger cabin. Some water may seep through unavoidable holes in the Mylar covering into the insulation blankets (fig. 2).

Insulation blankets generally keep most of the water out of the airplane crown. However, a small amount of water may drip onto passengers or cause electrical equipment failures.



3 WATER STAINS ON CEILING PANEL

Variables affecting condensation.
The amount of condensation that forms depends on many factors, all of which belong to one of four categories (table 1):

- Airplane design/configuration.
- Airplane operations.
- Environment.
- Maintenance.

Condensation on structure and the resulting moisture problems are influenced heavily by seating density and airplane operations, especially load factors and utilization rates. High passenger loads result in higher cabin humidities and higher condensation rates. High airplane-utilization rates result in more time during which the structure is below the dew point or frost point and greater accumulations of frost on a daily basis. *Some of the most severe moisture problems occur on airplanes with combinations of high seating density, high load factors, and high utilization rates.*

1

	CONFIGURATION	EFFECT
AIRPLANE DESIGN/ CONFIGURATION	Seating density	More people produce more moisture, causing higher cabin humidity levels and increased condensation rates.
	Insulation design	An insulation design that minimizes gaps will reduce condensation rates.
	Air-conditioning system design	The amount of outside air per occupant supplied to the airplane affects the in-flight humidity level. Increasing the outside air per occupant decreases the cabin humidity, which decreases the condensation rates.
AIRPLANE OPERATIONS	Load factor (percent of available seats occupied)	More people produce more moisture, causing higher cabin humidity levels and increased condensation rates.
	Utilization rate (hours per day the airplane is operating)	High airplane-utilization rates result in more time during which the structure is below the dew point and subject to greater accumulations of frost on a daily basis.
	Mach number	High-speed flight results in aerodynamic heating of the structure. Higher Mach numbers will result in warmer structure temperatures and lower condensation rates.
	Cruising altitude	In general, the outside air temperature and the airplane structure temperatures will decrease with altitude. Higher cruise altitudes will generally result in higher condensation rates.
ENVIRONMENT	Air-conditioning system operation	For airplanes with overhead recirculation fans or crown ventilation systems, operating these fans or air-conditioning packs on the ground will help dry out the crown space.
	Outside temperature	Colder structure temperatures cause higher condensation rates. Colder structure temperatures on the ground inhibit the evaporation of moisture from wet insulation.
	Outside humidity level	Outside humidity level is not a major influence on condensation on structure. Most condensation on structure occurs during flight when the structure temperature is very cold and the outside air is very dry. In most cases, rate of condensation on structure will be much lower during ground operations than in flight, even if the outside humidity level is very high.
MAINTENANCE	Insulation blanket installation	Gaps in insulation coverage created during maintenance can increase condensation rates. Damage to insulation cover material can increase moisture problems with wet insulation.
	Use of ground-based forced-air systems	Ground-based forced-air systems can be useful for drying airplanes parked for extended periods.

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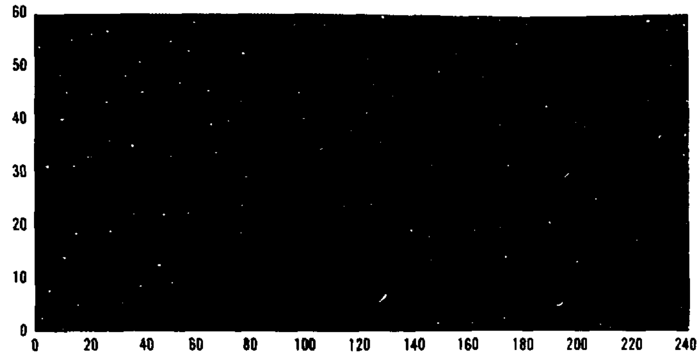
4 CONDENSATION VARIATION FOR THE 757 FLEET



Conditions:
Total number of airplanes is 708.
Estimated mean is 91 g.
Estimated standard deviation is 37 g.

Varying degrees of condensation and moisture problems across model fleets.

The amount of condensation and the severity of resulting moisture problems vary dramatically across airplane model fleets. The variation in daily crown area condensation for the 757 fleet is illustrated in figure 4.

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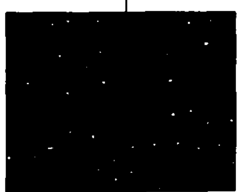
2 SERVICE EXPERIENCE WITH MOISTURE PROBLEMS

As part of its study, Boeing reviewed operator reports to learn where moisture problems were occurring and which operators were affected. Many operators have reported water dripping into the passenger cabin and problems with extremely wet insulation blankets.



Inspection of the upper surface of ceiling panels and stowage bins for water stains indicated that water was dripping through penetrations and gaps in the insulation blankets. Inspection also showed that water pooling on the upper surface of the ceiling panels and stowage bins (fig. 5) migrated through joints into the passenger cabin.

Boeing conducted numerous in-service reviews to determine the scope of the moisture problem. As an example, while inspecting airplanes with the most severe moisture problems, Boeing weighed each existing insulation blanket on three 737-300 airplanes (fig. 6). Comparing these weights with a new shipset of insulation blankets revealed that the removed blankets contained up to 80 lb (36 kg) of water per airplane.

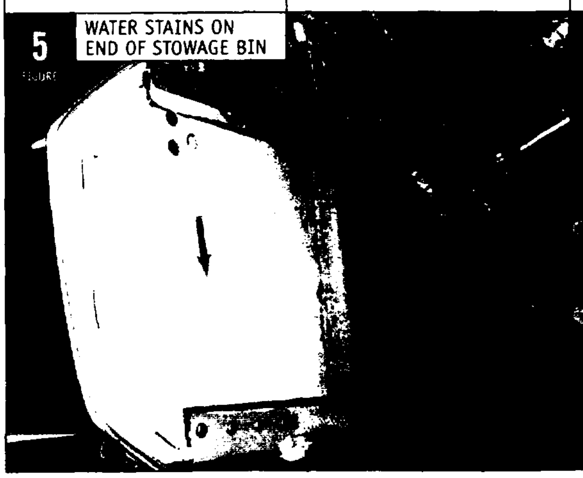
Other service experience results showed that water dripping into electrical equipment has caused some failures.

3 AVAILABLE MOISTURE-CONTROL SYSTEMS

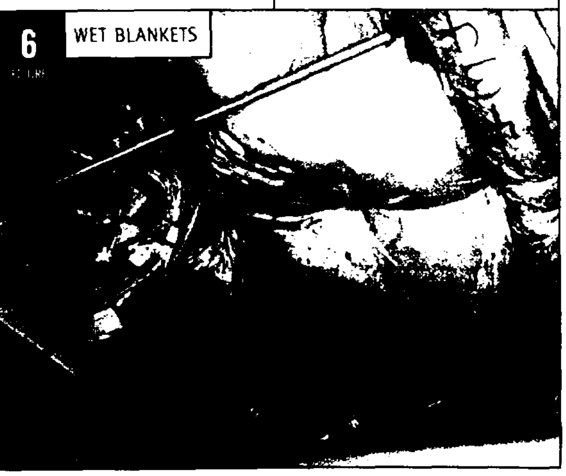
Because moist air will inevitably come in contact with cold structure, condensation cannot be eliminated. As a result, Boeing chose to evaluate potential moisture-control systems that can help operators accomplish the following:

- Minimize condensation.
- Minimize dripping onto equipment and into the passenger cabin.
- Maximize liquid drainage.
- Optimize evaporative drying from wet surfaces and insulation blankets.

Boeing used a test section of a 757 airplane in an environmental test chamber to simulate flight cycles. Over an extended period of time, the test section was used to evaluate frost levels, the



5 WATER STAINS ON END OF STOWAGE BIN



6 WET BLANKETS

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amount of water retained in insulation blankets, and new moisture-control methods. Video cameras recorded frost formation, melting, drainage, pooling, and drip paths into the passenger cabin. Cameras were also used to evaluate the performance of some potential moisture-control methods: insulation types, water diverters and collectors, and evaporative materials.

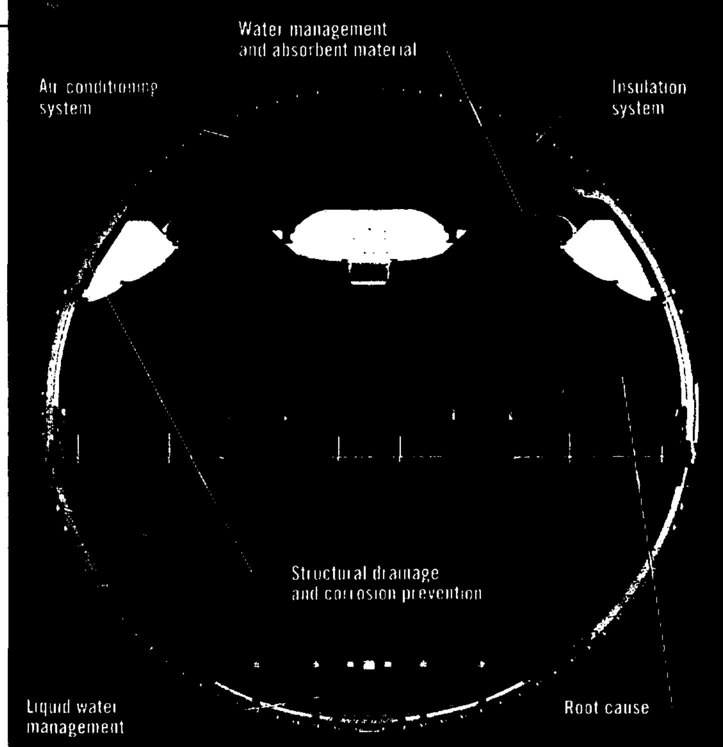
In-service airplanes, including those equipped with alternative materials for water collection and evaporation, were also tested. Results of these in-service evaluations determined that proper placement of moisture-control devices is crucial for their performance.

An analytical model was created to simulate the buoyancy-driven airflow from the crown volume to the skin. The model also estimated the amount of condensation (frost) that forms on the structure. The model was validated using in-service data and lab testing and showed how gaps in insulation, structural temperature variations, and cabin humidity levels affect condensation.

The testing produced the following information to help Boeing and operators reduce moisture-related problems:

- Test results.
- Moisture-control system design recommendations.
- Maintenance recommendations.

7 MOISTURE CONTROL SYSTEM



Test results.
Testing and inspections revealed the following findings:

- All blankets have holes and penetrations. Attempts at sealing them during testing were not effective.
- The best way to reduce condensation is by eliminating holes and gaps around the insulation blankets next to the structure.
- Nomex felt is an excellent material for collecting and evaporating moisture.
- Dehumidification systems (ground-based or onboard) are effective at removing moisture but are not cost effective.
- Water will seep into the insulation blankets through holes, penetrations, and edge seams. A drainage path is necessary to allow the water to drain.
- Evaporation is required to dry wet insulation blankets.
- Spray-on insulation is too heavy to meet thermal and acoustic requirements and makes visual inspection of the structure difficult.
- Inspections of aging airplanes revealed that corrosion in the crown area is extremely unusual and should be eliminated by incorporating corrosion-inhibiting compounds in the crown.
- Fiberglass batting treated with an enhanced hydrophobic coating does not reduce water retention.
- Any type of system that increases cabin humidity will exacerbate the moisture problem.

Moisture-control system design recommendations.
Boeing determin that a system (fig. 7), rather th an individual component, is require to effectively address a moisture problem. The syste includes

- Insulation blankets.
- Moisture-control devices.
- Airflow systems.
- Structural drainage.
- Bilge trays.
- Electrical-equipment protection.

Insulation blankets.
Key to controllin moisture, overlapped blankets (fig. 2) and minin gaps for structural supports can reduce air movement ar condensation. Penetrations for wire runs, electrical brackets, and other equipme should be kept to a minimu In addition, all blankets should have a drainage patl

Moisture-control devices.
Nomex felt should be usec to control water on ceiling panels (fig. 8), stowage bir (fig. 9), and structural pen trations. Active airflow will promote the evaporation of water collected in the felt.

Airflow systems.
Onboard systems for ventil ing the crown space will he control moisture problems. crown ventilation system tl provides a small portion of the cabin-supply air to the crown space will help reduc in-flight condensation and enhance drying of wet surfaces and wet insulation.

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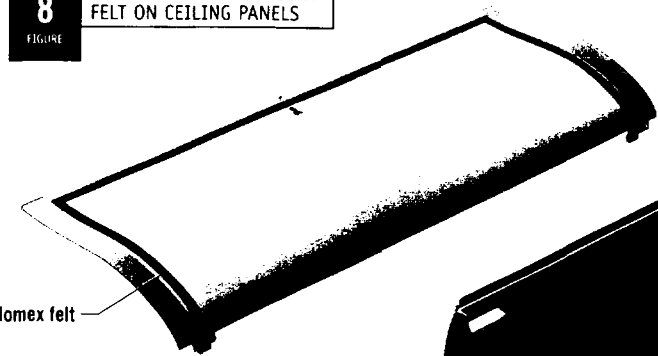
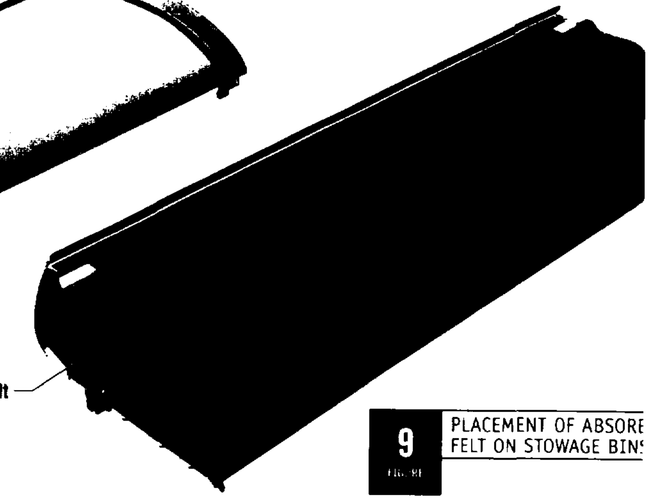
8 FIGURE PLACEMENT OF ABSORBENT FELT ON CEILING PANELS





9 FIGURE PLACEMENT OF ABSORBE FELT ON STOWAGE BIN

The addition of a crown ventilation system is not recommended for airplanes that have overhead recirculation fans as part of the air-conditioning system.

Structural drainage.
Water drainage through holes and channels should be considered in structural designs such as stringers and intercostals.

Bilge trays.
Bilge trays are sheets of molded plastic (fig. 10) intended to support the insulation blankets. Bilge trays should be used in the lower lobe of the airplane to keep insulation blankets away from any water that has traveled toward the drain valves.

Electrical-equipment protection.
Equipment that is sensitive to wet environments should be protected or moved from these environments. Sealed electrical connectors should be used to minimize moisture entry and to reduce the number of system failures.

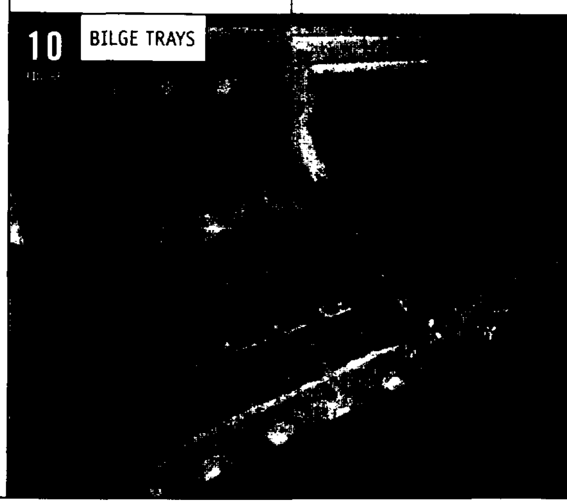
Maintenance recommendations.
Operators can take several steps to reduce moisture-related problems. These actions are related to

- Insulation blankets.
- Moisture-control methods.
- Bilge trays.
- Ground-based dehumidification systems.

Insulation blankets.
Reducing exposed structure and excessive gaps between insulation blankets will decrease the amount of condensation that forms. Ensuring that blanket joint areas — whether butt joints or overlaps — are properly installed will also reduce the creation of condensation and subsequent dripping into the crown area. If the blankets are overlapped, drainage holes will remove most of the water and keep it away from the passenger cabin.

Maintenance personnel remove wet insulation blankets during maintenance checks and often wring them to expel water. This helps dry the blankets, but it also damages the insulative material, reducing the blanket's thermal and acoustic capabilities.

10 FIGURE BILGE TRAYS



Moisture-control method.
A service letter (see has been distributed Boeing operators rega the use of Nomex felt ing panels and stowa Applying Nomex felt areas will reduce the of water that could d the passenger cabin.

Bilge trays.
Bilge trays provide l protection than string nets currently used ir cargo compartments airplanes.

Ground-based dehumidif systems.
Ground-based dehu cation systems can n very low humidity le an airplane. They car icantly enhance the of wet surfaces and insulation. However, considerable amount is required to dry an using these systems, airplane doors must closed for the durati the process. As a res most operators are n to choose this methc their daily operation ever, the systems ma useful for drying airp parked for longer per

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SUMMARY

Moisture in commercial airplanes is a complex issue, and its severity depends on many variables. Condensation on airplane structure is impossible to eliminate without prohibitive cost. However, Boeing has developed cost-effective methods for managing moisture once it has condensed that are both feasible and effective. The design improvements and other solutions recommended by Boeing were developed with assistance from operators and considered cost, weight, and ease of installation.

BOEING SERVICE LETTER

Boeing issued the following multi-part service letter regarding the installation of felt to prevent water from dripping into the passenger cabin of 707, 727, 737, 747, 757, 767, and 777 models. The letter was issued on Jan. 16, 1998.

707-SL-25-024

727-SL-25-035

737-SL-25-076

747-SL-25-166

757-SL-25-062

767-SL-25-081

777-SL-25-017

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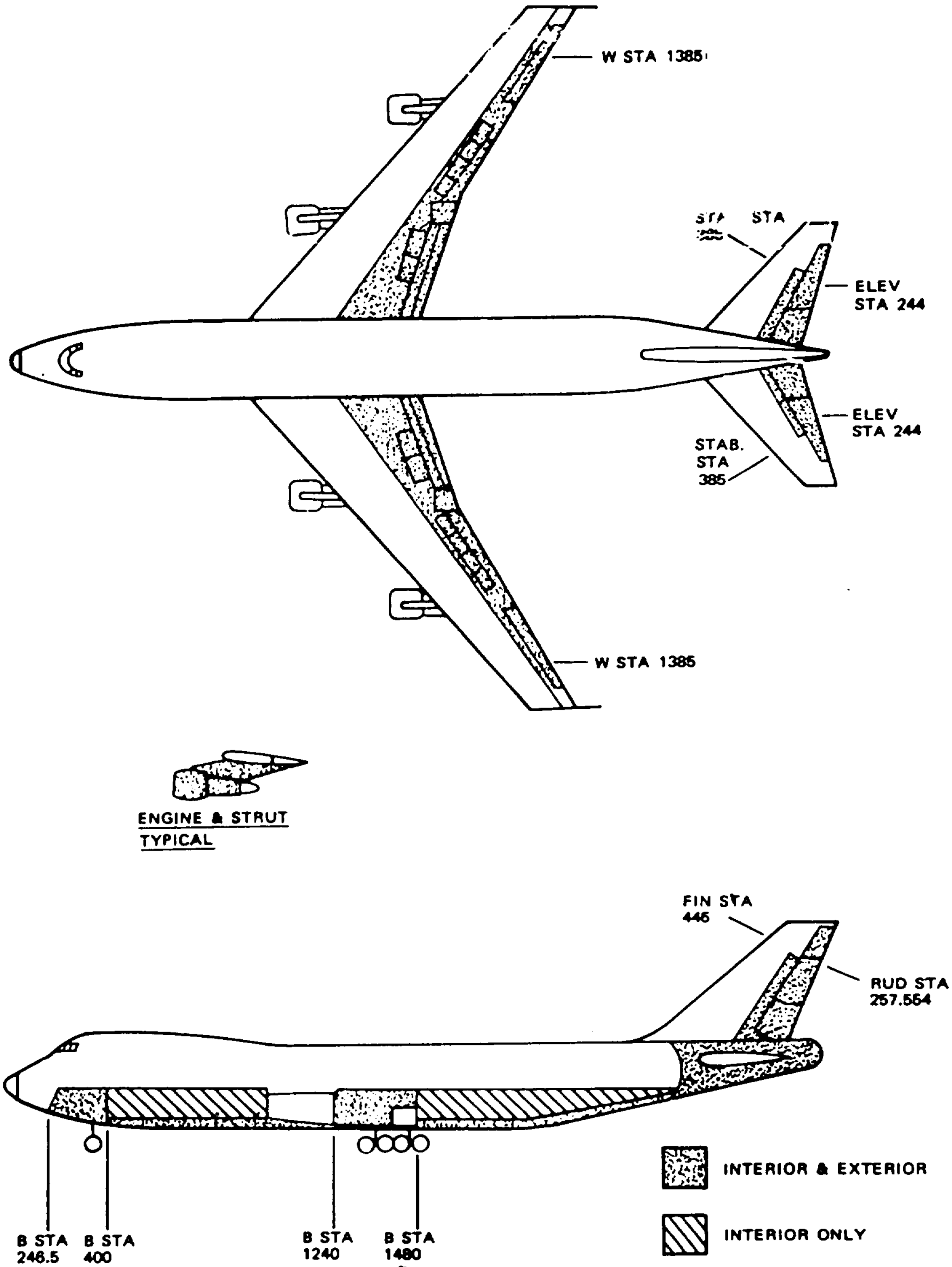

Possible Fire Resistant Hydraulic Fluid Contamination Areas
Figure 1

INTERIOR AND EXTERIOR FINISHES - CLEANING/PAINTING (PAINT STRIPPING)

1. General

WARNING: MANY ORGANIC-FINISH STRIPPERS ARE FLAMMABLE, TOXIC, OR CORROSIVE. CONSULT THE APPROPRIATE FIRE, INDUSTRIAL HYGIENE, AND SAFETY ORGANIZATIONS ON FACILITIES, EQUIPMENT, AND PROCEDURES REQUIRED FOR SAFE OPERATION WITH THESE MATERIALS.
AVOID PROLONGED OR REPEATED BREATHING OF SOLVENT AND STRIPPER VAPORS. THESE MATERIALS MUST NOT BE USED IN CONFINED SPACES WITHOUT ADEQUATE VENTILATION.
AVOID PROLONGED OR REPEATED CONTACT OF STRIPPERS WITH SKIN. CHEMICALLY RESISTANT GLOVES SHALL BE WORN WHEN USING PAINT STRIPPERS. GOGGLES OR PLASTIC FACE SHIELDS AND CHEMICALLY RESISTANT COATS AND HATS SHALL BE WORN WHEN STRIPPING OVERHEAD SURFACES OR OTHER SURFACES WHERE SPLASHING MAY RESULT.
ANY STRIPPER ON SKIN SHOULD BE WASHED OFF IMMEDIATELY WITH WATER. ANY MATERIALS SPLASHED IN THE EYES MUST BE FLUSHED OUT PROMPTLY WITH WATER AND THE AFFECTED PERSON SHALL REPORT TO A MEDICAL STATION.

A. Paint may be removed by the application of strippers or solvents. Paint applied to any metal surface may be removed by any of the specified strippers. Solvents may also be used if very small amounts of paints are to be removed. No paint stripper may be used, however, to remove paint from plastic laminates, fiberglass (bare or metalized), aerodynamic smoother or the edges of metal bonds, or rubber parts. Such materials as these may only be treated with prescribed solvents.
B. Paint stripping of metal surfaces may be done by immersion or by application of a stripper by brush or spray. For convenience in field work, the brush-on method is the one described in the following procedures.
C. Surfaces to be stripped must be perfectly dry and the temperature should be between 50°F and 100°F. Stripping should not be done in hot sun or rain.
D. If the surface to be stripped is excessively soiled, surface can be cleaned by application of the appropriate solvent alkaline or solvent emulsion cleaning agents or by solvent degreasing (Ref 12-25-01).
E. The stripper should be thoroughly mixed within the container before use. It is advisable to keep the container covered when not in use, to avoid losses by evaporation.

F. Critical areas subject to damage by strippers must be protected by proper masking, using polyethylene film and aluminum adhesive tape. Areas which must be protected from strippers include lubricated parts, rubber parts, laminated plastics, fiberglass (bare or metalized), aerodynamic smoother, and metal bonded edges. Mask all access doors, fairings and wing leading and trailing edges at least one inch onto the skins to insure that no stripper enters the joints. Drain holes and vents should be similarly plugged. Strippers should never be used in integral fuel tanks.

CAUTION: PAINT STRIPPERS SHOULD NOT BE ALLOWED TO COME IN CONTACT WITH TEFLON LINED SELF-LUBRICATED BEARINGS, ELECTRICAL TERMINAL PLUGS, NYLON-COATED WIRES, AND NYLON BUSHINGS. CHEMICALS IN THESE MATERIALS WILL ATTACK THE COMPONENTS.

2. Equipment and Materials

A. Polyethylene film and suitable adhesive tape for masking

B. Paint strippers - all purpose and qualified for use on metal parts, including steel parts heat treated above 180,000 psi (Ref 20-30-01).

(1) Turco 5351 (thick)
(2) Nuvite 631-3A
(3) Del Chem EZ Strip 19AC

NOTE: The above materials are preferred for removal of epoxy finishes. They are also usable on conventional finishes.

(4) DuBois R2134
(5) DuBow 1800 Sure-Strip
(6) Cee Bee A290
(7) Ardrox 204

NOTE: The order of stripping efficiency for other strippers listed has not been accurately determined. The user should check stripping efficiency on a given paint system, prior to large scale use.

C. Solvents (Ref 20-30-01)

(1) Ethylene Glycol Monobutyl Ether (Butyl Cellosolve), TT-E-776, flash point 165°F
(2) Ethyl Alcohol, U.S. Formula/denatured O-A-396, flash point 70°F
(3) Methyl Isobutyl Ketone, TT-M-268, flash point 75°F
(4) Xylene, TT-X-916, flash point 81°F
(5) Toluene, TT-T-548 (JAN-T-171 Grade A optional) flash point 40°F
(6) Methyl Ethyl Ketone, TT-M-261

D. Miscellaneous tools including brush or nonatomizing spray, stiff bristled brush, clean cloths, squeegee, or plastic scraper and proper protective clothing.

3. Referenced Procedures

A. 12-25-01, Airplane Servicing (Exterior Cleaning)

4. Application of Stripper

INTERIOR AND EXTERIOR FINISHES - CLEANING/PAINTING
(PREPAINT CLEANING AND PRETREATMENT)

1. General
   A. This section describes airplane surface preparation prior to application of exterior decorative finishes. The specific paint system section governs sequencing and selection of procedures in this section.
2. Equipment and Materials
   A. MASKING MATERIALS (Ref 20-30-04)
      (1) Plastic Film, Mylar, Polyethylene or Polyvinyl Chloride
      (2) Aluminum Foil Tapes
         (a) Permacel P11 or P12, 3M Co., No. 425
      (3) Masking Tapes
         (a) Permacel P-705
         (b) 3M Co., No 214, Y-223, 250, or 251
         (c) Mystik 6223
      (4) Polyethylene Coated Paper
      (5) Protex 20V
      (6) Mylar Tape, 17 inches wide, 0.005 inch gauge with interliner, Permacel 92
   B. Solvents (Ref 20-30-01)
      (1) Methyl Ethyl Ketone (MEK), TT-M-261
      (2) Methyl Iso-Butyl Ketone (MIBK), TT-M-268
      (3) Toluene (Toluol), TT-T-548 or JAN-T-171 Grade A
      (4) 1:1 MEK-Toluene Mixture
      (5) Thinner, TL-52
   C. Stripper - Turco 5351 (Ref 20-30-01).
   D. Alkaline cleaners (Ref 20-30-01)
      (1) Jet clean E
      (2) TEC 86-2
   E. Cheesecloth
   F. Abrasives (Ref 20-30-04)
      (1) Aluminum oxide abrasive paper, 100 to 240 grit, or finer.
      (2) Silicone carbide paper, 100 to 240 grit, or finer.
      (3) Silicone carbide abrasive disc (Bear Tex), 100 to 240 grit, or finer.
      (4) Scotchbrite pads, type A, aluminum oxide abrasive, 100 to 240 grit, or finer.
      (5) Nylon pad, aluminum oxide abrasive, type F, 100 to 240 grit, or finer.
      (6) Wooden or plastic scrapers
      (7) Abrasive paper - 150 grit or finer, 240 grit or finer, 400 grit or finer
   G. Alodine 1000 (Ref 20-30-02)
   H. Cheesecloth
   I. Tack rags
   J. Magna 28-C-1 Static Conditioner (Ref 20-30-02)
   K. Magna 8-W-5 Surfacer (Ref 20-30-02)
      (1) Hardener - 50-C-3 or 10-C-32
      (2) Reducer - 66-C-28

1. General
   A. Any structural part which has been subject to corrosive action must be carefully examined to determine its structural integrity. Corroded parts should be removed and if salvageable reworked. The same type of protective finish which was previously on the part should be reapplied. If it is not possible to remove the structurally sound part, specific treatments according to the type of material and degree of corrosion are to be applied.

      CAUTION: ACID BRIGHTENERS FOR ALUMINUM AND PHOSPHORIC ACID CORROSION REMOVERS FOR EITHER ALUMINUM OR STEEL SHOULD NOT BE ALLOWED TO COME IN CONTACT WITH TEFLON LINED SELF-LUBRICATED BEARINGS, ELECTRICAL TERMINAL PLUGS, NYLON-COATED WIRES, NYLON BUSHINGS OR WITH WHITE THERMAL PROTECTIVE FINISHES. CHEMICALS IN THESE MATERIALS WILL ATTACK COMPONENTS.

   B. Corrosion removal and control procedures listed in this section are applicable to all areas except the wing upper inspar surface as defined in 51-24-07. Procedures apply only to light corrosion. For severe corrosion removal, refer to Structural Repair Manual.
   C. In removing corrosion products it is of utmost importance for the removal to be complete. Failure to remove all residues permits corrosion action to start again after affected areas are refinished. For limits of corrosion removal, refer to Structural Repair Manual.
   D. Areas to be treated for corrosion must be free of oil, grease, dirt, and paint.
   E. Acid brighteners for aluminum have significant activity in not only removing corrosion but also the metallic surface and should therefore be used infrequently and only as required. Phosphoric acid type corrosion removers, on the other hand, are milder and while not effective in removing heavy corrosion do not appreciably attack the metallic surface.
   F. If corrosion cannot be removed immediately upon detection and the protective finish renewed, treat the area with BMS 3-23 to arrest growth of corrosion until this work can be accomplished (Ref 51-24-13).
2. Equipment and Materials
   A. Cheesecloth or new rags with less than 0.75 percent oil
   B. Cleaning brushes, nylon and wire
   C. Aluminum wool and stainless steel wool
   D. Aluminum oxide paper, 220 and 400 grit
   E. Polish per QPL-6888, under MIL-P-6888 (Ref 20-30-01)
   F. Acid brighteners for aluminum (Ref 20-30-01)

      NOTE: The following materials must be diluted with three parts water prior to use.

      (1) Kelite L-20
      (2) Metal Glo No. 2
   G. Phosphoric acid type corrosion removers for aluminum (Ref 20-30-01)

(1) Kelite Process K

NOTE: Before use, dilute with 5 parts water.

(2) Turco W.O. No. 1

NOTE: Before use, dilute with 6 parts water.

H. Phosphoric acid type corrosion removers for steel (Ref 20-30-01)

NOTE: The following materials must be diluted with 3 parts water before use.

(1) GMC 801
(2) Kelite Process K
(3) Oakite 31
(4) Turco Prepaint

I. Nitric acid, concentrated, Federal Specification O-A-88
J. Alodine 1000 and 1200S
K. Dow 1 and 19 solutions
L. Sodium dichromate or potassium dichromate
M. Chromic acid
N. Powdered calcium sulphate
O. Corrosion Preventive Compound, BMS 3-23 (Ref 20-30-03)

3. Referenced Procedures

A. 12-25-01, (Exterior Cleaning)
B. 51-21-01, Cleaning/Painting (Paint Stripping)
C. 51-24-07, Cleaning/Painting (Corrosion Control)
D. 51-24-13, Cleaning/Painting

4. Aluminum Corrosion Removal

A. General Exterior Skin Corrosion (brightening of aluminum)

(1) Place the airplane in a suitable location, which will allow rapid and thorough rinsing of all surfaces.
(2) Remove grease, oil and loose paint (Ref 12-25-01 and 51-21-01).
(3) Dilute acid aluminum brighteners per list in equipment and materials paragraph.
(4) Apply liberally to small areas starting from lower surfaces and working upwards so that there will be no runs to cause streaks.

CAUTION: KEEP SOLUTION OFF NONCLAD ALUMINUM ALLOYS, STEELS HEAT TREATED OVER 180,000 PSI, MAGNESIUM WHEELS AND MAGNESIUM SKIN PANELS, AND AWAY FROM FABRIC AND PLASTIC PARTS. IT IS NOT NECESSARY TO MASK FABRIC OR PLASTIC SURFACES, BUT THE BRIGHTENING SOLUTION SHOULD BE WASHED OFF PROMPTLY AND NOT ALLOWED TO DRY.

PROTECTIVE TREATMENT OF METAL REPAIR PARTS

1. General

   A. Any repair process which breaks the surface of original structure requires a protective treatment. The treatment acts as a paint base and corrosion inhibiter when applied prior to the installation of repair parts. Unclad aluminum alloys of the original structure require subsequent alodizing in cases where repair processes expose areas to possible corrosion. Unclad aluminum alloy and chamfered edges of clad aluminum alloy repair parts require alodizing and steel parts require cadmium plating.

   B. Structural components whose surfaces have not been damaged beyond the limits of allowable damage or whose surfaces have been damaged by corrosion must be refinished in accordance with the requirements of 51-21-00 of the Maintenance Manual.

   C. See 51-10-01, paragraphs 5.B. and 5.D., for mechanical cleanup operations required for the elimination of burrs or sharp edges.

2. Aluminum Alloy-Brush Alodize Process

   A. Alodine is the registered trade name of a proprietary process marketed by the American Chemical Paint Company. It is approved for the production of a chemical film on aluminum alloy. The film is softer than the anodic treatment but is acceptable as a protective coating and a paint base. Treat repair parts and original structure that has been cut or filed with Alodine 1200.

      WARNING: HANDLE BRUSH ALODINE 1200 WITH THE USUAL PRECAUTIONS FOR CORROSIVE CHEMICALS. USE RESPIRATORS, GOGGLES, RUBBER OR NEOPRENE GLOVES, BOOTS AND APRONS WHEN HANDLING THE POWDER AND APPLYING THE SOLUTION. DO NOT ALLOW THE POWDER OR SOLUTION TO CONTACT THE SKIN. WASH OFF IMMEDIATELY. IF SOLUTION CONTACTS THE EYES, WASH WITH WATER FOLLOWED BY AN EYE WASH OR BORIC ACID. OBTAIN MEDICAL AID IMMEDIATELY. DO NOT ALLOW SWABS, PAPER, ETC., USED FOR APPLYING OR REMOVING THE ALODINE SOLUTION, TO DRY OUT. THESE CONSTITUTE A FIRE HAZARD WHEN DRIED. IMMEDIATELY AFTER USE SOAK THOROUGHLY IN WATER BEFORE DISCARDING.

WATER DISPLACING CORROSION PREVENTIVE COMPOUND - CLEANING/PAINTING

1. General

A. This procedure provides information on application of water displacing corrosion preventive compound BMS 3-23. If used, it is recommended to reapply BMS 3-23 periodically.

WARNING: BMS 3-23 IS APPROXIMATELY EQUAL TO KEROSENE OR ALIPHATIC NAPHTHA IN TOXICITY. TO PROTECT SKIN, USE SAME PRECAUTIONS FOR BMS 3-23 AS FOR KEROSENE. WHEN SPRAYING BMS 3-23 IN AN ENCLOSED AREA, SUCH AS LOWER FUSELAGE, A VAPOR CONCENTRATION OF 500 PARTS PER MILLION IS THE MAXIMUM COMFORTABLE WORKING LIMIT. AT THIS CONCENTRATION A MAN CAN WORK AN 8-HOUR SHIFT. VAPOR LEVELS EXCEEDING 500 PMM ARE NOT DIRECTLY TOXIC, BUT FORCED VENTILATION MAY BE NECESSARY TO MAINTAIN A COMFORTABLE LEVEL. PERCHLOROETHYLENE IS PREFERRED SOLVENT AS IT IS NONFLAMMABLE. PERCHLOROETHYLENE IS TOXIC. IF USED IN EXTREMELY CONFINED AREAS, MECHANICAL VENTILATION IS MANDATORY. RESPIRATORY AND SKIN PROTECTION MAY BE NECESSARY.

NOTE: Each operator should evaluate his aircraft's environment, the inhibitor used, and the application schedule to ensure adequate corrosion protection. Although Boeing has developed BMS 3-23 as a standard for organic corrosion inhibitors and recommends its use, other water displacing corrosion preventive compounds may be satisfactory, based on operator evaluation and experience.

B. BMS 3-23 contains wax compounds and is not suitable on surfaces that will exceed 150°F.

CAUTION: AS A FIRE SAFETY PRECAUTION BMS 3-23 SHOULD BE KEPT AWAY FROM SURFACES WHICH MAY ATTAIN 300 DEGREES F OR MORE IN SERVICE. DRY FILM FLASH POINT IS 500 DEGREES F.

C. Application of additional finishes, such as paint or primer, may be difficult due to penetrating qualities of BMS 3-23, and possibility of bleedout from faying surfaces.

D. Allow primer and/or enamel to dry for 8 hours minimum before applying BMS 3-23.

E. Boeing recommends application of BMS 3-23 in the following areas, particularly into the faying surfaces of all assembled parts, (frame shear ties, stiffeners, intercostals) after attachment to the inner surface of the fuselage skin.

(1) Forward Cargo Compartment
  (a) Station 400 to station 1000 from S-36 left around lower fuselage to S-36 right.

(2) Aft Cargo Compartment
  (a) Station 1480 to station 1920 from S-36 left around lower fuselage to S-36 right.

(3) Bulk Cargo Compartment

1) Station 2360 pressure bulkhead (forward and aft faces) from WL 220 down to body skin.
2) Skin, stringers, frames and intercostals S-23 to bottom centerline left and right between STA 2360 and 2484, including structure around door opening, and in cracks between skin panels.

(f) Interior of inspar wing box
   1) On airplanes without No. 2 and No. 3 reserve tanks, Dry bay, Wing station 1280 to 1485.
   2) Front spar chord area (upper and lower) inside on airplanes having dry bay center section.
(g) Overwing longeron and crease beam.
(h) Wing rear spar aft cavity.
(i) Horizontal stabilizer rear spar cavity.
(j) Lower surface of wing center section.
(k) Upper surface of wing center section and sloping pressure deck (Sta 1230 to 1250).
(l) Trailing edge flap carriage spindle.
(m) Wing landing gear trunnion support fittings.
(n) Outboard wing boost pump cavities.
(o) Fuselage crown skin panels and crown frames from left and right of S-12 and Sta 380 to 2360.
(p) Structure below main and upper deck floors in area of door entryways and lavatory and galley envelopes.
(q) Interior of landing gear doors.
(r) Front spar, lower forward face and adjacent inner skin surface inboard and outboard nacelle areas.
(s) Chord and Web sections forward of front spar and aft of rear spar (Optional to fastener sealing).
   1) Mask areas not to be treated using masking tape and paper or plastic film.
   2) Mask electrical connectors to prevent contamination of electrical components.

   3) Do not apply BMS 3-23 to actuator rods; BMS 3-23 or any hydrocarbon may cause seals used with BMS 3-11 hydraulic fluid to swell.
   4) Use caution when applying BMS 3-23 in vicinity of silicone rubber seals or rubber lined clamps such as grease seals in bearings and liners in hydraulic line clamps or wiring clamps.
   5) Shield and protect oxygen system components from direct or indirect contact during application of BMS 3-23 on adjacent structure.

      <u>WARNING</u>: CORROSION PREVENTIVE COMPOUND MUST NOT GET INTO OXYGEN SYSTEM AS MIXTURE IS POTENTIALLY EXPLOSIVE.

D. Stress corrosion may occur in H-11 and maraging steel fasteners, resulting in cracked or broken fasteners. Replace these fasteners as follows:

(1) Remove fasteners and, if required, machine fastener holes to the smallest standard oversize diameter that will permit damage cleanup.

(2) Install permanent fasteners with wet BMS 5-95 sealant (except fasteners included in paragraph 5B and fasteners in special areas where a different sealant is required - such as integral fuel tank and fire wall areas). Also, apply BMS 5-95 sealant over nuts and boltheads except on aerodynamic surfaces. Note: See 51-10-06, Fig. 1 for sealants used in special areas.

(3) Install removable fasteners with BMS 3-23 water displacing, corrosion-inhibiting compound. Observe instructions and precautions in paragraph 6 regarding BMS 3-23.

E. When installing fasteners at stringer splices located at STA 1000, 1241, 1350, 1480, 1740, 1960, and 2180 between S-12L and S-12R apply extra corrosion protective finish as follows:

(1) Overspray all fasteners common to stringer splice fitting with one coat of BMS 10-11 primer.

(2) Overcoat all non-aluminum fasteners common to the body frames at the stations listed with one coat of BMS 10-11.

F. Install H-11 bolts using BMS 5-95 wet sealant in areas outlined in Figure 6. Fillet seal around bolt heads and nuts.

6. <u>Use of Water Displacing Corrosion Inhibiting Compounds as Corrosion Retardants</u>

A. General

(1) Water-displacing organic corrosion inhibiting compounds can be applied to metallic structures to prevent the onset and retard the spread of corrosion. These compounds can be applied to supplement the regular finish and sealing systems in those regions of the airplane which are susceptible to corrosion. Compounds to Spec MIL-C-16173, Grade 3 are effective as corrosion inhibitors.

(2) Corrosion inhibitors are used to supplement finish systems and as a means of preventing or retarding corrosion where the finish system has been damaged. These materials are volatile liquids which may be sprayed or brushed on the surfaces to be treated. The liquid carrier evaporates quickly to leave a thin film of wax-like residue over the coated surface. This material has the ability to penetrate into extremely small cavities and to displace water, consequently it is able to enter between faying surfaces or between fasteners and holes, where the finish has been broken. It is a durable material, not easily removed by normal use, and where used externally will withstand a certain amount of washing, although eventually reapplication will be required.

NOTE: Each operator should evaluate the aircraft's environment, the inhibitor used, and the application schedule, to ensure adequate corrosion protection. Although Boeing has developed BMS 3-23 as a standard for organic corrosion inhibitors and recommends its use, other water displacing corrosion inhibiting compounds may be satisfactory, based on operator evaluation and experience.

(3) There are two types of BMS 3-23 compounds as follows:

(a) Type I - A transparent colorless film which is only detectable with ultraviolet light.

(b) Type II - A colored film which is readily detected by the unaided eye.

(4) Materials qualified under BMS 3-23 and the suppliers are as follows:

Materials	Vendor
Boeshield T9	Oxy Metal Corporation Specialty Chemical Group 32100 Stephenson Highway Madison Heights, Michigan 48071
	Gibson Chemicals Ltd 350 Reserve Road Cheltenham Victoria, Australia 3192

(5) Water-displacing, corrosion-inhibiting compound can be applied to those areas of the airplane structure which have started to corrode or in which there may be a possibility of future corrosion. Water-displacing, corrosion-inhibiting compound will not decrease the existing torque on fasteners, but, application should be restricted to those areas directly affected by corrosion, such as the following:

(a) Surfaces exposed to the atmosphere during operation of control surfaces. Examples: Wing leading and trailing edge cavities, spar chords and faying surfaces between chords and spars.

(b) Structure where water might collect and not drain away. Example: Fuselage bilge areas.

(c) Structure which may corrode due to contact with corrosive liquids. Examples: Seat tracks and structure below galleys and toilets.

(d) Rivets and bolts after installation when no other finish is applied.

(e) All faying surfaces where paint, primer, or sealant is in any way deteriorated.

(f) Where the decorative paint film is broken around fasteners (to inhibit filiform corrosion).

(g) Any additional locations where existing corrosion is detected except where use of corrosion-inhibiting compound is restricted per par. 6.B.

(6) During construction of certain airplanes, water-displacing, corrosion-inhibiting compound was applied to specific locations of the airframe structure to provide supplementary protection against corrosion. Any rework or repair in these regions should be followed by a further application of water-displacing, corrosion-inhibiting compound. See Fig. 4 for definition of specific locations.

(7) For additional procedures on the use of water-displacing, corrosion-inhibiting compound to control and prevent corrosion, refer to D6-41910, Corrosion Prevention Manual.

B. Precautions for Use of Water-Displacing, Corrosion-Inhibiting Compounds

(1) For personal safety the following warning must be observed when using water-displacing, corrosion-inhibiting compounds.

WARNING: THESE COMPOUNDS ARE APPROXIMATELY EQUAL TO KEROSENE OR ALIPHATIC NAPHTHA IN TOXICITY. TO PROTECT SKIN, USE SAME PRECAUTIONS AS FOR KEROSENE. WHEN SPRAYING IN AN ENCLOSED AREA, SUCH AS LOWER FUSELAGE, A VAPOR CONCENTRATION OF 500 PARTS PER MILLION IS THE MAXIMUM COMFORTABLE WORKING LIMIT. AT THIS CONCENTRATION A MAN CAN WORK AN 8-HOUR SHIFT. VAPOR LEVELS EXCEEDING 500 PPM ARE NOT DIRECTLY TOXIC, BUT FORCED VENTILATION MAY BE NECESSARY TO MAINTAIN A COMFORTABLE LEVEL. PERCHLOROETHYLENE IS PREFERRED SOLVENT AS IT IS NONFLAMMABLE. PERCHLOROETHYLENE IS TOXIC. IF USED IN EXTREMELY CONFINED AREAS, MECHANICAL VENTILATION IS MANDATORY. RESPIRATORY AND SKIN PROTECTION MAY BE NECESSARY.

WHEN MIXED, WATER-DISPLACING, CORROSION-INHIBITING COMPOUNDS AND OXYGEN ARE POTENTIALLY EXPLOSIVE. KEEP CLEAR OF OXYGEN SYSTEM COMPONENTS.

(2) Being hydrocarbons these compounds are potentially dangerous when mixed with oxygen. Oxygen system components must be shielded to protect them from direct or indirect contamination.

CAUTION: AS A FIRE SAFETY PRECAUTION, THE MATERIAL SHOULD BE KEPT AWAY FROM SURFACES THAT WILL ATTAIN 300°F OR MORE IN SERVICE. THE DRY FILM FLASH POINT IS 500°F.

CAUTION: CORROSION INHIBITOR CONTAINS FLAMMABLE COMPONENTS. DO NOT EXPOSE THESE MATERIALS TO OPEN FLAME, ACTIVE CIRCUITS, OR OTHER COMPONENTS WHEREBY A POTENTIAL FIRE HAZARD WOULD EXIST. THE VOLATILE CARRIER IS ALSO FLAMMABLE. MAINTAIN SAFETY PRECAUTIONS UNTIL THE CARRIER HAS FULLY EVAPORATED.

(3) Precautions must be taken when using these materials which can constitute a fire hazard when subjected to high enough temperatures.

(4) Mask electrical connectors where there is a possibility of contamination of electrical contacts.

CAUTION: REMOVE EXCESS CORROSION INHIBITING COMPOUNDS FROM MECHANISMS AND MOVING PARTS WITH A CLEAN DRY RAG. THE RESULTANT THIN FILM IS ADEQUATE FOR CORROSION PROTECTION WHILE EXCESSIVE BUILD-UP COULD HARDEN AT LOW TEMPERATURES CAUSING OPERATING DIFFICULTIES.

(5) Shield control cables, pulleys, teflon bearings and lubricated surfaces from direct application. The carriers used in these materials are volatile hydrocarbons which act as a solvent for lubricants. Destruction of the lubricants can result in premature and excessive wear of the components.

(6) Water displacing corrosion inhibiting compounds may cause silicone rubber to swell consequently care must be exercised when making application in the vicinity of door or emergency hatch seals, grease seals in bearing assemblies or rubber-lined clamps for tubing or wiring. Skydrol seals may also be affected, so these corrosion inhibitors are not suitable for use on actuator rods.

C. Application of Water Displacing Corrosion Inhibiting Compound

(1) Water displacing corrosion inhibiting compound has a solvent carrier with a low surface tension which will aid in displacing existing water from a metal surface. As the solvent evaporates, a thin wax-like film is left to act as a barrier to prevent chemical reaction between the metal and water or other substances in the environment. Having properties similar to a penetrating oil, water displacing corrosion inhibiting compound will penetrate into cracks and crevices through capillary action; this peculiarity making pressure spraying unnecessary. Refer to 51-20-04 for sources of water displacing corrosion inhibiting compound.

(2) Water displacing corrosion inhibiting compound may be applied to the desired area with no preparatory work other than general cleaning. It may be applied with an airless paint spray pump, by aerosol can or brush. The most effective method of application depends upon the location and accessibility. Successive coats of water displacing corrosion inhibiting compound may be applied one on top of the other, but if the existing coat is badly contaminated with dirt or other solids, the affected area should be cleaned before applying a new coat. Refer to par. G.(1) for list of solvents that may be used for cleaning.

(3) The procedure in par. 6.D. thru 6.G. provides information on the application of water displacing corrosion inhibiting compound. Compound is to be applied only to areas authorized by released engineering information.

(4) Application of additional finishes, such as paint or primer, may be difficult due to penetrating qualities of water displacing corrosion inhibiting compound and possibility of bleedout from faying surfaces.

(5) Allow primer and/or enamel to dry for a minimum of 8 hours before applying water displacing corrosion inhibiting compound.

D. Equipment and Materials

(1) Water Displacing Corrosion Inhibiting Compound (MIL-C-16173)

(2) Masking tape

(3) Perchloroethylene, Technical - O-T-236

(4) Solvent - P-D-680

(5) Wipers - cheesecloth, gauze, new or laundered rags, tissue, paper, or other absorbent materials

(6) Protective caps and closure for exposed oxygen system tubing

E. Surface Preparation.

CAUTION: BATTERIES SHOULD BE DISCONNECTED WHEN WORKING IN THE VICINITY OF BATTERY OPERATED ELECTRICAL EQUIPMENT, ESPECIALLY WHEN FLAMMABLE MATERIALS ARE BEING UTILIZED. SOME PROCEDURES ALSO REQUIRE COPIOUS QUANTITIES OF WATER TO BE USED, SUCH AS PAINT REMOVAL OR ALODIZING. IN THESE INSTANCES DISCONNECTING BATTERIES IS ALSO PRUDENT IF THERE IS ELECTRICAL EQUIPMENT IN THE AREA. FAILURE TO ACCOMPLISH ABOVE COULD RESULT IN POTENTIAL FIRE HAZARD OR ELECTRICAL SHOCK.

(1) Remove external power and remove or disconnect airplane batteries as required.

(2) Statically ground airplane per 20-41-01 of the 747 Maintenance Manual.

(3) Vacuum surfaces as necessary to remove excess foreign matter.

WARNING: IF AREA TO BE TREATED IS EXTREMELY CONFINED, MECHANICAL VENTILATION IS MANDATORY. RESPIRATORY AND SKIN PROTECTION MAY BE NECESSARY. PERCHLOROETHYLENE IS PREFERRED SOLVENT FOR CONFINED AREA AS IT IS NONFLAMMABLE.

(4) Clean surface with perchloroethylene or solvent. If area is enclosed or confined, mechanical ventilation is required.

NOTE: Cleaning is required to enhance entry of water displacing corrosion inhibiting compound into surface to be treated and into faying surfaces.

(5) Mask area not to be treated using masking tape and paper or plastic film.

(6) Mask electrical connector to prevent contamination of electrical contacts.

CAUTION: WATER-DISPLACING, CORROSION-INHIBITING COMPOUND OR ANY HYDROCARBON, WHEN LIBERALLY APPLIED TO A SILICONE OR ETHYLENE PROPYLENE RUBBER WILL CAUSE IT TO SWELL AND PREVENT IT FROM PERFORMING ITS FUNCTION CORRECTLY. TYPICAL PARTS ARE WINDOW AND DOOR SEALS, GROMMETS IN WIRING, TUBING CLAMPS AND SKYDROL RESISTANT ACTUATOR SEALS.

(7) Oxygen system components must be shielded and protected from direct and indirect contact during application of water-displacing, corrosion-inhibiting compound on adjacent structure.

(8) Shield control cables, pulleys, teflon bearings and lubricated surfaces from direct application of corrosion preventive compound.

(9) Allow new primer or paint to dry for a minimum of 8 hours before applying a water-displacing, corrosion-inhibiting compound.

F. Corrosion-Inhibiting Compound Application

(1) Statically ground the airplane.

CAUTION: BATTERIES SHOULD BE DISCONNECTED WHEN WORKING IN THE VICINITY OF BATTERY OPERATED ELECTRICAL EQUIPMENT, ESPECIALLY WHEN FLAMMABLE MATERIALS ARE BEING UTILIZED. SOME PROCEDURES ALSO REQUIRE COPIOUS QUANTITIES OF WATER TO BE USED, SUCH AS PAINT REMOVAL OR ALODIZING. IN THESE INSTANCES DISCONNECTING BATTERIES IS ALSO PRUDENT IF THERE IS ELECTRICAL EQUIPMENT IN THE AREA. FAILURE TO ACCOMPLISH ABOVE COULD RESULT IN POTENTIAL FIRE HAZARD OR ELECTRICAL SHOCK.

(2) Remove external power and remove or disconnect airplane batteries as required.

(3) Observe the precautions given in par. B and mask or shield components which must not be contaminated with corrosion-inhibiting compounds.

(4) Ensure that all primers or enamels have been permitted to cure for a minimum of 8 hours.

(5) Provide mechanical ventilation of enclosed areas such as spar cavities and cargo compartments.

(6) Apply a continuous wet coat so that joint penetration will be achieved by capillary action. An application rate by spraying of 1 gallon per hour at a coverage rate of 15 to 20 square feet per minute will produce a film thickness of 0.0003 inch. Alternately these materials may be brushed. The use of pressure equipment that applies these compounds under pressure direct to a joint or lap will improve the penetration. A soak period of 30 minutes is required before excess compound is removed to ensure maximum penetration.

(7) Remove puddles from treated surface using clean wipers or gauze after the 30 minute minimum soak period.

(8) Remove all masking tape, protective paper or plastic film installed.

(9) Maintain ventilation of enclosed areas until evaporation of volatile solvents is complete before enclosing area.

(10) Water-displacing, corrosion-inhibiting compound contains wax compounds and is not suitable on surfaces that will exceed 150°F.

G. Corrosion-Inhibiting Compound Removal

(1) Complete removal of corrosion-inhibiting compound is required before repainting is attempted. Thorough solvent cleaning is also required before penetrant inspection. The following solvents have been successfully used to remove these compounds:

(a) Perchlorethylene

(b) Trichloroethylene

(c) Trichlorethane

(d) Naphtha

(e) Magnaflux Corp. Solvent

(f) Stoddart Solvent

NOTE: Methyl Ethyl Ketone (MEK) or Acetone is not recommended.

(2) Ventilation requirements stipulated in par. 6.F. (8) must be adhered to while removing corrosion inhibiting compound.

H. Exterior Discoloration by Corrosion-Inhibiting Compounds

(1) Liberal use of water-displacing compounds on the internal surfaces of the airplane can lead to discoloration of the external surface. Because of the excellent penetrating properties of these materials, a "bleed through" can be expected at fasteners that are not fluid-tight. This is normal and does not indicate a requirement to replace or redrive the fasteners. The tiny passages should seal themselves within a short time.

(2) Corrosion inhibiting compounds on the exterior surface may be removed using one of the solvents listed in par. G. They will not stain or damage the exterior of the airplane or decorative finish, but a noticeable difference in oxidation of the exterior surfaces can occur between those areas which have been coated with the compound and areas that have not. Where this difference in color is apparent it can be buffed out using the materials listed in Chapter 20 of the Maintenance Manual.

7. Use of Solvent-Dispersed Corrosion Inhibiting Compound to MIL-C-16173, Grade I

A. General

(1) Although the water-displacing corrosion inhibiting compounds are the primary corrosion inhibitors used in airplane manufacture, in certain applications where a more durable surface protection is required solvent dispersed corrosion inhibiting compounds to MIL-C-16173, Grade I are used. These materials are volatile liquids which may be sprayed or brushed on the surfaces to be treated. The liquid carrier evaporates and leaves a residue (hard grease in appearance) which will become sufficiently dry to permit handling after approximately 4 hours. The Grade I compound provides a hard film, however, does not have the penetrating or water displacing qualities of the BMS 3-23 or similar corrosion inhibiting compounds. Applications should be limited to areas where specific callout of this inhibitor is made.

(2) Materials qualified under MIL-C-16173, Grade I and the suppliers are provided on QPL-16173-54.

NOTE: A commonly known corrosion inhibitor meeting the specifications noted is Cosmolene.

B. Precautions for Use of MIL-C-16173, Grade I Corrosion Inhibiting Compounds

(1) The precautions listed for water-displacing corrosion inhibiting compounds apply to the MIL-C-16173, Grade I, corrosion inhibitors (Ref par. 6.B.).

C. Compatability of MIL-C-16173, Grade I Corrosion Inhibitors

(1) These materials are all usually hydrocarbons and new applications of a different compound may be applied over existing corrosion inhibitors without deleterious effects.

D. Cleaning Before Application of MIL-C-16173, Grade I Corrosion Inhibiting Compounds

(1) Extreme cleanliness is not required for the application of these compounds, but a better continuous film will be achieved if the area is cleaned before application. Loose dirt or other foreign matter can be removed by vacuum or wiping. The surfaces can then be cleaned, where necessary, by using normal airplane cleaning agents or solvents.

E. Application of MIL-C-16173, Grade I Corrosion Inhibiting Compounds

(1) Statically ground the airplane.

(2) Observe the precautions given in par. 7.B. and mask or shield components which must not be contaminated with corrosion inhibiting compounds.

(3) Ensure that all primers or enamels have been permitted to cure for a minimum of 8 hours.

(4) Apply a continuous wet coat so that a continuous surface film is achieved. Although spray application is recommended to provide a more even film thickness these materials may be alternately brush coated. Refer to par. 7.F. for further detail of spraying equipment and procedures.

(5) Ventilate the area until the volatile solvents have completely evaporated and remove the masking or shielding from the area treated.

F. Spray Application of MIL-C-16173, Grade I Corrosion Inhibiting Compounds

(1) Aerosol cans can be used in conjunction with plastic nozzle extensions but they are not generally recommended due to cost and the amount of overspray generated.

(2) The preferred application method is with standard pressure pot equipment using an airless spray gun operated at low pressure (45 psi). Suitable spray equipment is available from the following suppliers:

(a) Nordson Corporation, Franklin and Jackson, Amherst, Ohio 44001

(b) The DeVilbiss Company, P.O. Box 913, 300 Phillips, Toledo, Ohio 43601

(c) Binks Manufacturing Company, 9201 W. Bellmont Ave., Franklin Park, Illinois 60131

(d) Graco Incorporated, 60, 11th Avenue NE, Minneapolis, Minnesota 55413

(3) Greater accessibility will be provided with the use of accessories such as spray gun extension kits and swivel adapters for variable nozzle positioning.

(4) Standard air atomizing equipment (siphone or pressure pot) may be used when access is sufficient to allow application of a wet coat. A spray nozzle-to-surface distance of no more than 12 inches is required for wet application. When spray is operated with a pressure pot, a suitable extension with nozzle may be made.

NOTE: If thinning of the MIL-C-16173, Grade I corrosion inhibitor is required, use solvent BMS 3-2 until spraying is possible.

G. Removal of MIL-C-16173, Grade I Corrosion Inhibiting Compounds

(1) Complete removal of MIL-C-16173, Grade I Corrosion Inhibiting Compounds is required before repainting is attempted. Solvent cleaning is also required before penetrant inspection. The following solvents have been successfully used to remove these compounds:

(a) Naptha

NOTE: Methyl Ethyl Ketone (MEK) or Acetone is not recommended.

(2) When using solvents for the removal of corrosion inhibitors, ventilate the area in the same manner as described for corrosion inhibitor application in par. 7.B.

Ronald J. Hinderberger
Director
Airplane Safety
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BOEING

10 December, 1999
B-H200-16824-ASI

Dr. Bernard S. Loeb
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington D.C. 20594

Subject: Fuel Leaks, TWA 747-100 N93119, Accident off Long Island, NY – 17 July 1996

Reference: Letter B-H200-16798-ASI, Dated 22 Oct 1999

Dear Dr. Loeb:

In the reference letter, item 7, we advised that we would provide more details regarding the fuel leaks reported by two operators during accomplishment of SB 747-28-2205 inspection.

As stated in the meeting, there was little detail provided with the two visual data reports of fuel leaks. These were the only 2 reports of fuel leaks from the over 400 airplane inspections for which we received data.

One operator reported a fuel leak into the Center Wing Tank (CWT) dry bay at the lower right hand side of spanwise beam 3. The airplane involved had approximately 108,000 flight hours.

The second report of a fuel leak occurred on an airplane with approximately 10,000 flight hours. The leak was reported as an APU pump internal leak. The pump and connector were replaced.

Fuel system design includes many details to seal tanks and preclude fuel leaks. Nonetheless, due to structural deflection and expansion, over the life of an airplane, some small leaks may occur. The aircraft is designed to preclude any hazard should leaks occur. Typical safety measures employed in control of flammable fluids include the following:

Leakage prevention using seals, sealant, safety wire and locking devices. Directed flow using dams, barriers, closure ribs and shrouds. Fluid accumulation prevention using leveling compound, drains, and drain valves. Fluid discharge provisions using drain tubes, holes, and masts. Separation and isolation of ignition sources and combustibles. Electrical ignition prevention

BOEING LETTER OF DEC 10, 1999

using explosion proof equipment. Flammable fluid shutoff valves located outside of fire and rotor burst zones with redundant and isolated actuation.

Design measures include secondary fuel barriers between the pressurized cabin and any fuel source. Dry bays are provided above engine hot sections. The dry bay in the above report is the forward bay of the center wing box which is dry for weight and balance considerations. Outside of the pressurized cabin, drain paths overboard and venting are provided to avoid the accumulation of any hazardous leakage. Drainage is designed such that leaks can be identified during preflight walk-around inspection if significant. Examples include engine struts, which contain drainage bulkheads with drain lines exiting an area away from the hot section. Wing spar areas contain drainage control ribs, some of which are vapor barriers in crucial areas. The Aircraft Manuals provide operator information on dispatch disposition and the repair of fuel leaks if they occur.

BOEING

If you have any questions, please do not hesitate to call.

Very truly yours,

Ronald J. Hinderberger

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CC: Mr. B. Berman, AS-10
Mr. A. Dickinson, IIC
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BOEING LETTER OF DEC 10, 1999

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Revised 13 September 1999
10 September 1999
B-H200-16764 -ASI

Mr. R. Swaim, AS-40
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington DC 20594

BOEING

Subject: Aging Materials, TWA 747-100 N93119, Accident off Long Island, NY – 17 July, 1996

Reference: B-B600-16471-ASI, dated 4 Aug 1998

Dear Mr. Swaim:

The reference letter provided information as to the programs in place to examine wiring after the airplane has been in service for prolonged periods. Following information supplements that contained in the reference letter.

The Boeing Materials Specifications for Electrical Wire and Cable contain a requirement entitled "Immersion" which addresses the issue of fluid resistance. The Immersion requirement in the BMS refers to the Immersion Test Method in Section 7.**30** of BSS 7324 which contains all the test methods for electrical wire and cable. Section 7.**30** is on pages **72** and **73** of the BSS 7324

Section 7.30, Table **XVII** lists the test fluids for the Immersion test. They are:

Monsanto Low Density Aviation Hydraulic Test Fluid (BMS 3-11)
Isopropyl Alcohol, TT-I-735
MethylElthylKetone (MEK), TT-M-261
Anti Icing Fluid, MIL-E-9900
Lubricating Oil, MIL-L-23699
Alkaline Detergent, ph 10-10.5
Fuel JP4, MIL-T-5624
Hydraulic Fluid MIL-H-5606

These fluids are selected for their unique effect on insulation materials e.g., BMS 3-1,1 or as being representative a generic type of fluid, e.g., MIL-23699 represents oils in general.

After the wire has been subjected to exposure to each of these fluids

BOEING LETTER OF SEPT 13, 1999

at a specific temperature Table **XVII** for a specific period of time, it is wrapped around a mandrel **(Table XVIII)** and subjected to a 2500 Wet Dielectric Withstand test.

If you have any questions, please do not hesitate to call.

Very truly yours,

BOEING

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CC: Mr. A. Dickinson, IIC

BOEING LETTER OF SEPT 13, 1999

Boeing Commercial Airplane Group
P.O. Box 3707
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BOEING

4 August 1998
B-B600-16471-ASI

Mr. R. Swaim, AS-40
National Transportation Safety Board
490 L'Enfant Plaza East, S.W.
Washington D.C. 20594-2000

Subject: Aging Materials TWA 747-100 N93119 Accident off Long Island, N Y - 17 July 1996

Reference: Your email to D. Rodrigues, dated May 29, 1998

Dear Mr. Swaim:

In your reference message you advised that during inspections of older airplanes as well as some new airplanes, the systems group found such things as anti-corrosion spray, grease, coffee stains etc on aircraft wiring. In the reference message you asked what specific programs are in place to re-examine wiring after the airplane has been in service for prolonged periods. You also asked what periodic re-examinations are in place for compliance of aged materials to original materials standards.

Boeing provides input to the Maintenance Planning Data (MPD) document and the Maintenance Review Board (MRB) document for the 737-300/400/500, 757, 767, 747-400, DC9, DC10, MD80, MD90, and MD11 which gives guidance to the airline on zonal inspection programs. The other Boeing airplanes have wire inspection programs as part of the systems inspection requirements and are found in the particular ATA chapter for that system. These programs inspect the aircraft for visual evidence of wire damage, wire chafing, loose hardware, corrosion, and general condition.

When Boeing acquires wire and cable or wire harness components returned from service for whatever reason, we do testing to evaluate the integrity of the component and to determine if corrective action is required. If we have a report of a specific problem with an installation, we will inspect that installation, and depending on the results of the inspection, remove the item for further examination. We also inspect airplanes that have been in-service for some period of time on an ad hoc basis.

BOEING LETTER OF AUGUST 4, 1998

BOEING

The FAA, Boeing, and some large domestic airlines have been inspecting older aircraft and reviewing aging systems. A preliminary draft of a report on aging systems produced by the FAA is now in Washington for review. The final report was scheduled to be released June 30, 1998. It is our understanding that the report should be available to the public by August 7, 1998. This report is expected to cover wiring inspection and debris on wiring. After this report is released, Boeing will review it for applicability to the wire bundle inspection program.

If you have any questions, please do not hesitate to call.

Very truly yours,

for John W. Purvis

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cc: Mr. A. Dickinson, IIC

BOEING LETTER OF AUGUST 4, 1998

Message Number:

M 7240-95-1131

Action File Name:

M-7240-95-1131

Status:

Closed

Model: 747

ATA: 2800-00

Subject: NOTIFICATION OF RELEASE OF ALERT SERVICE BULLETIN 747-28A2194 /REF SRP 28-0027/

M-7240-95-1131 17 AUG 95
ATA 2800 00 MODEL 747
NOTIFICATION OF RELEASE OF ALERT SERVICE BULLETIN 747-28A2194
/REF SRP 28-0027/
REF /A/ SB 747-28A2194 DTD 3 AUG 95
/B/ SB 747-28-2167 DTD 8 JUL 95

/// CORRECTED COPY ///
PLEASE DESTROY ALL PREVIOUS COPIES OF M-7240-95-1131.

THE FOLLOWING MESSAGE SENT TO ALL BOEING 747 FIELD SERVICE BASES FOR TRANSMITTAL TO AIRLINE PERSONNEL. A COPY IS PROVIDED TO BOEING REGIONAL DIRECTORS, THE AIR TRANSPORT ASSOCIATION, INTERNATIONAL AIR TRANSPORT ASSOCIATION AND AIRLINE RESIDENT REPRESENTATIVES IN EVERETT AND RENTON.

SUMMARY

THIS MESSAGE IS A REVISED VERSION OF MESSAGE NUMBER M 7240-95-1131 DATED 02 AUG 95. THIS RESEND CORRECTS THE TEXT TO STATE THAT REF /A/ INTRODUCES A PERIODIC INSPECTION OF ALL 747/747-400 BOOST PUMPS AND OVERRIDE/JETTISON PUMPS, NOT A ONE TIME INSPECTION.

THIS MESSAGE IS SENT TO NOTIFY ALL 747/747-400 OPERATORS OF THE RELEASE OF THE REF /A/ ALERT SERVICE BULLETIN ADDRESSING FUEL BOOST PUMP AND OVERRIDE/JETTISON PUMP ELECTRICAL CONNECTOR CORROSION/ARCING. REF /A/ WAS RELEASED ON 3 AUG 95.

A FIRE IN THE LEFT WING LANDING GEAR WHEEL WELL AREA OF A 747 AIRCRAFT WITH 67438 HOURS AND 11757 CYCLES OCCURRED ON 29 MAY 95. IT WAS THE RESULT OF ELECTRICAL ARCING AND BURN THROUGH OF THE #2 MAIN TANK INBOARD JETTISON PUMP CONNECTOR. THE PUMP INVOLVED WAS THE ORIGINAL UNIT DELIVERED WITH THE AIRCRAFT AND WAS IN ITS DELIVERED LOCATION ON THE AIRCRAFT. SRP NUMBER 28-0027 WAS GENERATED AS A RESULT OF THE ABOVE EVENTS.

IT WAS FOUND THAT WATER AND CONTAMINANTS HAD MIGRATED BETWEEN THE CONNECTOR SHELL AND POTTING AND HAD COME IN CONTACT WITH ONE OF THE PINS THAT SUPPLIES POWER TO THE PUMP STATOR COILS PROVIDING A PATH TO GROUND VIA THE CONNECTOR SHELL.

HYDRO-AIRE AND BOEING ARE CURRENTLY WORKING TOGETHER TO DETERMINE A PERMANENT RESOLUTION TO CONNECTOR CORROSION PROBLEMS ON HIGH TIME 747 FUEL PUMPS.

REF /A/ INTRODUCES A PERIODIC INSPECTION OF ALL 747/747-400 BOOST PUMPS AND OVERRIDE/JETTISON PUMPS TO VERIFY ACCEPTABLE RESISTANCE BETWEEN CONNECTOR PINS AND GROUND. THE RECOMMENDED INSPECTION INTERVAL IS EVERY C CHECK. PRIOR TO THE START OF PERIODIC INSPECTIONS, AN INITIAL INSPECTION AT THE NEXT OPPORTUNITY WHEN

BOEING S/B 747-28A2194

PREPARED FOR: KhaoulyTE

DATE: 21 Jul 96 07.56pm

MANPOWER AND FACILITIES ARE AVAILABLE IS REQUIRED. LOW RESISTANCE READINGS INDICATE WATER WITHIN THE CONNECTOR AND THE POTENTIAL FOR ARCING. REF /A/ WILL REQUIRE REPLACEMENT OF ALL CONNECTORS THAT DO NOT MEET ACCEPTABLE MINIMUM RESISTANCE REQUIREMENTS.

REF /A/ DOES NOT REPLACE REF /B/. ACCOMPLISHMENT OF BOTH SERVICE BULLETINS IS RECOMMENDED.

BILL STAUFENBERG
747/767 AIRLINE SUPPORT MANAGER
CUSTOMER SERVICES DIVISION
BOEINGAIR M7250 04-ER REC

26 JUL 95 1835

02 AUG 95 1033

BOEING S/B 747-28A2194

WIRE CLEANING

SWPM CLEANING

BOEING (CLEANLINESS) LETTER OF SEPT 13, 99

CLEANING OF ELECTRICAL CONNECTORS

This Subject gives procedures to clean an electrical connector when the connector has too much contamination on the connector interface, but the replacement of the connector is not necessary.

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1. General Data

   A. Recommended Solvents

   In order, the recommended solvents to clean all electrical connectors are:

   - Isopropyl Alcohol
   - Acetone
   - Freon.

   NOTE: When a fast turnaround is necessary, high temperature connectors can be cleaned with the recommended procedure to clean general purpose connectors with acetone. Refer to Paragraph 3.B.

   Before any solvent is used, obey:

   - The local environmental regulations
   - The local necessary conditions for personnel safety.

NOTE: The solvents must only be used for authorized or approved purposes.

B. Conditions of Inspection

After an inspection:

- The connector must be replaced if the steel bayonet pins on the receptacle shell are worn
- The contacts must be replaced if the contacts are worn.

C. Personnel Safety

To make sure that the solvent does not touch the skin, any of these items can be used if they do not permit the solvent to touch the skin:

- Aprons
- Boots
- Coveralls
- Neoprene gloves
- Rubber gloves.

To make sure that the solvent does not touch an eye, any of these items can be used:

- Chemical goggles
- Approved eye protection.

To make sure that the solvent vapors do not get breathed, any of these conditions must occur:

- The area has a good air flow
- Respiratory protection is used.

D. Fire Safety Precautions

Refer to Subject 20-00-10 for the precautions in relation to the electrical power of the circuits.

These conditions are applicable in an area where there are flammable solvents or vapors:

- All flames, smoking, sparks, and other sources of ignition must not occur
- Tools that are used must not make sparks
- Clothing, materials, or processes that can make electrostatic discharges must not be used
- All electrical equipment, such as lights, motors, wiring, etc., must meet the necessary electrical and fire codes
- The accumulation of vapors must be prevented by sufficient ventilation.
- Flammable solvents must be kept in closed containers
- Only the sufficient quantity of a flammable solvent must be used or kept near.

2. Cleaning of General Purpose Connectors With Methyl or Isopropyl Alcohol

WARNING: METHYL ALCOHOL AND ISOPROPYL ALCOHOL ARE FLAMMABLE. MAKE SURE THAT THE QUANTITY ON HAND IS NO MORE THAN IS NECESSARY TO CLEAN THE CONNECTOR.

SWPM CLEANING

A. Necessary Materials and Tools

These are the necessary tools and materials:

- Alcohol, either methyl or isopropyl
- A small, fine brush that is long enough to reach the bottom of the connector and has bristles that are not affected by methyl or isopropyl alcohol
- Swabs that do not have any lint
- An container of the sufficient size to catch any solvent
- Compressed air or nitrogen that is clean and dry.

B. Connector Cleaning with Methyl or Isopropyl Alcohol

(1) Separate the plug and the receptacle.

(2) Clean each connector:

(a) Apply the alcohol with a brush or swab.

(b) Brush the face of the connector until the contaminants have been dissolved.

(c) Flush the face of the connector with the sufficient quantity of alcohol to remove the contamination.

(d) Let the connector dry in the air for one hour.

When it is possible, put the connector in a position so that it is not fully on its side to let the solvent drain.

NOTE: A satisfactory alternative to decrease the time that is necessary for the connector to dry is to use compressed air or nitrogen.

WARNING: COMPRESSED GAS CAN BE DANGEROUS. TO PREVENT AN INJURY, CAREFULLY APPLY THE GAS IN THE DIRECTION AWAY FROM THE EYES, THE FACE, AND OTHER PERSONNEL.

CAUTION: THE CONNECTOR MUST BE FULLY DRY BEFORE THE PLUG IS INSTALLED. ANY REMAINING SOLVENT CAN CAUSE DAMAGE TO THE CONNECTOR OR UNSATISFACTORY PERFORMANCE OF THE SYSTEM, OR BOTH.

(3) Install the connectors again. Refer to the applicable maintenance manual.

NOTE: To make the installation easier, Dow Corning 4 lubricant compound can be applied to the inner O-ring.

(4) Do the necessary functional tests.

3. Cleaning of General Purpose Connectors With Acetone

WARNING: ACETONE IS VERY FLAMMABLE. MAKE SURE THAT THE QUANTITY ON HAND IS NO MORE THAN 0.25 PINT (0.125 LITER) IN A CLOSED, ONE PINT (0.5 LITER) SQUEEZE CONTAINER.

SWPM CLEANING

CLEANING OF ELECTRICAL CONNECTORS

A. Necessary Materials and Tools

- 0.25 pint (0.125 liter) of acetone
- A closed, one pint (0.5 liter) squeeze container
- A small, fine brush that is long enough to reach the bottom of the connector and has bristles that are not affected by acetone
- Swabs that do not have any lint
- An container of the sufficient size to catch any solvent
- Compressed air or nitrogen that is clean and dry.

B. Connector Cleaning with Acetone

(1) Separate the plug and the receptacle.

<u>WARNING</u>: DO NOT SEPARATE THE CONNECTORS UNTIL THE TEMPERATURE IS LESS THAN 150 DEGREES F (65 DEGREES C). DAMAGE TO THE PLUG OR THE RECEPTACLE, OR BOTH CAN OCCUR.

<u>CAUTION</u>: DO NOT SEPARATE THE CONNECTORS UNTIL THE TEMPERATURE IS SUFFICIENTLY COOL ENOUGH, APPROXIMATELY 100 DEGREES F (28 DEGREES C), TO TOUCH WITH BARE HANDS.

(2) Clean each connector:

(a) Put 3 cc to 5 cc of acetone into the connector with the squeeze container.

<u>WARNING</u>: DO NOT PERMIT ANY DROPS OF ACETONE TO FALL ON THE ENGINE.

(b) Brush the face of the connector until all of the contamination has been loosened.

(c) Let any remaining solvent drain from the connector into a container.

(d) Remove the unwanted solvent in the container from the work area.

(e) Flush the connector with no more than 5 cc of the solvent to remove the thin film of contamination from the connector.

Make sure to catch the solvent in the container.

(f) Remove the unwanted solvent in the container from the work area.

(g) If the connector has any remaining contamination, do Step (e) again.

(h) Dry the connector with compressed air or nitrogen.

Make sure the inside of the socket contacts and the inserts around the socket contacts are fully dry.

<u>WARNING</u>: COMPRESSED GAS CAN BE DANGEROUS. TO PREVENT AN INJURY, CAREFULLY APPLY THE GAS IN THE DIRECTION AWAY FROM THE EYES, THE FACE, AND OTHER PERSONNEL.

<u>CAUTION</u>: THE CONNECTOR MUST BE FULLY DRY BEFORE THE PLUG IS INSTALLED. ANY REMAINING SOLVENT CAN CAUSE DAMAGE TO THE CONNECTOR OR UNSATISFACTORY PERFORMANCE OF THE SYSTEM, OR BOTH.

(3) Install the connectors again. Refer to the applicable maintenance manual.

SWPM CLEANING

NOTE: To make the installation easier, Dow Corning 4 lubricant compound can be applied to the inner O-ring.

(4) Do the necessary functional tests.

4. Cleaning of General Purpose Connectors With Freon

A. Necessary Materials and Tools

TABLE I
NECESSARY MATERIALS AND TOOLS

Description	Part Number	Supplier
Freon TF Degreaser, Aerosol Can	MS-180	Miller Stephenson Chemical Company
Freon T-P35 Solvent, Aerosol Can	MS-160	Miller Stephenson Chemical Company
Extension Hose, Nozzle, Solvent Spray Brush	MS-226	Miller Stephenson Chemical Company
Silicone Compound Lubricant	Dow Corning 4 Compound	Dow Corning Corporation

WARNING: FREON T-P35 MS-160 IS NOT TOXIC, BUT IT IS FLAMMABLE. DO NOT USE WHEN FLAMMABLE CONDITIONS OCCUR.

CAUTION: FREON TF MS-180 IS NOT FLAMMABLE AND NOT TOXIC. HOWEVER, MAKE SURE THAT THE VENTILATION IS SUFFICIENT AND THE VAPORS ARE NOT BREATHED FOR A LONG TIME.

B. Connector Cleaning with Freon

(1) Install the MS-226 extension hose and brush on the aerosol spray can.

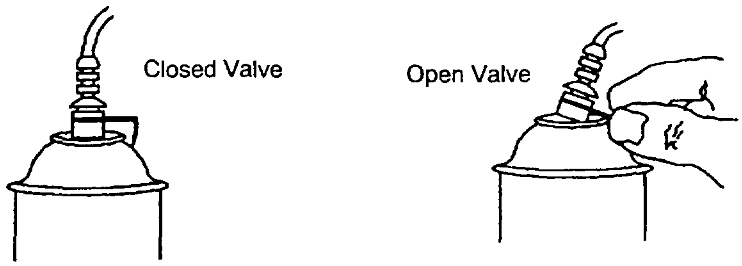
CAUTION: INSTALL THE HOSE AND BRUSH CAREFULLY. IF THE HOSE AND THE BRUSH ARE NOT INSTALLED CORRECTLY, A SPRAY OF SOLVENT CAN GET INTO THE EYES.

(a) Remove the standard valve cap from the aerosol can.

(b) Push the hose assembly tightly into the valve of the aerosol can.

(c) Engage the hook assembly with the edge of the aerosol can to pressurize the cleaning brush.

NOTE: The flow of cleaning fluid is controlled by side pressure that is applied to the brush. Refer to Figure 1.



OPERATION OF MS226 EXTENSION HOSE
Figure 1

(2) Separate the plug and the receptacle.

(3) Clean each connector:

(a) Apply the solvent or degreaser with the brush assembly.

(b) Brush the face of the connector until all of the contamination has been loosened.

(c) Flush the face of the connector with the sufficient quantity of solvent or degreaser to the remaining contamination.

(d) Let the connector dry in the air for one hour.

When it is possible, put the connector in a position so that it is not fully on its side to let the solvent drain.

<u>NOTE</u>: A satisfactory alternative to decrease the time that is necessary for the connector to dry is to use compressed air or nitrogen.

<u>WARNING</u>: COMPRESSED GAS CAN BE DANGEROUS. TO PREVENT AN INJURY, CAREFULLY APPLY THE GAS IN THE DIRECTION AWAY FROM THE EYES, THE FACE, AND OTHER PERSONNEL.

<u>CAUTION</u>: THE CONNECTOR MUST BE FULLY DRY BEFORE THE PLUG IS INSTALLED. ANY REMAINING SOLVENT CAN CAUSE DAMAGE TO THE CONNECTOR OR UNSATISFACTORY PERFORMANCE OF THE SYSTEM, OR BOTH.

(4) Install the connectors again. Refer to the applicable maintenance manual.

<u>NOTE</u>: To make the installation easier, Dow Corning 4 lubricant compound can be applied to the inner O-ring.

(5) Do the necessary functional tests.

5. <u>Cleaning of WALTER KIDDE Fire Detection System Connectors</u>

A. General Conditions for Connector Cleaning

Before any plug and receptacle in the sensing element loop are connected, they must be free from contamination.

SWPM CLEANING

These conditions are applicable for connectors with contamination:

- If it is thought that the connector is contaminated, the connector must be cleaned with acetone or alcohol; refer to Paragraph 5.D. or Paragraph 5.C.
- If any of the connectors in the fire detection system show possible contamination from liquids, the connector must be cleaned with acetone or alcohol; refer to Paragraph 5.D. or Paragraph 5.C.
- Whenever the flex cable connector has been disconnected, the sensing element connectors must be inspected and, if it is necessary, cleaned.

These conditions are applicable for connectors with corrosion:

- If the internal part of a connector shows corrosion or does not have the correct color, the connector must be cleaned with a grit blast; refer to Paragraph 5.E.
- If the connector is connected to the aircraft wiring, it is possible that it is better to replace it with a new connector
- If the connector is part of a sensing element, it possible that it is better to replace the sensing element with a serviceable spare and clean the connector in the maintenance facility.

B. Necessary Materials

CAUTION: ONLY THOSE CLEANERS SPECIFIED IN TABLE Table II CAN BE USED. OTHER SOLVENTS, ESPECIALLY ANY THAT ARE MADE WITH CHLORIDES MUST NOT BE USED.

TABLE II
NECESSARY MATERIALS

Material	Part Number	Supplier
Grease, MIL-S-8660	DC-4	Dow Chemical
Grit Blast Kit	Model AEC-K	Hunter Associates
100 Mesh Aluminum Oxide Grit	AEX 602	Hunter Associates
Acetone	-	Any source
Hooded Socket Contact	802508	Walter Kidde
Methyl Alcohol	-	Any source
Isopropyl Alcohol	-	Any source

NOTE: The grit blast kit has the sufficient quantity of aluminum oxide abrasive to clean approximately ten connectors.

C. Connector Cleaning with Methyl or Isopropyl Alcohol

This procedure is used to clean a connector if there is contamination from oil or other solutions in the connector cavity.

WARNING: METHYL ALCOHOL AND ISOPROPYL ALCOHOL ARE FLAMMABLE. MAKE SURE THAT THE QUANTITY ON HAND IS NO MORE THAN IS NECESSARY TO CLEAN THE CONNECTOR.

(1) Separate the plug and the receptacle.

(2) If it is necessary, remove the hooded socket contact:

(a) Carefully pull the contact out with a small pair of needle nose pliers.

(b) Discard the contact; it cannot be used again.

(3) Clean each connector:

(a) Apply the alcohol with a brush or swab.

(b) Brush the applicable surface of the connector until all of the contamination has been loosened.

(c) Flush the face of the connector with the sufficient quantity of alcohol to remove the contamination.

(d) Let the connector dry in the air for one hour.

When it is possible, put the connector in a position so that it is not fully on its side to let the solvent drain.

NOTE: A satisfactory alternative to decrease the time that is necessary for the connector to dry is to use compressed air or nitrogen.

WARNING: COMPRESSED GAS CAN BE DANGEROUS. TO PREVENT AN INJURY, CAREFULLY APPLY THE GAS IN THE DIRECTION AWAY FROM THE EYES, THE FACE, AND OTHER PERSONNEL.

CAUTION: THE CONNECTOR MUST BE FULLY DRY BEFORE THE PLUG IS INSTALLED. ANY REMAINING SOLVENT CAN CAUSE DAMAGE TO THE CONNECTOR OR UNSATISFACTORY PERFORMANCE OF THE SYSTEM, OR BOTH.

D. Connector Cleaning with Acetone

This procedure is used to clean a connector if there is contamination from oil or other solutions in the connector cavity.

WARNING: ACETONE IS VERY FLAMMABLE. MAKE SURE THAT THE QUANTITY ON HAND IS NO MORE THAN 0.25 PINT (0.125 LITER) IN A CLOSED, ONE PINT (0.5 LITER) SQUEEZE CONTAINER.

(1) Separate the plug and the receptacle.

(2) If it is necessary, remove the hooded socket contact:

(a) Carefully pull the contact out with a small pair of needle nose pliers.

(b) Discard the contact; it cannot be used again.

(3) Clean each connector:

(a) Put 3 cc to 5 cc of acetone into the connector with the squeeze container.

(b) Brush the face of the connector until all of the contamination has been loosened.

(c) Let any remaining solvent drain from the connector into a container.

(d) Remove the unwanted solvent in the container from the work area.

(e) Flush the connector with no more than 5 cc of the solvent to remove the thin film of contamination from the connector.

Make sure to catch the solvent in the container.

(f) Remove the unwanted solvent in the container from the work area.

(g) If the connector has any remaining contamination, do Step (e) again.

(h) Dry the connector with compressed air or nitrogen.

Make sure the inside of the socket contacts and the inserts around the socket contacts are fully dry.

<u>WARNING</u>: COMPRESSED GAS CAN BE DANGEROUS. TO PREVENT AN INJURY, CAREFULLY APPLY THE GAS IN THE DIRECTION AWAY FROM THE EYES, THE FACE, AND OTHER PERSONNEL.

<u>CAUTION</u>: THE CONNECTOR MUST BE FULLY DRY BEFORE THE PLUG IS INSTALLED. ANY REMAINING SOLVENT CAN CAUSE DAMAGE TO THE CONNECTOR OR UNSATISFACTORY PERFORMANCE OF THE SYSTEM, OR BOTH.

E. Connector Cleaning with Grit Blast

A grit blast gun:

- Can be used to clean a connector either on or off the aircraft
- Is used to clean a connector with corrosion or heavy contamination.

<u>WARNING</u>: THE GRIT BLAST GUN MUST BE USED ONLY IN AREAS WITH SUFFICIENT VENTILATION. A RESPIRATOR WITH A DUST FILTER AND EYE PROTECTION MUST BE WORN BY THE OPERATOR SO THAT THE OPERATOR DOES NOT BREATHE THE ALUMINUM OXIDE DUST.

<u>CAUTION</u>: DUST FROM THE GRIT BLAST GUN IS ABRASIVE. OBEY THESE PRECAUTIONS:

- PUT A COVER ON OR REMOVE THE ACTUATOR RODS OR ANY OTHER POLISHED FINISHES
- KEEP THE COVER ON THE OIL TANK SCUPPER IN ORDER TO PREVENT CONTAMINATION OF THE ENGINE OIL SYSTEM.

(1) Separate the plug and the receptacle.

(2) If it is necessary, remove the hooded socket contact:

(a) Carefully pull the contact out with a small pair of needle nose pliers.

(b) Discard the contact; it cannot be used again.

(3) Clean each connector:

SWPM CLEANING

(a) With a fine tool, carefully scrape away as much of the corrosion as possible.

(b) Attach the source of clean, dry compressed air or nitrogen to the grit blast gun.

(c) Set the air pressure of the grit blast gun at 20 psi to 25 psi.

(d) Clean the internal part of the connector with the grit blast.

Make sure to clean the bottom of the connector and around the base of the pin.

(e) Flush the connector with acetone or methyl alcohol.

(f) Dry the connector with compressed air or nitrogen.

WARNING: COMPRESSED GAS CAN BE DANGEROUS. TO PREVENT AN INJURY, CAREFULLY APPLY THE GAS IN THE DIRECTION AWAY FROM THE EYES, THE FACE, AND OTHER PERSONNEL.

CAUTION: THE CONNECTOR MUST BE FULLY DRY BEFORE THE PLUG IS INSTALLED. ANY REMAINING SOLVENT CAN CAUSE DAMAGE TO THE CONNECTOR OR UNSATISFACTORY PERFORMANCE OF THE SYSTEM, OR BOTH.

F. Connector Installation

(1) After the connector is cleaned, install a new hooded socket contact, if it was removed:

(a) Putt the glazed end of the hooded socket contact on a 0.060 maximum diameter pin.

(b) Push the unglazed end onto the connector pin until it touches the bottom.

(2) Install the plug in the receptacle to make the environmental seal.

CAUTION: IT IS ABSOLUTELY NECESSARY THAT THE ENVIRONMENTAL SEAL IS MADE.

(a) Put a very light layer of DC-4 silicone grease on the copper sealing gasket of the plug connector.

CAUTION: MAKE SURE THAT NO GREASE IS APPLIED IN THE CONNECTOR CAVITY OR ON THE CONTACT.

(b) Push the nose of the plug connector into the threaded bushing of the receptacle.

(c) Engage the threads of the nut and the threaded bushing.

(d) Torque the nut approximately 50 inch-pounds to 70 inch-pounds.

NOTE: Use two wrenches to so that the connectors do not turn.

(3) Do the fire detection cockpit test.

SWPM CLEANING

Ronald J. Hind rberger
Director
Airplane Safety
Commercial Airplanes Group

The Boeing Compan
P.O. Box 3707 MC (7-XK
Seattle, WA 98124-2 07

BOEING

13 September 1999
B-H200-16766 -ASI

Mr. R. Swaim, AS-40
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington DC 20594

Subject: Maintenance Manual Inspe tion, TWA 747-100 N9311 , Accident off Long Island, NY – 17 July, 1996

Dear Mr. Swaim:

You inquired as to whether the maintena ce manual wiring inspectio instructions included the removal of lint to assist in the inspection of he w res, and whether the instructions included inspecting for metal or other debris n wire harnesses.

The Standard Wiring Practices documen performs the Maintenance Manual function for standard procedures associated with electrical wire harn ess assembly, installation and repair. The existing document does not a ldress removal of lint from wire or analysis of the lint to determine it's content or or gin. Also, it does not contain procedures that govern inspection for, and remova of, metal or other debris from wire harnesses.

If you have any questions, please do not hesitate to call.

Very truly yours,

for [signature]

Ronald J. Hinderberger
Director, Airplane Safety
Org. B-H200, M/S 67-PR
Telex 32-9430, STA DIR AS
Phone (425) 237-8525
Fax (425) 237-8188

CC: Mr. A. Dickinson, IIC

BOEING (CLEANLINESS) LETTER OF SEPT 13, 99

WIRING DATA

"AGE DETERIORATION" AND CRACKS IN WIRE INSULATION

BOEING LETTER, JULY 18, 1995

DOUGLAS LETTER, JULY 20, 1995

BOEING LETTER, MAY 4, 1998

PO Box 3707
Seattle, WA 98124-2207

July 18, 1995
B-U01B-15311-ASI

Mr. Greg Phillips
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington, D.C. 20594

BOEING

Subject: Inquiry Regarding the Use of Certain Raychem Manufactured Wires on Boeing Commercial Airplanes

Reference: Your letter to John Purvis dated 17 Mar 95, same subject

Dear Mr. Phillips:

In the reference letter you asked Boeing to provide information concerning the use of certain Raychem manufactured wires on Boeing airplanes. The letter describes Mr. Edward B. Block's belief that the insulation materials for "Poly-X, Raychem 55 and Stilan" wires break down in the presence of water, hydraulic fluid and deicing fluid and may result in stray or spurious signals emitted from the insulation cracks. He also reportedly states that this breakdown may cause stray signals to adversely affect aircraft spoilers and autopilots. Finally, he reports that the U.S. Department of Defense ordered the removal and replacement of "Poly-X, Raychem 55 and Stilan" wires installed on Grumman F-14 aircraft because of known deficiencies.

Before we reply to your specific questions, we would like to provide some background information. Before wires can be purchased for use in Boeing commercial airplanes they must be "qualified" to Boeing material specifications. These Boeing material specifications are similar in nature to the Military Specifications (Mil Specs) that govern electrical wires and cables, however, they typically contain additional performance and manufacturing handling requirements. We qualify new wire products to the Boeing material specifications by testing them in our own facilities. The specifications are revised to address in-service problems, should they arise, and to incorporate improvements that become available.

Boeing monitors and corrects in-service problems reported by our customers, the FAA and foreign regulatory agencies, our suppliers, component manufacturers, other airplane manufacturers, etc. If we hear of problems from any of these, or other, sources that we do not already understand, we research the reported problem in our laboratories to determine if it could affect the airplanes we make. Our intent is to study and address any significant problems before changes are required by regulatory authorities.

BOEING LETTER, JULY 18, 1995

The Raychem "Poly-X, Raychem 55 and Stilan" wires have all been "qualified" and have been used with good success in Boeing airplanes. We have not experienced the problems Mr. Block alleges and we do not have safety concerns with these wires.

Your specific requests for information and our replies follow:

BOEING

Q1) 'Any known adverse characteristics related to age deterioration of "Poly-X, Raychem 55, or Stilan" wire used in aircraft manufactured by Boeing. Also provide the details of any known deterioration of these wires that are related to the presence of water, hydraulic fluid, [or] deicing fluid.

A1) We are aware of reports of radial cracks on Poly-X wires in some military airplane applications. However, we have not received reports of unusual or accelerated deterioration of insulation on these wires on Boeing commercial airplanes.

In the early 70's, we experienced high wire-to-wire abrasion in some Poly-X wiring installed in high vibration areas of the 747 airplane. This in-service problem was corrected by changing clamping locations, wire routing and installation procedures. We applied what we had learned from studying this situation to the design and manufacturer procedures used on later airplanes. We do not attribute this higher than expected abrasion to deficiencies in the wires and it did not result in any safety concerns.

The Poly-X wires were replaced by Stilan wires in production as a product improvement. We found in the laboratory that the Stilan wires are susceptible to deterioration with prolonged exposure to certain alcohols. This has not lead to in-service problems because the exposure times necessary to cause deterioration are much greater than that experienced in service.

Q2) 'Any known or suspected failure of "Poly-X, Stilan, and Raychem 55" wire that resulted in an adverse effect to the safety of flight of a Boeing commercial transport category aircraft.'

A2) We are not aware of, nor do we suspect, any failure of Poly-X, Stilan or Raychem 55 wire that resulted in an adverse effect to the safety of flight of a Boeing commercial transport category airplane. (This excludes cases of wire chaffing as the result of improper installation or maintenance practices, or wires damaged as the result of explosion, intense fire, etc.)

Q3) "Any design changes made to Boeing commercial transport category aircraft in response to electrical wire design deficiencies identified by the Department of Defence or other government agency (other than the FAA).

BOEING LETTER, JULY 18, 1995

A3) We are not aware of any requirement or procedure for the DOD to notify us of problems experienced on aircraft not manufactured by Boeing. However, as explained below, there are many sources of information from which we are able to learn of reported wire problems.

For example, in the mid 1980's the resistance to moisture and the arc resistance of wire and cable insulated with Kapton (Polyimide) insulation was the subject of much debate, particularly within the Military. (These wire were not manufactured by Raychem.) We investigated the situation by analysis of the Kapton insulated wire in the fleet and by analysis of many laboratory tests. Although the in-service performance of Kapton insulated wire was extremely good, there was need for improvement. This lead to the development of a new Boeing specification for wire that is now common use. It is not possible to identify the DOD or any other single source of the information which led to Boeing taking this action.

BOEING

Q4) "Any program, policy, or procedure that Boeing has in place to review material defects or discrepancies that may be identified by another aircraft manufacturer."

A4) It is Boeing's policy to monitor problems reported by our customers, the FAA and foreign regulatory agencies, our suppliers, component manufacturers, other airplane manufacturers, and others. There is also frequent interchange of information as the result of our membership in national technical committees and contact with counterparts in other airplane manufacturers. The aircraft wire and cable community is relatively small and it is relatively easy to keep up to date on the problems reported by others.

We should also point out with regard to Mr. Block's reported suggestion that an insulation breakdown may cause stray signals to adversely affect airplane systems, that even if insulation is deteriorated, it does not necessarily follow that a stray signal will adversely affect the safety of the airplane. Airplane system redundancy and wire/wire bundle separation, minimize the possibility of a wire anomaly, from causing a safety problem.

If The Boeing Company can be of further service, please do not hesitate to call.

Very truly yours,

FLIGHT TEST

John W. Purvis
Director, Air Safety Investigation
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BOEING LETTER, JULY 18, 1995

MCDONNELL DOUGLAS

Douglas Aircraft Company

C1-255-LLF-95-422
July 20, 1995

Mr. Gregory J. Phillips
National Resource Specialist-Airworthiness Engineering
National Transportation Safety Board
490 L'Enfant Plaza East, S.W. - Room 5330
Washington, DC 20594

Subject: Raychem Electrical Wire

Reference: NTSB letter dated 17 March 1995 to Steve Lund of Douglas Aircraft Company from Greg Phillips

Dear Mr. Phillips:

Representatives of Douglas Aircraft Company (DAC) and McDonnell Douglas Aerospace (MDA) have reviewed the subject letter and applicable files involving the versions of "Poly-X, Stilan, and Raychem 55A" electrical wiring manufactured by Raychem Corporation and used in DAC commercial transport category aircraft. DAC installed "Poly-X" wire only on early production DC-10 aircraft.

In response to the four questions in your letter, DAC offers the following information:

1. DAC is not aware of adverse characteristics related to "age deterioration" of the versions of "Poly-X, Raychem 55A and Stilan" wire utilized on DAC commercial transport aircraft. In addition, DAC is not aware of any deterioration of these wires related to the presence of water, hydraulic fluid and/or deicing fluid.

   During the first six months of 1978, DAC became aware of instances of "Poly-X" wire insulation wear damage caused by wire chafing in high vibration areas of DC-10 aircraft. Many of the wires were associated with the flight guidance system and some were autoland critical wires. DAC issued DC-10 Alert Service Bulletin A24-99 to inspect and test these wires, DC-10 Service Bulletin 24-99 to replace the "Poly-X" wire with an approved alternate wire (Stilan, Raychem 55A or Kapton) and DC-10 Service Bulletin 24-98 to revise bundle supports and clamping in high vibration areas. In addition, the FAA issued Airworthiness Directive 79-05-01.

DOUGLAS LETTER, JULY 20, 1995

3855 Lakewood Blvd., Long Beach, CA 90846-0001 (310) 593-5511 TELEX 67-4357

During 1976, DAC became aware of a DC-10 wheelwell wire bundle failure involving "Poly-X" wire. The failure occurred on the ground after the wheelwell had been washed. DAC determined that the most probable cause was wire insulation failure due to overstamping of the wire identification in combination with the highly conductive cleaning solution which resulted in subsequent arcing. This particular failure could occur with any electrical wiring and is not peculiar to wire manufactured by the Rachem Corporation. DAC All Operator Letter (AOL) 10-1065 was issued to advise operators of this occurrence.

2. DAC is not aware of any known or suspected failure of "Poly-X, Stilan, or Raychem 55A" which resulted in an adverse effect to the safety of flight of a DAC commercial transport category aircraft.

3. No design changes have been made to any DAC commercial transport category aircraft in response to electrical wire design deficiencies identified by the Department of Defense or other government agency (other than the FAA).

4. With regard to any program, policy or procedure that DAC has in place to review material defects or discrepancies that may be identified by another manufacturer, DAC states that in addition to informal industry-wide channels, DAC participates in the Government Industry Data Exchange Program (GIDEP) and industry associations.

In summary, DAC believes that the versions of "Poly-X, Stilan, and Raychem 55A" wire used by DAC on commercial transport category aircraft are suitable general purpose wires provided that the wiring is properly handled, installed and maintained throughout the service life of the aircraft.

For your convenience, I have enclosed copies of the following documents:

1. DC-10 Service Bulletins A24-99, 24-99 and 24-98; AD 79-05-01; and AOL's 10-1073 and 10-1073A which relate to wire chafing in high vibrations areas.

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2. AOL 10-1065 which relates to the wheelwell wire bundle failure.

3. AOL's 10-1288, 10-1407, 9-1478, 9-1478A, 8-949, 10-1724 and 10-1724A which relate to general purpose wire replacement programs on DAC commercial transport category aircraft.

Please do not hesitate to contact me if you have any questions or desire additional information.

Very truly yours,

Larry L. Fogg

Larry L. Fogg
Senior Principal Specialist
Design Assurance & Safety

LLF:bew
Enclosures - Noted

DOUGLAS LETTER, JULY 20 1995

Boeing Commercial Airplane Group
P.O. Box 3707
Seattle, WA 98124-2207

4 May 1998
B-B600-16400-ASI

Mr. R. Swaim, AS-40
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington DC 20594-2000

BOEING

Subject: Electrical Wire Hot Stamp Marking, TWA 747-100 N93119 Accident off Long Island, NY - 17 July 1996

Reference: Your Email to D. Rodrigues dated 16 March 1998

Dear Mr. Swaim:

The reference message stated that there were some open questions from the group notes taken at Huntsville, Alabama in early 1997. The questions we believe concerned electrical wire hot-stamp marking. Following is the information requested on this subject:

1. **Boeing was asked to research in-service difficulties with hot-stamp marking of the BMS 13-42 wire type.**

We have had no problems or reports of problems with hot-stamp marking of the BMS 13-42 (known as Poly-X) type of wire. We have seen occasional occurrences of radial cracks in Poly-X type wire on in-service airplanes, but there was no indication of any arcing or other damages. Laboratory analysis of these radial cracks associated with Poly-X type wire shows that mechanical stress, moisture, bend radius are contributing to the radial cracking phenomena of the Poly-X wire.

2. **What is the maximum specification depth for the hot-stamp marking?**

Boeing Process Specification No. BAC 5152, "Identification of Electric Wire and Wire Bundles", provides the detailed information on wire marking. The specification does not provide the maximum depth for the hot-stamp marking. However, the following parameters are controlled in order to preclude any damage to the wire; pressure, dwell time, foils type, typeface requirements, temperature for the hot-stamp machine etc. We believe that if all of these parameters on the hot-stamp machine are maintained properly, there will be

BOEING LETTER, MAY 4, 1998

proper hot-stamp marking on the wire and the wire will be able to withstand the RMS potential of 1500 to 4000 volts at 60 HZ.

If you have any questions, please do not hesitate to call.

Very truly yours,

BOEING

for

John W. Purvis
Director, Air Safety Investigation
Org. B-B600, M/S 67-PR
Telex 32-9430, STA DIR PURVIS
Phone (425) 237-8525
Fax (425) 237-8188

cc: Mr. A. Dickinson, IIC

BOEING LETTER, MAY 4, 1998

ALKANE-IMIDE WIRE INSULATION

RAYCHEM, DEC 69

A NEW EXTRUDED ALKANE-IMIDE WIRE

V. L. Lanza

R. M. Halperin

RAYCHEM CORPORATION
MENLO PARK, CALIFORNIA

A TECHNICAL PAPER FOR PRESENTATION AT THE 18TH INTERNATIONAL WIRE AND CABLE SYMPOSIUM, ATLANTIC CITY, NEW JERSEY, DECEMBER 3, 4, & 5, 1969

A NEW EXTRUDED ALKANE-IMIDE WIRE

V. L. Lanza

R. M. Halperin

RAYCHEM CORPORATION
MENLO PARK, CALIFORNIA

RAYCHEM, DEC 69

A NEW EXTRUDED ALKANE-IMIDE WIRE

The need for smaller, lighter and tougher wire insulation materials has continued to accelerate over the past few years. With the rapid development of microcircuitry, space in many electrical and particularly electronic devices has been placed at a premium. As both military and commercial aircraft grow in size and complexity, increasing amounts of wire are used in their instrumentation, navigation, communication and computer systems. Several years ago, in recognizing the need for new wire constructions, we developed a dual layer insulation system of crosslinked polyalkene/polyvinylidene fluoride. This wire received ready acceptance and was supplied to various users under both military and commercial specifications. Military Specification MIL-W-81044 describing this wire was issued in 1964. Specification sheets 1 through 15 have covered such wires. Within the past few years the need for materials with improved properties has become evident. Research on a number of new materials has been under way in many industrial laboratories for some time. Several different approaches to manufacturing improved insulation systems have been developed. This paper will describe the approach used by Raychem and characterize the resulting product.

APPROACH

Wires initially manufactured to MIL-W-81044 had several advantages over previous insulation systems. From a functional point of view they were lighter in weight, smaller and generally more durable than their predecessors. Made entirely of melt extrudable materials, MIL-W-81044 wire could be processed, using conventional extrusion techniques, at speeds in excess of 1,000 feet per minute. In designing a new insulation system, one of the major criteria was to maintain the good properties of a continuous insulation provided by melt extrusion. In addition, it was deemed necessary to improve some of the properties of the earlier products. The principal one was associated with the maintenance of mechanical durability of the wire at its rated temperature. In addition, some of the newer aircraft hydraulic fluids attacked the MIL-W-81044 wires at elevated temperatures. Thus, improvement in mechanical strength and fluid resistance at elevated temperatures became principal design objectives.

POLYMER DEVELOPMENT

Our research and development laboratories began an extensive screening program in a search for existing base polymers which could serve as the foundation for a new wire insulation system. Polymers examined included ionomers, polycarbonate, polyphenylene oxide, polysulfone and a range of polyimides. None of these by itself satisfactorily met all of the criteria described earlier. The imide polymers did, however, show great promise and it was decided to concentrate the most effort in this area. Polyimides were first made at the du Pont laboratories presumably in the early 1940's for in 1945 the first patent

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was issued describing these polymers. Apparently little work was done on them in the next decade. The imide polymer, whose chemical formulation is illustrated below (Fig. 1), is very tough, has excellent mechanical properties throughout a wide range of temperatures, but is difficult to process.

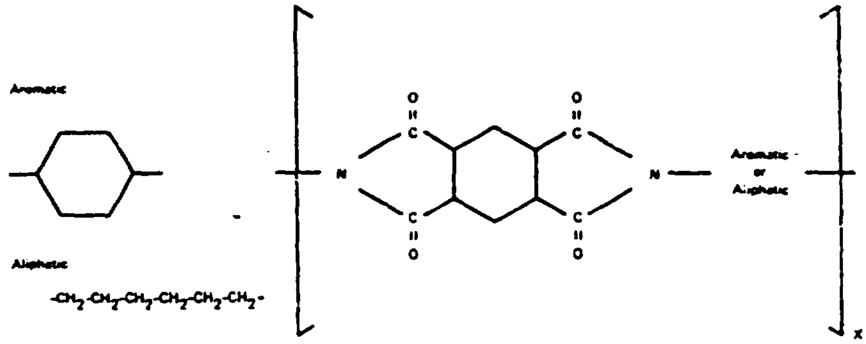

FIGURE 1.

The linking of the anhydride moiety through imidization could be accomplished using either aromatic or aliphatic diamines. The resulting polymer formed from a total aromatic system has certain advantages over the polymers formed with the aliphatic moiety. The aromatic polymer is non-burning and oxidatively more stable. Development work at du Pont apparently then focused in the late 1950's on the aromatic polymers. However, aromatic polymers are difficult to process.

When we commenced work we decided to re-examine the entire polyimide field. We reconfirmed the fact that the manufacture of a melt processable aromatic polyimide was not currently technically feasible. We therefore concentrated on the creation of a new class of aliphatic polyimides which would overcome some of the disadvantages of such materials which had been discarded as uninteresting several years ago. After a major research effort a new alkane-imide polymer was produced which was extremely tough at room temperature, had high strength at elevated temperatures, was radiation crosslinkable and could be processed at very high speeds on conventional wire handling equipment. To manufacture the polymer, however, a specially designed plant was constructed. A portion of it is pictured in Figure 2. The alkane-imide polymer which was developed was designed to have all of the superior properties of the older MIL-W-81044 wire and, in addition, to have improved high temperature mechanical strength and chemical resistance.

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FIGURE 2.

The general physical and electrical properties of this polymer are listed below (Fig. 3).

PHYSICAL AND ELECTRICAL PROPERTIES OF ALKANE-IMIDE POLYMER

Property	Method of Test	Typical Value
Tensile Strength	FED-STD-228, Method 3031 (2"/min)	10,000 psi
Elongation	FED-STD-228, Method 3021 (2"/min)	300 %
Young's Modulus	Vibron Dynamic Mechanical Modulus (3.5 cps)	25C 180,000 psi 100C 120,000 psi 150C 50,000 psi 200C 30,000 psi
Density	ASTM D 1505	1.21g/cc
Melting Point	Infra-red, DSC, X-ray Diffraction	286C
Dielectric Constant	ASTM D 150	2.77 (50 Hz to 100 KHz)
Dissipation Factor	ASTM D 150	0.0007 - 0.0008 (50 Hz to 100 KHz)

FIGURE 3

It can readily be seen that the alkane-imide polymer has great strength over a wide temperature range and has excellent electrical properties. This suggests that thinner insulations than have heretofore been commonly used may be technically feasible.

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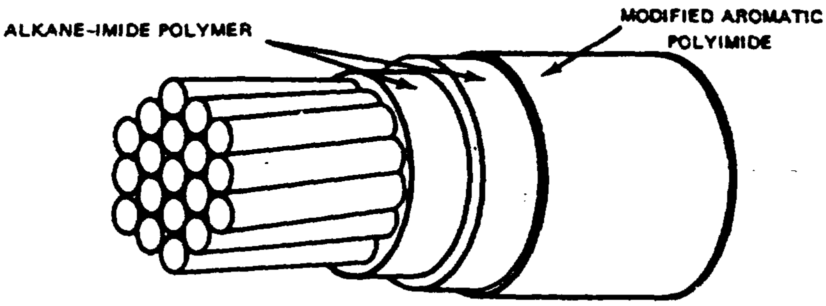
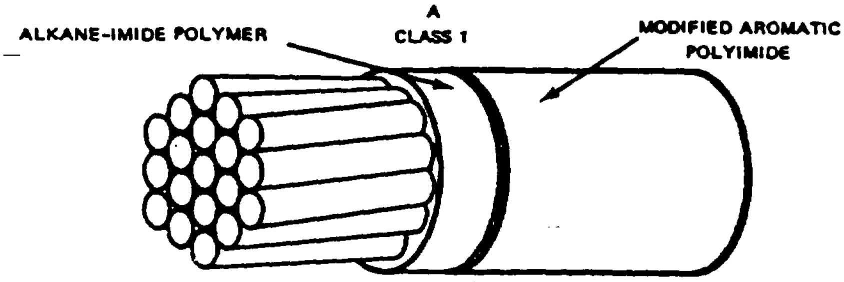
WIRE DESIGN

In designing a wire to take advantage of the alkane-imide polymer, the sandwich insulation concept embodied in the earlier MIL-W-81044 wires was followed. The concept was to have a multilayer construction fabricated in a fashion which would reduce the notch sensitivity of the wire and at the same time provide a mechanism for utilizing some of the outstanding properties of the aromatic polyimides. As the result of much experimentation, two basic wire constructions were developed. They are illustrated below (Fig. 4).



A
CLASS 1



B
CLASS 2

FIGURE 4.

In both, an alkane-imide polymer layer is extruded next to the conductor. In case A, a second layer is extruded over the first. The outermost covering consists of several very thin layers of a modified aromatic polyimide which serve as the base for a compatible polyimide coat which carries the color. Being constructed of two or more basic layers, each wire provides an insulation system with natural barriers against notch propagation. All parts of the total insulation system are polyimides, thus avoiding some of the problems associated with earlier mixed polyimide/non-polyimide insulation systems wherein the insulating materials had vastly different physical properties.

The rugged mechanical properties of the base alkane-imide polymer permit the use of thinner insulation. Thus it is possible to achieve substantial space and weight savings. At the same time, most of the basic handling properties are improved over previous wires.

The insulation system described herein is processed at temperatures which permit tin, silver or nickel plated copper conductor to be used. Other polyimide insulations necessitate the use of only silver or nickel plated copper conductor.

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WIRE PROPERTIES

The finished wire product can best be described by comparing its properties with some of the more common wires as well as other new wires.

Two sets of comparisons will be made utilizing 20 AWG wires. The first compares the three layer 10-mil wall construction with other 10-, 15- and 20-mil wall wires which are designed to be used in unprotected harnesses. The second compares a two layer 6-mil wall construction to wires of 6- to 13-mil walls designed for use in protected harnesses and the interior of black boxes. The data presented below will cover the physical-mechanical, chemical, and electrical properties of the wires.

The wires compared are as follows:

CLASS 1

MIL-W-5086/1

A tin coated copper conductor insulated with 14 mils of polyvinyl chloride and 3 mils of nylon, rated at 105 C.

MIL-W-81044/6

A tin coated copper conductor insulated with 15 mils of crosslinked polyalkene and 5 mils of crosslinked polyvinylidene fluoride, rated at 150 C.

MIL-W-81044/9

A tin coated copper conductor insulated with 10 mils of crosslinked polyalkene and 5 mils of crosslinked polyvinylidene fluoride, rated at 150 C.

Aklane-Imide - 88A0811

A tin coated copper conductor insulated with 8 mils of crosslinked alkane-imide polymer and 2 mils of a modified polyimide, rated at 150 C.

Kapton* - 029/616

A silver or nickel coated copper conductor insulated with 2 contrahelically applied tapes. The first tape consists of 2 mils of polyimide coated on one surface with 1/2 mil of fluorinated ethylene propylene polymer while the second tape is a 1-mil thick polyimide film coated on both surfaces with 1/10 mil of fluorinated ethylene propylene polymer. Over these tapes, which are fused together with a nominal 50% overlap, a 1-mil thick color coat of dispersion of fluorinated ethylene propylene polymers is applied. The wire is rated at 200 C.

TFE/H

A silver or nickel coated copper conductor insulated with 7 mils of polytetrafluoroethylene over which is placed 2 mils of a polyimide. This wire is rated at 200 or 260 C, depending upon the coating on the copper conductor.

*du Pont trademark

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CLASS 2

MIL-W-16878/BN

A tin coated copper conductor insulated with 10 mils of polyvinyl chloride and 3 mils of nylon, normally rated at 105 C.

MIL-W-81044/12

A tin coated copper conductor insulated with 4 1/2 mils of crosslinked polyalkene and 3 mils of crosslinked polyvinylidene fluoride, rated at 150 C.

Alkane-Imide - 88A0111

A tin coated copper conductor insulated with 4 mils of crosslinked alkane-imide polymer and 2 mils of a modified polyimide rated at 150 C.

Kapton - 019/616

A silver or nickel coated copper conductor insulated with 2 contrahelically applied tapes. The first tape consists of 1 mil of polyimide coated on one surface with 1/2 mil of fluorinated ethylene propylene polymer while the second tape is a 1-mil thick polyimide film coated on both surfaces with 1/10 mil of fluorinated ethylene propylene polymer. Over these layers, which are fused together with a nominal 50% overlap, a nominal 1-mil thick color coat of a dispersion of fluorinated ethylene propylene polymer is applied. This wire is rated at 200 C.

The dimensions and weight of the wires tested are given in Fig. 5.

WEIGHT AND DIMENSIONS – ALL WIRES AWG 20

	MIL-W-5086/1	MIL-W-81044/6	MIL-W-81044/9	Alkane-Imide 88A0811	Kapton 029/616	TFE/H
Wall Thickness, inches, nom.	.020	.020	.015	.010	.009	.010
OD, inches, nom.	.078	.078	.070	.059	.056	.059
Cross section area, circ. mils	6084	6084	4900	3481	3136	3481
Weight, nom. lbs/M'	6.0	5.8	5.3	4.6	4.7	5.1

	MIL-W-16878/ 8N	MIL-W-81044/12	Alkane-Imide 88A0111	Kapton 019/616
Wall Thickness, inches, nom.	.013	.0075	.006	.007
OD, inches, nom.	.064	.055	.051	.053
Cross section area, circ. mils	4096	3025	2601	2809
Weight, nom. lbs/M'	4.8	4.4	4.2	4.4

FIGURE 5

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The space and weight advantages of the alkane-imide 88 type wire compared to the older wires is readily apparent. The Kapton 029/616 and Kapton 019/616 and TFE/H share in some of these advantages.

MECHANICAL HANDLING

There is no single test of mechanical handling which can fully describe a wire. Rather, a combination of tests, both of a static and dynamic nature are generally used. The tests should seek to duplicate not only the problems associated with installing a piece of wire, but also the type of service it will see after it is applied. Five such tests have been run on these wires. They are:

1) Tape abrasion
2) Scrape abrasion
3) Dynamic cut-through – room temperature and elevated temperature
4) Static cut-through
5) Notch sensitivity

The tape abrasion test conforming to MIL-T-5438 (Fig. 6) measures the number of inches of an abrading tape required to wear through the insulation to the conductor. The results of this test are primarily dependent upon the thickness of the insulation and secondarily on the toughness of the insulation. The test is designed to simulate the abrading of a wire insulation during installation and possible subsequent vibration-abrasion in service. The results of abrasion testing are shown in Figs. 7 and 8.

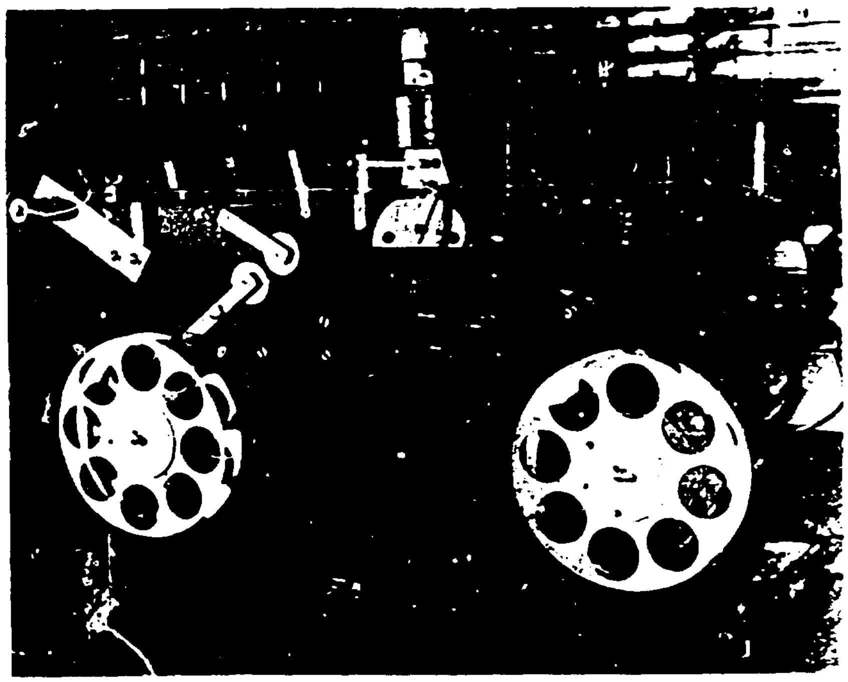

FIGURE 6. TAPE ABRASION TESTER

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TAPE ABRASION RESISTANCE OF VARIOUS CLASS I WIRES

	MIL-W-5086/1	MIL-W-81044/6	MIL-W-81044/9	Alkane-Imide 88A0811	Kapton 029/616	TFE/H
Wall Thickness, mils	20	20	15	10	9	10
Tape Abrasion Inches of tape 400/grit-1 lb.	102	69	82	43	21	32

FIGURE 7.

TAPE ABRASION RESISTANCE OF VARIOUS CLASS 2 WIRES

	MIL-W-16878/BN	MIL-W-81044/12	Alkane-Imide 88A0111	Kapton 019/616
Wall Thickness, mils	13	7.5	6	7
Tape Abrasion Inches of tape 400/grit-1/4 lb.	117	38	31	27

FIGURE 8.

The data generated clearly demonstrate that the results are primarily dependent upon the thickness of the insulation and only secondarily on the toughness of the insulation.

The scrape abrasion test measures the ability of the wire insulation to resist the repeated action of a rubbing sharp edge under load. This could simulate the action of a bundle of wires going through a hole of some type or around a sharp corner and possibly be subjected to vibration or repeated minor flexing. The test used is the General Electric type Repeated Scrape Abrasion machine in which a 5-mil edge is moved back and forth longitudinally across the wire insulation. The tester and its operation are illustrated in Figs. 9 and 10. Results of the scrape abrasion testing are summarized in Figs. 11 and 12.

FIGURE 9.

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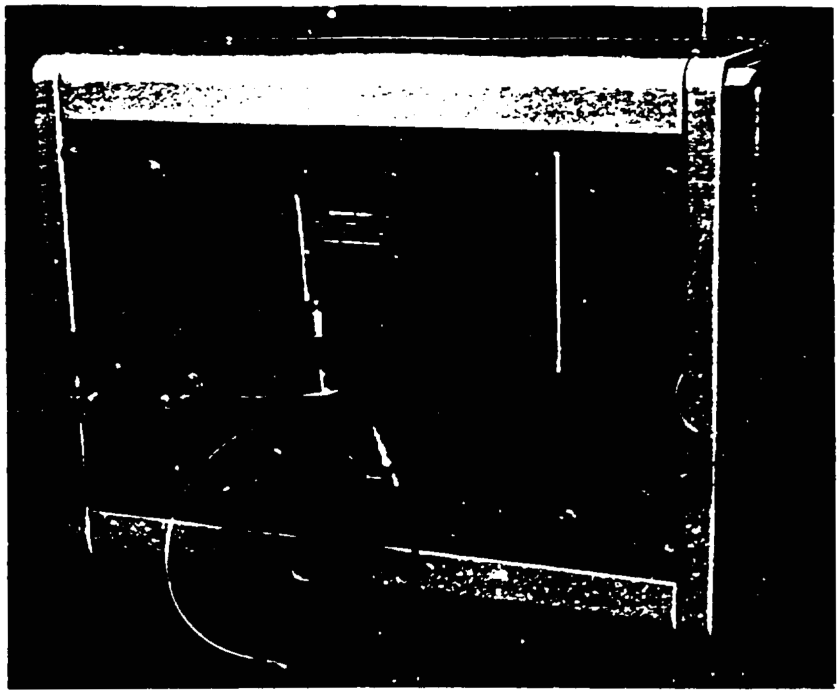

FIGURE 10.

SCRAPE ABRASION TESTING OF VARIOUS CLASS I WIRES

	MIL-W-5086/I	MIL-W-81044/6	MIL-W-81044/9	Alkane-Imide 88A0811	Kapton 029/616	TFE/H
Cycles to scrape through at 25 C (2.5 lb load)	70	195	75	98	37	15

FIGURE 11

SCRAPE ABRASION TESTING OF VARIOUS CLASS 2 WIRES

	MIL-W-16878/8N	MIL-W-81044/12	Alkane-Imide 88A0111	Kapton 019/616
Cycles to scrape through at 25 C (1 lb. load)	352	107	250	1[illegible]1

FIGURE 12

In analyzing the results of the scrape abrasion testing of the Class 1 wires, it is clear that the MIL-W-81044/6 wire with its 20-mil wall has the best scrape abrasion resistance. However, the 10-mil wall alkane-imide 88 type wire has significantly better scrape abrasion resistance than any of the other wires tested and is far superior to the other newer thinner

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wall wires. The Class 2 wires tested also show very similar results. The MIL-W-16878/BN wire which has a 13-mil wall is the best. The alkane-imide 88 type wire with a 6-mil wall is again superior to the other wires tested. The reason for the high scrape abrasion resistance of the alkane-imide 88 type wire is due to its toughness (high modulus) and the fact that it is a continuous melt extruded, completely compatible polyimide system.

The static and dynamic cut-through tests measure the ability of a wire insulation to resist the penetration of a sharp edge. In the dynamic test a 5-mil edge is forced into the wire insulation at a rate of .2 inch per minute over a wide range of temperatures. The force required to penetrate the insulation is then measured. In the static cut-through test, the insulated wire is placed between a flat surface and a 5-mil edge loaded with a weight. The maximum weight which can be supported for a given period of time without insulation cut-through is both a measure of the strength of the insulation at temperature and the resistance of the insulated wire to long term cold flow. The test simulates a condition where a wire is in direct contact with a sharp object such as a sharp corner, etc., with some force on it for some time. The test equipment for dynamic cut-through is shown in Figs. 13 and 14. The results of the dynamic cut-through tests are depicted in Figs. 15 and 16. The test equipment for static cut-through is shown in Fig. 17. The results for the static cut-through test are in Figs. 18 and 19.

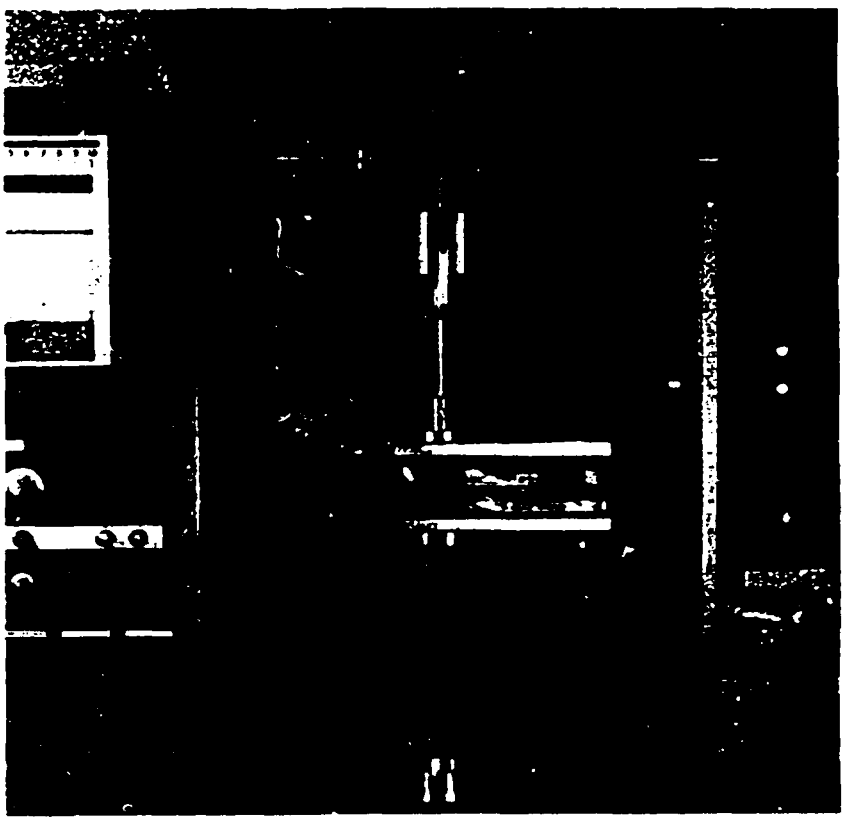

FIGURE 13.

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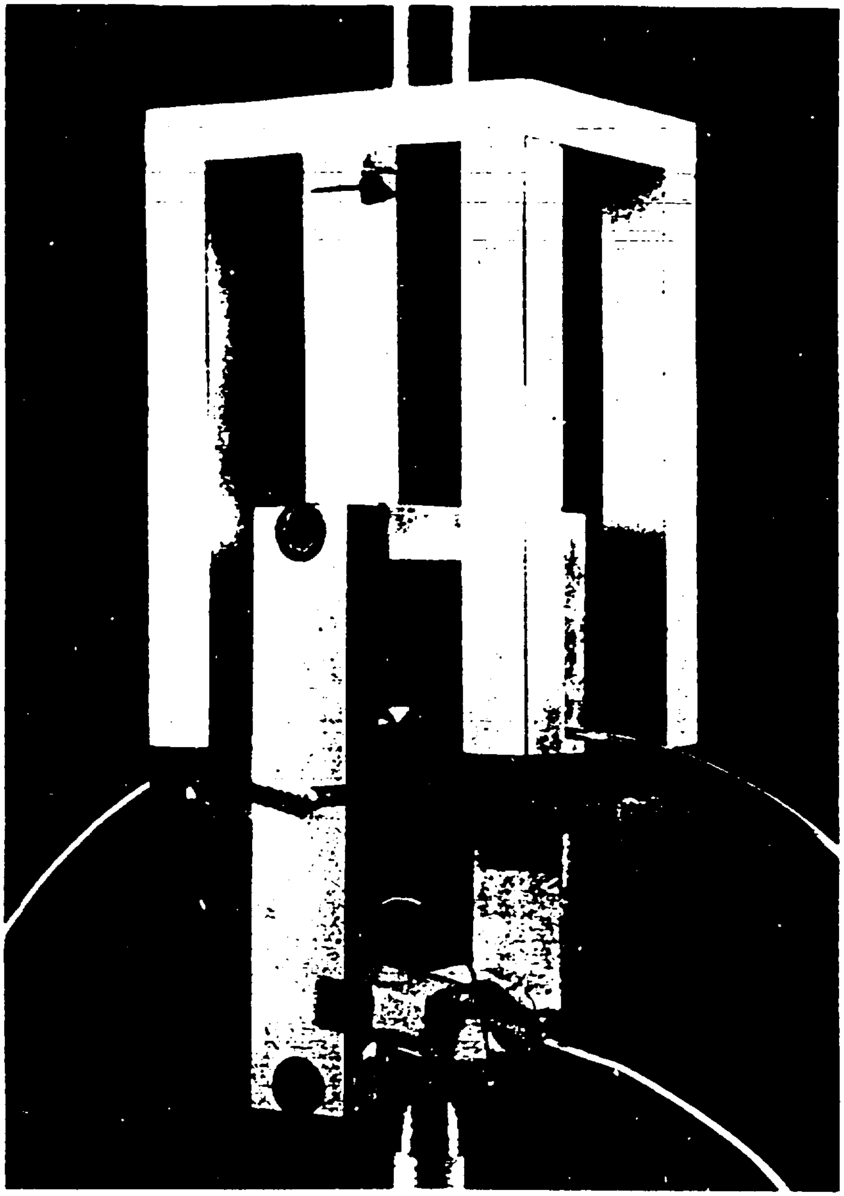

FIGURE 14.

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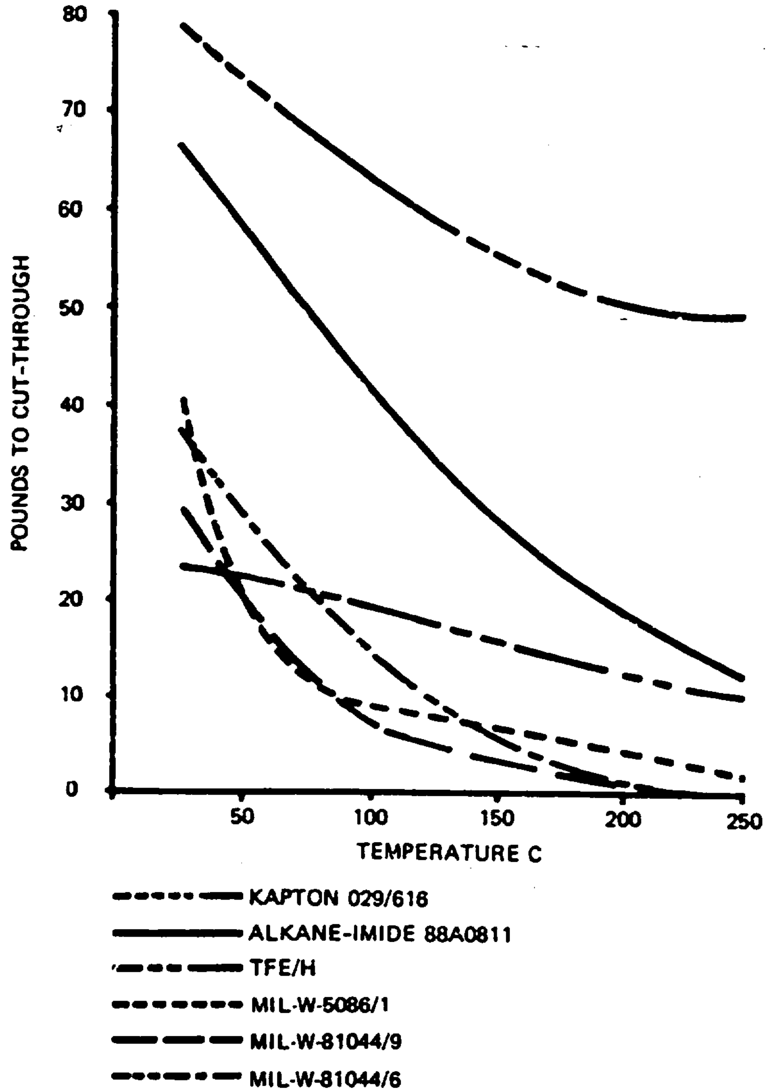

FIGURE 15. DYNAMIC CUT-THROUGH CLASS 1 WIRES

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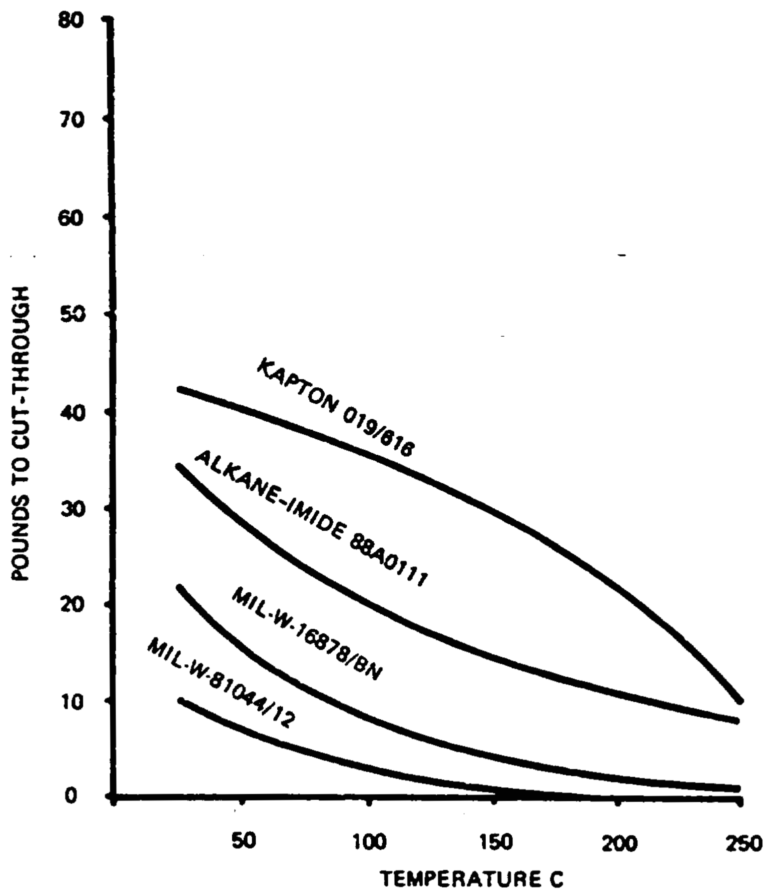

FIGURE 16. DYNAMIC CUT-THROUGH CLASS 2 WIRES

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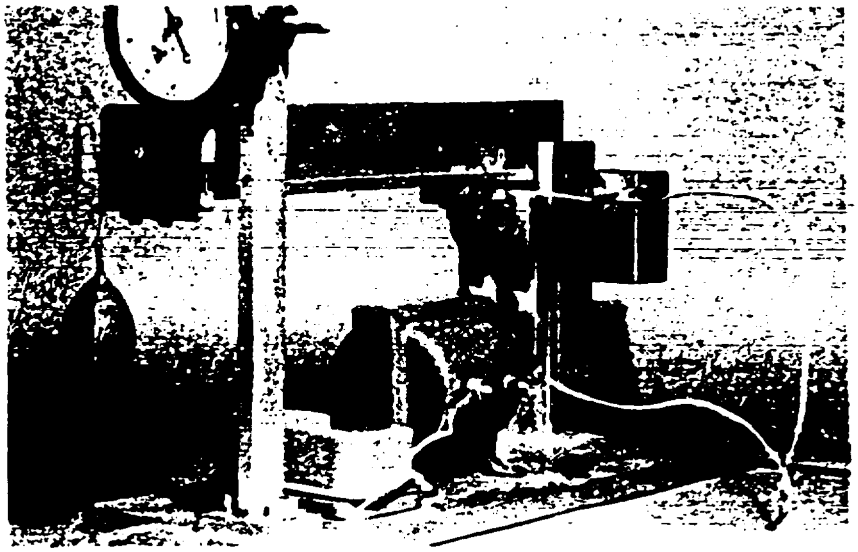

FIGURE 17.

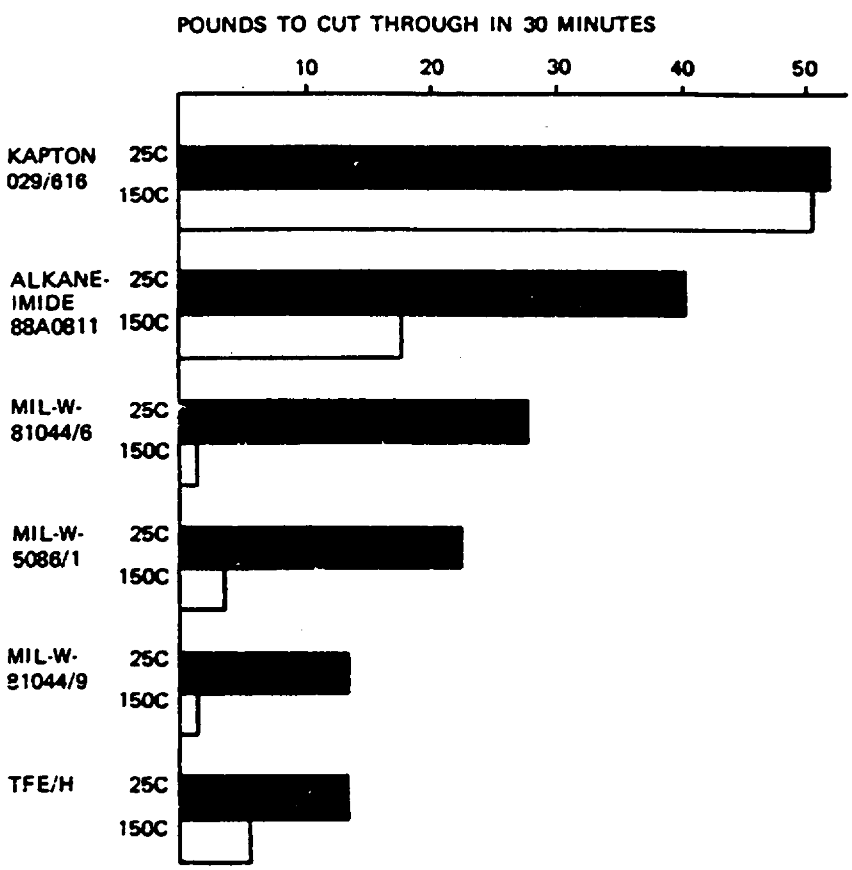

FIGURE 18. STATIC CUT-THROUGH OF CLASS 1 WIRES

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POUNDS TO CUT-THROUGH IN 30 MINUTES

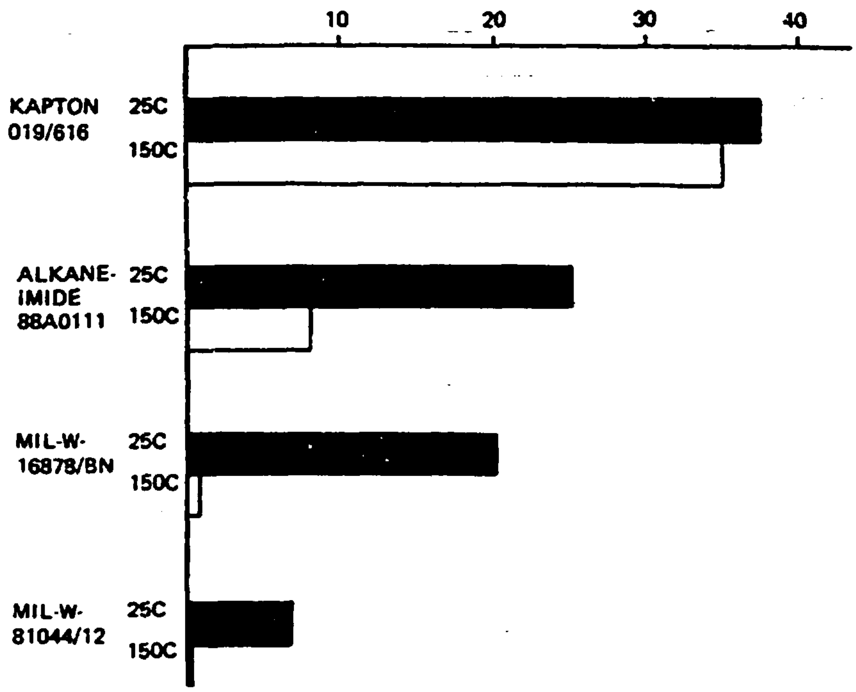

FIGURE 19. STATIC CUT-THROUGH OF CLASS 2 WIRES

In the dynamic cut-through test the very high modulus Kapton wires have the highest cut-through values. The alkane-imide 88 type wires have very significantly higher cut-through values than any of the other wires tested. Indeed, even at temperatures well in excess of its rated temperature, the alkane-imide 88 type wire has cut-through values higher than the values obtained for all other non-imide wires at their rated temperatures.

In the static cut-through test, only the Kapton and alkane-imide 88 type wires exhibited a significant amount of static cut-through resistance at 150 C. The Kapton wire showed little change in cut-through from room temperature to 150 C. Although the alkane-imide 88 type wire fell off some at its rated temperature, it was superior to all the other wires when tested at room temperature and far superior to all the other wires when tested at 150 C.

The notch sensitivity test measures the ability of a wire to resist having a notch penetrate through to the conductor. In this test, a 3 to 7-mil notch is made in the wire which is subsequently bent and subjected to a dielectric withstand test (Fig. 20). This test simulates

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the situation where a wire is knicked during assembly or installation and subsequently bent. The results of a series of tests are shown in Figs. 21 and 22.

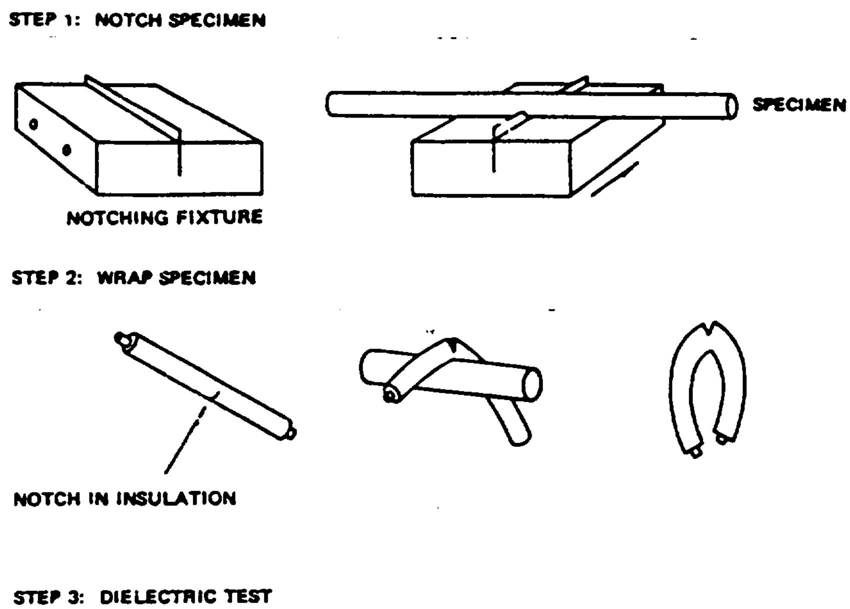

FIGURE 20. NOTCH SENSITIVITY TEST

NOTCH SENSITIVITY OF VARIOUS CLASS I WIRES

	MIL-W-5086/I	MIL-W-81044/6	MIL-W-81044/9	Alkane-Imide 88A0811	Kapton 029/616	TFE/H
Penetration depth (inches)	.004	.004	.004	.004	.004	.004
Voltage Withstand 3 KV/1 min.	Pass	Pass	Pass	Pass	Pass	Pass
Penetration depth (inches)	.0C8	.006	.006	.006	.006	.006
Voltage Withstand 3 KV/1 min.	Pass	Pass	Pass	Pass	1/4 Pass	1/4 Pass
Penetration depth (inches)	.007	.007	.007	.007	.007	.007
Voltage Withstand 3 KV/1 min.	Pass	1/4 Pass	1/4 Pass	All Fail	All Fail	All Fail

FIGURE 21

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NOTCH SENSITIVITY OF VARIOUS CLASS 2 WIRES

	MIL-W-16878/ 8N	MIL-W-81044/12	Alkane-Imide 88A0111	Kapton 019/616
Penetration depth (inches)	.003	.003	.003	.003
Voltage Withstand 3 KV/1 min.	Pass	Pass	Pass	Pass
Penetration depth (inches)	.004	.004	.004	.004
Voltage Withstand 3 KV/1 min.	Pass	Pass	All Fail	All Fail

FIGURE 22

The test data clearly demonstrate that the multilayer constructions serve effectively to stop notch propagation. It should, however, be reiterated that the tougher materials are more prone to notch propagation. As illustrated below (Fig. 23), there are either 1 or 2 layer interfaces which serve to stop a notch from further penetration.

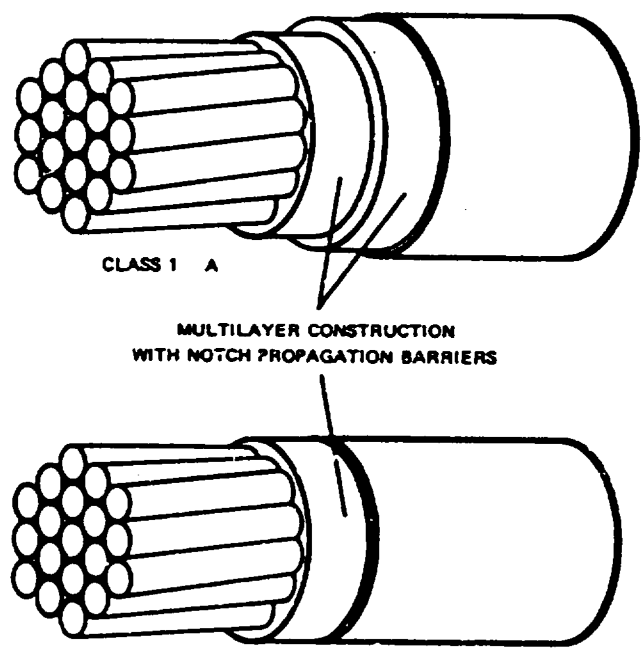

FIGURE 23.

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SHOP HANDLING

Three important properties in shop handling are stripping, hot stamp marking and soldering.

A series of tests were run on a number of representative wires to measure the force required to strip 1/2 inch slugs of insulation from the wire. The results are shown in Fig. 24.

STRIPPABILITY OF VARIOUS WIRES

	MIL-W-5086/1	MIL-W-81044/6	MIL-W-81044/9	Alkane-Imide 88A0811	Kapton 029/616	TFE/H
Force to remove 1/2 inch insulation from wire (lbs)	3.0	6.5	7.3	3.2	4.7	2.0

FIGURE 24

It can be seen that the alkane-imide wire is readily strippable and appears to be superior to some of the other wires tested.

The new 88 type wire described in this paper offers advantages over other new thin wall wires because of the ease with which it can be permanently hot stamped at high speeds.

Typical foils are: Kingsley: K-486 and K-46
M. W. Swift & Sons: C-20114 and C-20118
Howmet Corp., Rolleaf Division: 8034

Details of application are listed below (Fig. 25).

TYPICAL CONDITIONS FOR HOT STAMPING

Type of Machine	Type Face Temp. °F	Pressure	Dwell	Type Material
Kingsley	500 (600 dial reading)	Minimum consistent with legible marks	≈ 27 ms	Engraved steel or brass
Conrac	500		≈ 27 ms	As supplied
TAB	500		≈ 27 ms	As supplied
Trojamatic	500		80% speed	As supplied

FIGURE 25

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A typical marked wire is shown in Figure 26.

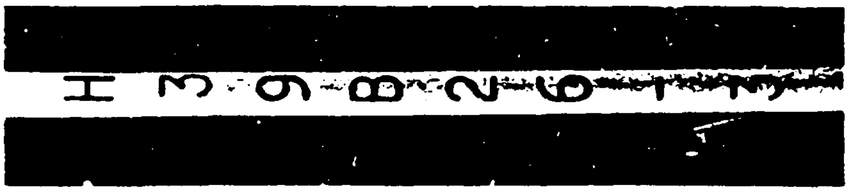

FIGURE 26.

Users of 88 type wire report that they are able to process 35,000 feet of wire per shift through automatic cutting, stripping and marking equipment.

As with all the wires tested, 88 type wire can readily be soldered using normal soldering techniques. It also resists the impact of a hot soldering iron. To test this, 20 AWG alkane-imide 88A0811 wire was subjected to the test described below and shown in Fig. 27. A 6-inch length of wire was stripped at both ends, formed into a loop, conductors twisted together, and a 1-lb. weight attached to the ends. The wire was then draped over a solder iron tip whose temperature was maintained at approximately 350 C. A detection circuit between the conductor and solder iron tip measured the time required to burn or melt through the insulation. The test was stopped if the insulation did not burn or melt through in 5 minutes. The 88 type wire tested readily passed this test.

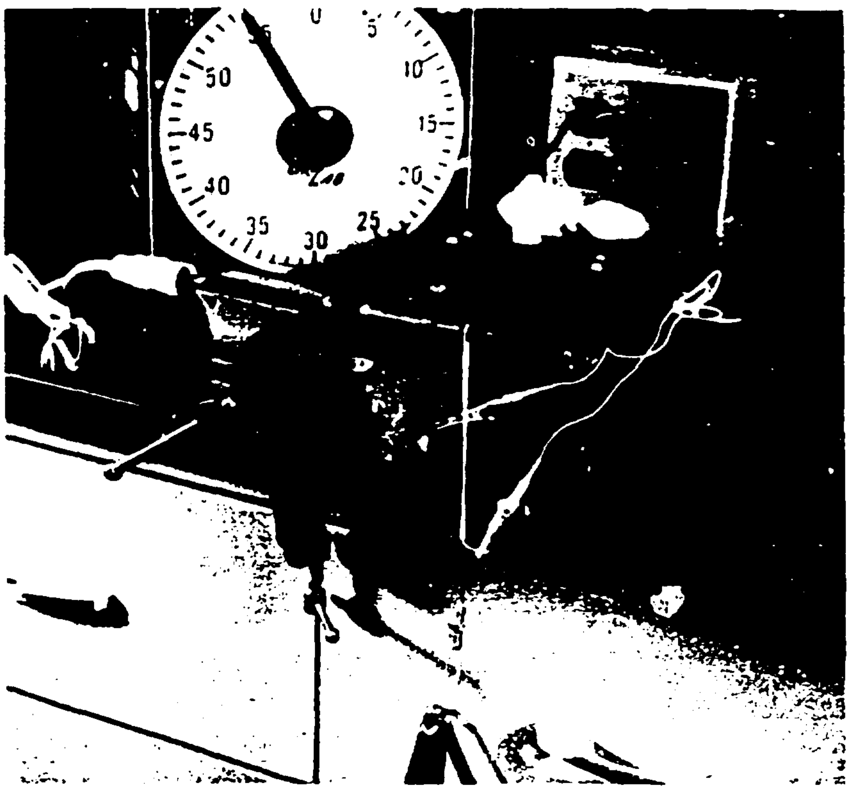

FIGURE 27.

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CHEMICAL

Wires previously manufactured to MIL-W-81044 have generally resisted the action of most common solvents and fluids when immersed at 49 C, the standard temperature for such testing. However, when such wires were immersed in some fluids at the rated temperature of the wires (135 or 150 C) their resistance to swelling and attack was considerably reduced although dielectric integrity was maintained. Therefore, one of the design criteria in the new alkane-imide insulated wire was to create a resistance to solvent and fluid attack at all temperatures up to the rated temperature of the wire even though such temperatures are above the safe operating limit of the fluid. The alkane-imide insulated wire will resist all common solvents and fluids at its rated temperature. This includes the common aircraft hydraulic fluids: Skydrol 500, Oronite M2V and Aerosafe 2300. It should be noted, however, that as expected with any imide polymer construction, certain of the rocket fuels have a deleterious effect on the insulation. Results for several different wires tested in Skydrol 500, Oronite M2V and Aerosafe 2300 are summarized below (Fig. 28).

FLUID IMMERSION
150 C/4 HOURS

	Skydrol 500A (Monsanto)		Oronite Hyjet (Chevron)		Aerosafe 2300 (Stauffer)	
	Visual	Voltage Withstand 2.5 KV/5 min.	Visual	Voltage Withstand 2.5 KV/5 min.	Visual	Voltage Withstand 2.5 KV/5 min.
MIL-W-81044/6	Badly swollen PVF_2	Pass	Badly swollen PVF_2	Pass	Badly swollen PVF_2	Pass
MIL-W-81044/9	Badly swollen PVF_2	Pass	Badly swollen PVF_2	Pass	Badly swollen PVF_2	Pass
Alkane-Imide 88A0811	No effect	Pass	No effect	Pass	No effect	Pass
Kapton 029/616	No effect	Pass	No effect	Pass	No effect	Pass
TFE/H	No effect	Pass	No effect	Pass	No effect	Pass
MIL-W-5086/1	No effect	Pass	No effect	Pass	No effect	Pass

FIGURE 28

The flammability properties of the alkane-imide insulated wire have been improved over previous MIL-W-81044 constructions. Three elements in any assessment of these properties are: a) the vigorousness of burning including the propagation of flame along the wire, b) some measure of the quantity and physiological effects of the smoke generated, and, c) the nature of the combustion products. The standard flammability test described in MIL-W-81044 and MIL-W-81381 involves placing the wire at a 60° angle to the horizontal and subjecting it to a vigorous flame for 30 seconds. The length of insulation consumed and the time of burning of the insulation after removal of the flame is then measured. Typical results for a variety of wires are listed in Fig. 29.

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60° FLAMMABILITY TESTS ON A SERIES OF 20 AWG WIRES		
	Length of Burn (inches)	Time After Burn (seconds)
MIL-W-5086/1	1 sample 2.3 2 samples completely consumed	1 sample 0 2 samples completely consumed
MIL-W-81044/6	1.8	0
MIL-W-81044/9	1.8	0
Alkane-Imide 88A0811	1.3	0
Kapton 029/U16	1.25	0
TFE/H	1.25	0

FIGURE 29

As can be seen all wires are considerably better than MIL-W-5086 in this test. A second type of test which is different from the first is a vertical test in which the wire is burned in a small draft-free enclosure.

The apparatus used in this test is illustrated below (Fig. 30).

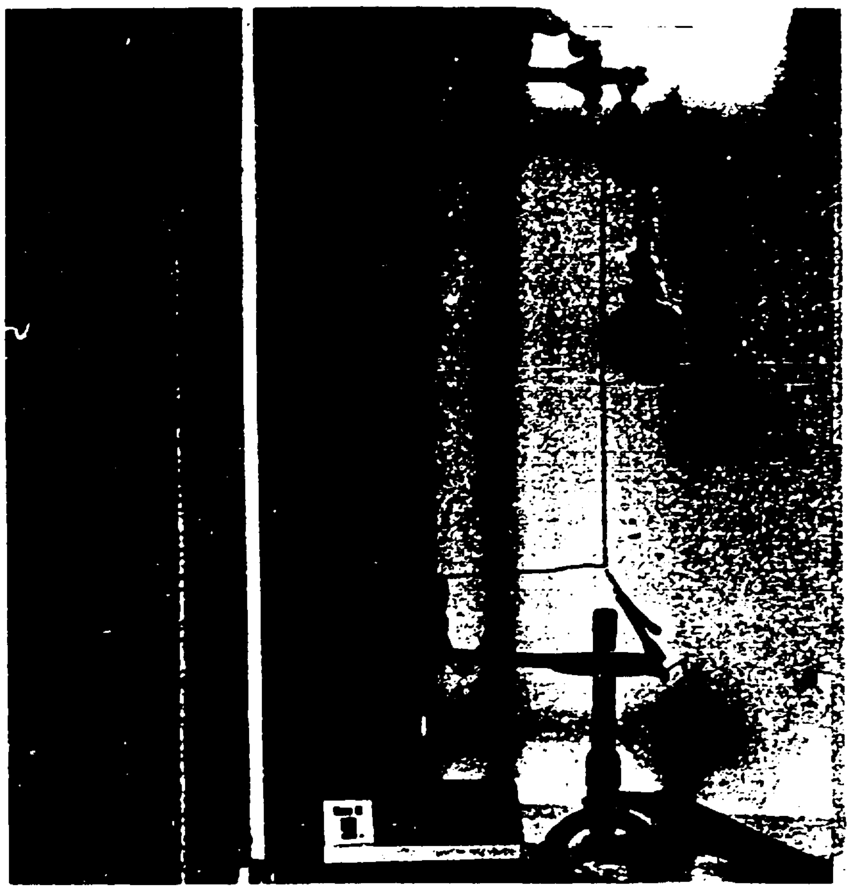

FIGURE 30.

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In this test, a soft yellow flame is applied to the stripped end of the wire for 12 seconds. The length of time for flame extinction, and distance burned are measured. It is also possible to get some measure of the relative quantities of smoke generated and an indication of how irritable this smoke is when inhaled. The last two measures are, of course, subjective, but nevertheless give some idea of relative ranking as shown in the following table (Fig. 31).

VERTICAL FLAME TESTS ON A SERIES OF WIRES

	Length of Burn (inches)	Time after Burn (seconds)	Ranking of * Amount of Smoke	Ranking of * Irritability
MIL-W-5086/1	Completely consumed	Completely consumed	10	10
MIL-W-81044/6	3.7	1.1	7	5
MIL-W-81044/9	3.5	1.0	7	5
Alkane-Imide 88A0811	3.2	1.0	2	1
Kapton 029/616	2.7	0	1	7
TFE/H	2.7	0	1	8

* 1 low 10 high

FIGURE 31

As can be seen all of the constructions are vastly superior to the MIL-W-5086 wire. The after-burn of Kapton 029/616 and TFE/H wires is zero indicating outstanding performance. However, they appear to generate a very small amount of highly irritable smoke. The alkane-imide type 88 wire burns more vigorously than either of the above wires. The small amount of smoke generated appears to be innocuous. The chemical nature of the insulation yields upon burning hydrocarbon gaseous species. These are known to be relatively non-toxic.

ELECTRICAL

All the wires tested in this study have adequate electrical properties. Listed below in Fig. 32 are some typical electrical properties for the alkane-imide 88 type wire.

SOME TYPICAL ELECTRICAL PROPERTIES FOR ALKANE-IMIDE 88 TYPE WIRE (88A0811-20 AWG)

Insulation Resistance	20,000 megohms/1000 ft.
Dielectric Voltage Withstand	2.5 KV/5 mins. - pass
Dielectric Strength	20 KV
Surface Resistance	5 x 10^5 megohm-inches
Humidity Resistance	18,000 megohms/1000 ft.

FIGURE 32

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HEAT RESISTANCE

The alkane-imide wire is rated for continuous operation at 150 C. As has been shown earlier, the wire has great strength at this temperature, actually equalling the strength of some other wires at room temperature. The wire is routinely tested for accelerated aging by heat aging for 7 hours at 250 C with weights over a mandrel. Life cycle testing is done with the same weights and mandrels for 168 hours at 200 C. Previous long-time aging tests run on MIL-W-81044, 150 C wire have shown that the wire will last at least 12,000 hours at sea level where the partial pressure of oxygen is the highest. Aging data accumulated for 88 type wire clearly demonstrates that it will age better than MIL-W-18044 wire, thus indicating that the alkane-imide 88 type wire has a very conservative rating of 150 C. Some of the long term aging data collected in our laboratories is shown in Fig. 33. Work is in progress which may result in permitting the wire to be used for even longer periods of time at elevated temperatures and long term aging tests are continuing.

OXIDATIVE STABILITY OF ALKANE-IMIDE AND MIL-W-81044 150 C WIRES

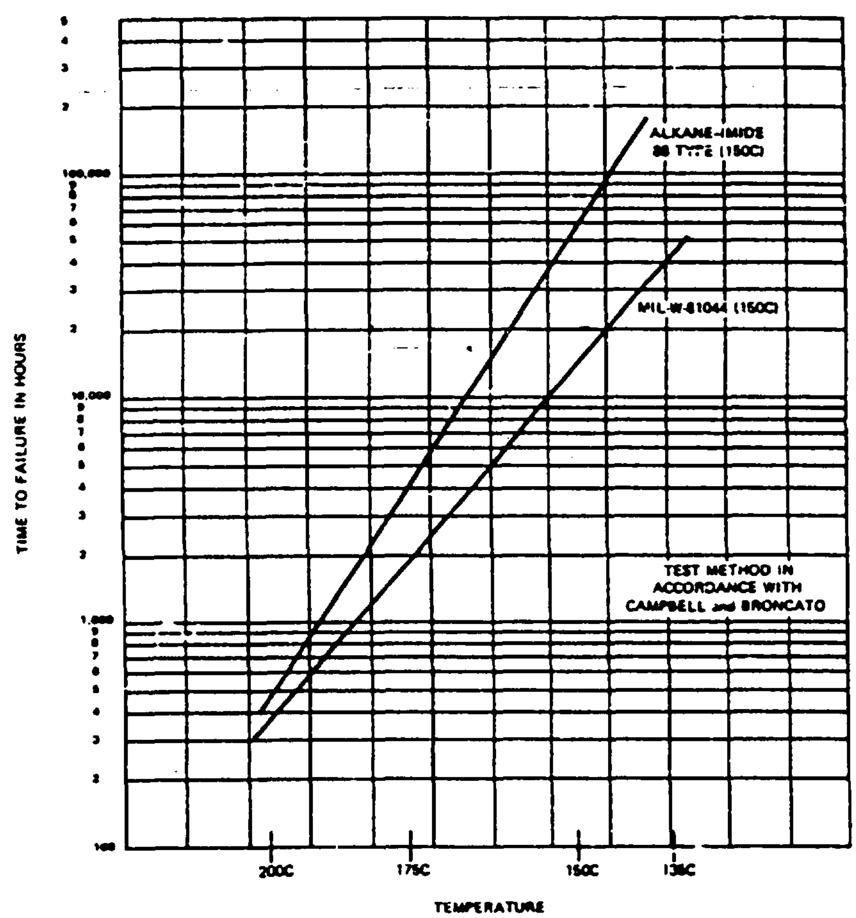

FIGURE 33.

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In addition to the properties described on the previous page a wire must possess certain others if it is to be a completely functional wire. The alkane-imide wire has very excellent low temperature properties and is routinely tested at -65 C. At 200 C, a temperature well in excess of its rated temperature (150 C), the wire exhibits less than .08 inch shrinkage in a 1-ft. sample when subjected to a 6-hour test. The wire does not smoke when heated to 250 C. When subjected to repeated temperature cycling between 150 C and -65 C, the wire exhibits virtually no shrinkage thus demonstrating its dimensional stability over a wide temperature range. Preliminary tests have indicated that a special alkane-imide 88 type wire should be uniquely suited for use in outer space.

SUMMARY

A new sandwich construction insulation system consisting completely of polyimides has been developed to meet the need for smaller and lighter weight wires. This has required the synthesis of a new alkane-imide polymer. This polymer, in combination with other polyimides, has yielded a wire construction which has an overall combination of useful properties not found in other wires. In addition to its excellent physical-mechanical, electrical and handling characteristics, it can be fabricated on conventional wire processing equipment. The rapidly increasing technological and functional needs in the electronic and aerospace industry has prompted us to continue our substantial research efforts to seek out new insulating materials.

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NAVY WIRE INSULATION REPORTS

NAVY LETTER OF DEC 16, 1999

NAFI-TR-2145

NAFI-TR-2199

NAFI-TR-2201

NAFI-TR-2210

NAVY MEMO OF 9/20/85

DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
NAVAL AIR SYSTEMS COMMAND HEADQUARTERS
47123 BUSE ROAD, UNIT #______
PATUXENT RIVER, MARYLAND 20670-1547

IN REPLY REFER TO

5000
PAO
16 Dec 99

Robert L. Swaim
Systems Group Chairman, TWA 800 Investigation
National Transportation Safety Board
490 L'Enfant Plaza, E, SW
Washington, DC 20594

Mr. Swaim,

Your request to place four NAFI reports concerning testing and aging properties of different types of wire that were released in the 1970s in the public docket as background for your investigation is approved.

You may place the reports listed below, and their appendices, in the public docket as background for your investigation, provided you redact names of suppliers in the appropriate places as previously discussed:

Naval Avionics Facility (now the Wiring Qualification Group of Raytheon Systems Company) reports titled "Fluid Resistance Testing Of Electrical Wire Used in Aircraft And Missiles" comprised of:

NAFI-TR-2145
NAFI-TR-2199
NAFI-TR-2201
NAFI-TR-2210

Your point of contact in this matter is John Milliman who may be reached at the address above, by phone at (301) 757-6638 or by email at millimanjc@navair.navy.mil Please feel free to contact him if you need any further assistance.

Thank you,

Lola Hilton

Lola R. Hilton
Director of Corporate Communications

NAVY LETTER OF DEC 16, 1999

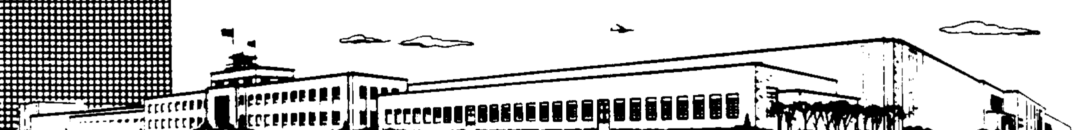
TR 2145
11 AUGUST 1976

NAFI publication

FLUID RESISTANCE TESTING OF ELECTRICAL WIRE USED IN AIRCRAFT AND MISSILES

DISTRIBUTION LIMITED TO U.S. GOVERNMENT AGENCIES ONLY: TEST AND EVALUATION. OTHER REQUESTS MUST BE REFERRED TO NAVAL AVIONICS FACILITY, INDIANAPOLIS, INDIANA 46218

DISTRIBUTION UNLIMITED WITH APPENDIX C REMOVED



NAVAL AVIONICS FACILITY

INDIANAPOLIS, INDIANA 46218

PREFACE

This report describes an investigation into the ability of the insulation on aircraft electrical wire to withstand immersion in various cleaners, paint removers, etc., which are used on aircraft surfaces. Seventeen wire samples specified by three military specifications were tested by immersion in thirteen solvents or fluids specified by seven military or federal specifications.

This work was performed for NAVAIR under Work Request No. N001976WR68881 BCN AKA11 Appn. 1761506.45BF.

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ABSTRACT

Electrical wiring in Navy aircraft often is subjected to inadvertent exposure to solvents and chemicals used to clean the aircraft surfaces in the course of maintenance operations. Wire types purchased to MIL-W-22759, MIL-W-81044 and MIL-W-81381 are used in aircraft wiring. These specifications are under NAVAIR cognizance. Each has solvent resistance requirements employing liquids such as jet fuel, hydraulic fluid, etc., which are used by the aircraft. The testing reported herein employs thirteen cleaners or solvents which are purchased to military or federal specifications and used on aircraft surfaces. The insulation on seventeen electrical wire samples purchased to the above wire specifications was evaluated after immersion in the cleaners or solvents.

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I. CONCLUSIONS

1. Only M22759/18-20-9 wire passed all testing in all test fluids. This wire is a light weight, tin-coated copper wire (AWG 20) insulated with extruded ethylene-tetrafluoroethylene polymer (ETFE).

2. Wire types,

M22759/18-20-9	ETFE Fluoropolymer-Insulated
M81381/7-20-2	Fluorocarbon/Polyimide Insulated
M81381/7-20-N	Fluorocarbon/Polyimide Insulated
M81381/7-20-9	Fluorocarbon/Polyimide Insulated
M81381/11-20-N	Fluorocarbon/Polyimide Insulated
M81381/11-20-9	Fluorocarbon/Polyimide Insulated

pass the dielectric withstand test after four week immersion in,

MIL-C-43616 (pH ≤ 9.8)*	cleaning solution
MIL-C-25769	cleaning solution
MIL-R-81294	paint remover
MIL-C-5541/MIL-C-81706	chromate conversion coating chemicals
MIL-L-23699	lubricating oil, synthetic base

3. Only two test fluids induced failures in MIL-W-81044 and MIL-W-81381 wire. They were:

TT-R-248

MIL-C-43166 (with pH ≥ 13.3)

4. All wires met the requirements for "life cycle" tests of their corresponding purchase specification.

5. MIL-W-81381 wires with white cosmetic coating perform better than the natural or red color modified imide coated wires in fluid resistance, however, they are the poorest in potting pull-out strength.

6. If potting is employed with either white coated MIL-W-81381 wire or MIL-W-22759 ETFE wire, the surface should be treated for better potting adherence.

* NOTE: Two of the five MIL-C-43616 fluids used for testing had pH values of 13.3 and 13.4 in concentrated form, see Conclusion 3.

7. Surface treatments applied to some wires to increase potting adherence had little effect on fluid resistance.

8. The most significant information obtained on failing wires was obtained in the first week of testing.

II. RECOMMENDATIONS

The following recommendations should be considered for implementation as soon as practicable.

1. Review aircraft maintenance instructions for adequacy in warning the user of cleaning fluids of the danger to aircraft electrical wiring inherent in high pH cleaning fluids and in paint and lacquer removers.

2. Request the custodian of MIL-C-43616 to revise the specification so that both the concentrated and 1:4 dilutions be tested for pH. Reduce the pH requirement from 12 to 11 maximum, the requirement to apply to both the concentrated and 1:4 dilution.

3. Request the qualifying activity for MIL-C-43616 to perform the pH testing on concentrated and 1:4 dilutions for product review information.

4. Instruct the aircraft manufacturers and Navy repair and overhaul facilities that no MIL-W-81044/16 through /19 wire be used as new or replacement wire in Navy aircraft.

5. Inspect on a regular basis all Navy aircraft currently in service that were wired with MIL-W-81044/16 through /19 wire for insulation damage.

6. Request the custodian of MIL-W-22759, MIL-W-81044 and MIL-W-81381 to change the solvent resistance test procedure so that additional solvents are added and test time is extended to one week. Serious consideration should also be given to changing the specimen maximum loop diameter during immersion.

7. Request the custodian of MIL-W-5088 to add a new requirement in Appendix A which establishes "overbraided harness" as a separate item and adds the requirement, "Open harness or overbraided harness containing MIL-W-81381 wire shall not be used in wheel well, stores pylons or SWAMP* areas.

III. INTRODUCTION

The Naval Air Rework Facility, North Island (NARF-NORIS) recently reported on an investigation of the fluid resistance of aircraft electrical wire[1]. Their findings showed that some of the commonly used aircraft wire insulations were deficient in their resistance to certain fluids. In addition to chemicals such as alkalies, acids, alcohols, aromatic and aliphatic hydrocarbons, esters, ketones, and chlorinated hydrocarbons, the fluids evaluated included a tetra ester lubricating oil, a synthetic hydrocarbon hydraulic fluid and a MIL-R-81294 paint remover.

Of the wires tested only Teflon® TFE and Tefzel® ETFE types specified by MIL-W-22759 were not degraded by immersion in any of the test fluids for periods up to and including 8 days. Wire types found in both MIL-W-81044 and MIL-W-81381 with the modified imide topcoat were adversely affected by one or more of the fluids. In general the fluorocarbon/polyimide insulation of MIL-W-81381/1 and /11 and the crosslinked alkane-imide type of MIL-W-81044/16 and /18 did not perform well in high pH solutions and in the paint remover. On the other hand the polyarylene insulation of MIL-W-81044/20 and /25 wire, while resistant to alkaline solutions, did not perform well in acidic ones. This insulation was also degraded by the paint remover.

* Severe Wind And Moisture Problems

[1] Fluid Immersion Testing of Aircraft Electrical Wire, Report No. 03-76 NARF-NORIS, dated 13 Feb 1976

Many of the fluids employed by NARF-NORIS were formulated in their chemistry laboratory and some lacked proprietary ingredients which are added by manufacturers of cleaning solvents and paint removers. It was felt that the 8 day maximum immersion time used by NARF-NORIS was probably too short.

Since Navy aircraft surfaces are frequently cleaned using a variety of chemicals and solvents, those chemicals and solvents should be used in wire immersion tests. The actual chemical or solvent content of many of the solutions are not controlled by the specification. It is possible, therefore, to purchase a cleaner on a QPL list from two different manufacturers and have two different products both of which meet the requirements of the specification in all respects including cleaning ability.

This "dual product" situation also exists in wire purchased to MIL-W-81381/7 or 11. Some manufacturers supply white color wire (-9), others natural color (-N). The outermost coating on the wires differ in chemical composition and the insulation is not affected in same manner by particular solvents.

As a result of these finding NAFI was funded by NAVAIR to perform fluid immersion tests for periods to one month in actual cleaning fluids obtained directly from manufacturers listed on the QPL of the specifications. The wires chosen for test were also QPL items with several colors (either, red, white or natural) of the outermost insulation layer.

Three of the wire samples obtained had a proprietary surface treatment to enhance the adherence of potting compounds. These wires were tested to see if the treated wire performed differently in fluid immersion than the same untreated types.

IV. MATERIALS

The fluids chosen for this investigation are as follows:

1. MIL-C-43616, "Cleaning Compound, Aircraft Surface". This cleaning compound used by the Navy is water rinsable and required to be 90% biodegradable. The flash point is 142^{o}F (min) and the pH of a 1:4 water dilution must fall between 8.0 and 12.0. The specification does not limit the composition of the cleaner; however it does list a comparison formula by which to compare the cleaning efficacy. Five fluids were obtained from four manufacturers.

2. TT-R-248, "Remover, Paint and Lacquer, Solvent Type". This is a non-flammable, water rinsable solvent type paint and lacquer remover. It must not contain phenol, cresol, creosote oil, cresylic acid, benzene, carbon tetrachloride, perchloroethylene, trichloroethylene, or dichlorethylene. It may contain other chlorinated hydrocarbons if shown to have no deleterious effect on the aircraft. There is no requirement for pH. The specification does not contain a comparison formula. Fluids were obtained from two manufacturers. Both contained methylene chloride.

3. MIL-R-81294, "Remover, Paint and Epoxy System". This is a paint remover containing organic solvents, evaporation retardants and other ingredients. It contains no comparison formula and has no requirement for pH. Fluids were obtained from two manufacturers.

4. MIL-C-25769, "Cleaning Compound, Aircraft Surface, Alkaline Waterbase". This cleaning compound used by the Air Force must not contain sugar and shall be 90% biodegradable. The pH must not exceed 12.0 in a 1:4 dilution and it is required to contain 5 ± 0.1% (by weight) ethylene glycol n-mono butyl ether. There is a comparison formula. Fluids were obtained from two manufacturers.

5. MIL-C-5541, "Chemical Conversion Coatings on Aluminum and Aluminum Alloys" and MIL-C-81706, "Chemical Conversion Materials for Coating Aluminum and Aluminum Alloys". These chemical compositions are

proprietary. They are used on a continuing basis in the production plating department at NAFI. The products involved are:

a. Ridoline # 53 (pH = 10.0)

b. Deoxidizer #17 (pH = 0.4)

c. Alodine 1200S (pH = 1.9)

6. MIL-L-23699, "Lubricating Oil, Aircraft Turbine Engine, Synthetic Base". This is a synthetic diester base oil.

The wires chosen for this investigation are as follows:

1. MIL-W-22759/18-20-9. This is an extruded ETFE fluorocarbon insulation on silver coated 19 strand copper conductor (AWG 20) and is white (-9). One sample was obtained.

2. MIL-W-81044/16-20-9. This is a double extruded alkane-imide with an imide topcoat. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). Samples were obtained from two sources. The manufacturer of both wire samples is the same.

3. MIL-W-81044/18-20-9. This is a single extruded alkane-imide with an imide topcoat. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). One sample was obtained.

4. MIL-W-81044/20-20-9. This is a double extrusion polyarylene. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). One sample was obtained.

5. MIL-W-81044/25-20-9. This is a single extrusion polyarylene. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). One sample was obtained.

6. Experimental. This wire is similar to MIL-W-81044/9-20-9 except that the polyvinylidene fluoride jacket has been replaced with polyarylene. The primary extrusion is polyalkene. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). One sample was obtained.

7. MIL-W-81381/7-20-2. This is a fluorocarbon/polyimide insulated wire with imide topcoat. It has a silver coated 19 strand copper conductor (AWG 20) and is red (-2). Samples were obtained from three sources but represent only two manufacturers.

8. MIL-W-81381/7-20-2. This wire is the same as 7 above except that the topcoat has a proprietary surface treatment to enhance adherence of potting compounds. One sample was obtained.

9. MIL-W-81381/7-20-N. This wire is the same as 7 above except that the color is natural (-N). One sample was obtained.

10. MIL-W-81381/7-20-9. This wire is the same as 7 above except that the color is white (-9). One sample was obtained.

11. MIL-W-81381/7-20-9. This wire is the same as 10 above except that the topcoat has a proprietary surface treatment to enhance adherence of potting compounds. One sample was obtained.

12. MIL-W-81381/11-20-N. This is a fluorocarbon/polyimide insulated wire with imide topcat. It is the same as MIL-W-81381/7-20-N wire except that the insulation is thicker. It is natural (-N) color. One sample was obtained.

13. MIL-W-81381/11-20-9. This is the same as 12 above except that the color is white (-9). One sample was obtained.

14. MIL-W-81381/11-20-9. This is the same as 13 above except that the topcoat has a proprietary surface treatment to enhance adherence of potting compounds. One sample was obtained.

V. PROCEDURE

Numeric and alphabetic identifier codes were assigned to the wire and fluid samples respectively (see Table 1). These code designations are used in other tables for ease in compilation of data.

The fluids were used in the concentrated "straight from the can" form. This is the usual procedure for using the paint removers. While the cleaning solutions are sometimes used in the concentrated condition, they are usually diluted for use. Specifications requiring pH to be measured use a 1:4 dilution with water. For this investigation solutions were measured in concentrated, 1:4 and 1:9, dilution form.

Three specimens from each of the seventeen wire samples were tested in each of the thirteen fluids for immersion times of 1 day, 1 week, 2 weeks, 3 weeks and 4 weeks. To test all combinations 3,315 specimens would have been needed. However, this number was reduced to about 2,500 by eliminating some of the wire-fluid-time combinations reported by NARF-NORIS as having no effect.

The wire samples were cut to 2 foot lengths with the ends stripped on an automatic Eubanks wire cutting machine. The specimens were formed from the 2 foot lengths by making a single turn loop with the ends of the wire run through the loop twice to secure the loop. The loop was formed to a 1 inch diameter on a rod of that size and the stripped conductor ends twisted together. Identification tags were placed upon each specimen indicating the wire and fluid code and the time of immersion (see Photo 1).

All specimens (#1, #2, and #3) are immersed in test fluids in the "as looped" condition.

After immersion, specimen #1 was rinsed in tap water and allowed to dry one hour at room ambient conditions. It was then immersed in tap water containing an anionic wetting agent for 1 hour. While still in the tap water the insulation was subjected to a 1 minute dielectric withstand test of 2500 volts rms. The specimen was considered to have failed if it did not pass the dielectric withstand test.

After immersion, specimen #2 was rinsed in tap water, uncoiled and allowed to dry for 1 hour at room ambient conditions. It was then subjected to the "double reverse wrap" on a 0.125" diameter mandrel as specified in the solvent resistance test procedure of the wire specifications. Following this the specimen was formed into a loose coil and immersed in tap water for 1 hour before being subjected to a 1 minute dielectric withstand test of 2500 volts rms.

After immersion, specimen #3 was rinsed in tap water , uncoiled and allowed to dry for 24 hours at room ambient conditions. Next it was subjected to the "double reverse wrap" on a 0.125" mandrel, formed into loose coil and immersed in tap water for 1 hour. The insulation was then subjected to a 1 minute dielectric withstand test of 2500 volts rms.

A variation of test procedure time of immersion was made on one group of 17 wire sample types. These were immersed in three fluids in succession as is done in MIL-C-5541 to form chemical conversion coatings on aluminum and aluminum alloys by dipping. The three fluids were:

1. Ridoline #53 (pH = 10.0)...immersed 5 min ($\approx 170^{o}F$)
2. Deoxidizer #17 (pH = 0.4)..immersed 1 min ($\approx 70^{o}F$)
3. Alodine 1200S (pH = 1.9)...immersed 1 min ($\approx 70^{o}F$)

The pH values were measured at room temperature on samples of the fluids taken from the production baths.

One group of wire specimens was also tested after 4 weeks immersion in Alodine 1200S.

Twelve specimens of wire from each of the seventeen samples were potted to a depth of 1/2 inch, six in polyurethane potting compound (MIL-M-24041) and six in polysulfide potting compound (MIL-S-8516). The potting compound was cured according to the manufacturers recommendations. No special preparation of the wire surfaces was done except that three of the wire samples already had surface treatments. The wires were pulled from the potting by an Instron tensile testing machine at a rate of 1 inch/minute.

Five 2 foot lengths of wire from each of the seventeen wire types were subjected to the life cycle test of their corresponding purchase specifications. All passed.

VI. RESULTS AND DISCUSSION

A. pH TESTING

The results of determining pH are found in Table 1. Fluids A and D are not buffered and in the concentrated form have pH values above 12. In the 1:4 dilution both meet the specified maximum of 12. All fluids meet the pH requirements of their respective specifications.

B. FLUID IMMERSION TESTING

The dielectric withstand failures are shown in Tables 2 through 6 inclusive for each period of immersion. Tables 7 and 8 were generated from Tables 2 through 6. Table 7 is a ranking of fluid activity based on the total number of wire specimen failures resulting from immersion in each fluid. Notice that the most alkaline (highest pH) fluids were not the most active. It is obvious that there are synergistic effects. However, among products qualified to the same specification, greater number of failures are obtained with the most alkaline fluid. TT-R-248 paint and lacquer removers are the most harmful to the insulation of wires tested. The more alkaline, non-buffered cleaning solutions of MIL-C-43616 are the next most harmful.

It should be kept in mind that wire codes 2, 3 and 4 are no longer being manufactured. However, they are employed on several operational Navy aircraft now in service. It may still be possible to obtain these wires through warehouse stocks not yet depleted. Also wire codes 5, 6 and 7 are being manufactured only as long as the present stock of insulation material lasts. When this is gone these wires will no longer be available.

The "5" failures shown in Table 7 for fluid J, and the "2*" failures shown for fluid H are all from wire codes 2 through 7 (see Tables 3, 4, 5 and 6 also). No MIL-W-81381 or MIL-W-22759 wires failed in fluids J and H.

There were no failures observed for wire code 1, the M22759/18-20-9 wire, in any test fluid.

The only failures observed for MIL-W-81381 wires were in fluids G and F (TT-R-248) and fluids A and D (MIL-C-43616 with pH $\geq$ 13.3). The white (-9) wire performed better than the natural (-N) or red (-2). The white topcoat is a fluorocarbon cosmetic color coating. Even though it can be easily scraped away, it is a definite advantage in providing resistance to alkaline fluids. Also it was observed that the red (-2) wire from one manufacturer did not perform as well as the red wire obtained from the other manufacturer.

The sample of wire purchased to MIL-W-81381/7-20-N (wire code 10) was found to have individual conductor strands sticking together. This seriously affects the flexibility and flex life of the wire. It is sufficient cause to reject the wire. About half of the sample was affected. Sufficient 2 foot lengths of good wire were available for the testing herein.

From Table 2 it is evident that fluids A and D are initially more active than fluids F and G. However, after one week the severity is the same. The MIL-W-81044/16 and /18 wire reacts about the same as MIL-W-81381/7-20-2 (or -N). The MIL-W-81381/11-20-N is somewhat more resistant than the MIL-W-81381/7-20-2 (or -N) This is to be expected since the /11 has thicker insulation than the /7. Wires react in an erratic manner in fluid D.

Specimens which failed the dielectric withstand test are shown in Photos 2 and 3. The damage seen is typical of that observed with other solvents in the one to two week immersion period. However, the insulation was completely dissolved from the conductor of MIL-W-81044 and MIL-W-81381/7 wires after four weeks immersion in the TT-R-248 paint remover. Such drastic damage is easily recognized, but the dielectric failures which occur when the wire still looks good are the failures which are the most important to find.

Specimen # 1 does not receive the "double reverse wrap" applied to specimens #2 and #3, and therefore should be the least likely of the three to fail. Since after one week specimen #1 always fails along with specimens #2 and #3 where failures occur, it is concluded that any testing beyond one week is overtesting.

There is one advantage gained in fluid immersion testing by using a specimen prepared in the configuration used herein compared to the specimen configuration allowed by the wire specifications. The bend radius or loop diameter of the test specimen used in the wire specifications may not always allow solvent stress cracking to be observed since the loop can be large and the stress in the insulation low. The loop is controlled herein to approximately 20 times the finished wire diameter and will almost always result in solvent stress cracking being determined. The wire specifications are deficient in this respect.

C. POTTED WIRE PULL-OUT STRENGTH TESTING

The results of the potted wire pull-out strength testing are shown in Table 9 (for polyurethane) and Table 10 (for polysulfide).

The wires are ranked from the highest strength to the lowest in Bar Chart 1. This shows the average pull-out strength for each wire type potted in polyurethane. The rank is the same for polysulfide but the values obtained were lower.

In three of the five wire types showing the lowest pull-out strength, the wire has a white cosmetic coating with no surface treatment (M81381/7 or /11). While the white cosmetic coating is an advantage to fluid resistance, it is a disadvantage to potting adherence. One of the five was insulated with ETFE with no surface treatment (M22759/18-20-8). The remaining one is a red colored M81381/7 which has a proprietary surface treatment. In this instance the treatment did not enhance the adherence of the potting compound (see wire code 12).

In wire code numbers 12 through 17, the fluid resistance of the wires was not adversely effected by the surface treatment on the wire. More extensive testing may be necessary to establish a difference if there is one.

APPENDIX A

TABLE 1. FLUID AND WIRE CODES TO SPECIFICATION IDENTITY

FLUID CODE	SPECIFICATION	MANUFACTURER	pH*** CONC.	pH*** 1:4	pH*** 1:9
A	MIL-C-43616	a	13.3	11.9	11.6
B*	MIL-C-43616	b	9.6	10.0	10.3
C*	MIL-C-43616	b	9.8	10.0	10.1
D	MIL-C-43616	c	13.4	11.3	11.0
E	MIL-C-43616	d	8.4	7.3	6.8
F	TT-R-248	b	11.2	10.9	10.4
G	TT-R-248	c	11.6	11.2	11.0
H	MIL-R-81294	b	9.6	8.4	8.5
I	MIL-R-81294	c	8.5	-	-
J	MIL-C-25769	b	11.5	10.6	10.3
K	MIL-C-25769	c	10.5	10.3	10.2
O	MIL-L-23699	e	NA	NA	NA
P	MIL-C-5544/MIL-C-81706	f	See Procedure		

WIRE CODE	SPECIFICATION	MANUFACTURER
1	MIL-W-22759/18-20-9	g
2	MIL-W-81044/16-20-9	h
3	MIL-W-81044/16-20-9	h
4	MIL-W-81044/18-20-9	h
5	MIL-W-81044/20-20-9	h
6	MIL-W-81044/25-20-9	h
7	Experimental (See #5)	h
8	MIL-W-81381/7-20-2	i
9	MIL-W-81381/7-20-2	i
10	MIL-W-81381/7-20-N	i
11	MIL-W-81381/11-20-N	i
12	MIL-W-81381/7-20-2	j
13	MIL-W-81381/7-20-2**	j
14	MIL-W-81381/7-20-9	j
15	MIL-W-81381/7-20-9**	j
16	MIL-W-81381/11-20-9	j
17	MIL-W-81381/11-20-9**	j

* Different products from the same manufacturer.

** Surface of these wires have been treated with a proprietary treatment to enhance potting adhesion.

*** The pH was measured on concentrated, 1:4 and 1:9 dilutions with water.

TABLE 2, DIELECTRIC WITHSTAND FAILURES, 1 DAY IMMERSION

WIRE CODE	MILITARY PART NO.	SPECIFICATION, DESCRIPTION, FLUID CODE AND pH												
		MIL-C-43616 NAVY AIRCRAFT SURFACE CLEANER					TT-R-248 PAINT AND LACQUER REMOVER		MIL-R-81294 EPOXY PAINT REMOVER		MIL-C-25769 AIR FORCE AIRCRAFT SURFACE CLEANER		MIL-L-23699 SYNTHETIC LUBRICATING OIL	MIL-C-5541 MIL-C-81706 ALODINE 1200S
		A	B	C	D	E	F	G	H	I	J	K	O	P
		pH 13.3	9.6	9.8	13.4	8.4	11.2	11.6	9.6	8.5	11.5	10.5	-	1.9
1	M22759/18-20-9													
2	M81044/16-20-9	1,2,3			3									
3	M81044/16-20-9	1,2,3			2,3									
4	M81044/18-20-9	1,2,3			1,2,3			1,2,3						
5	M81044/20-20-9													
6	M81044/25-20-9													
7	Experimental													
8	M81381/7-20-2	1,2,3												
9	M81381/7-20-2	1,2,3												
10	M81381/7-20-N	1,2,3												
11	M81381/11-20-N													
12	M81381/7-20-2	2,3												
13	M81381/7-20-2													
14	M81381/7-20-9													
15	M81381/7-20-9													
16	M81381/11-20-9													
17	M81381/11-20-9													

NOTE: No entry means all three specimens passed.

1: Specimen No. 1 Fails
2: Specimen No. 2 Fails
3: Specimen No. 3 Fails

TABLE 3. DIELECTRIC WITHSTAND FAILURES, 1 WEEK IMMERSION

WIRE CODE	MILITARY PART NO.	SPECIFICATION, DESCRIPTION, FLUID CODE AND pH												
		MIL-C-43616 NAVY AIRCRAFT SURFACE CLEANER					TT-R-248 PAINT AND LACQUER REMOVER		MIL-R-81294 EPOXY PAINT REMOVER		MIL-C-25769 AIR FORCE AIRCRAFT SURFACE CLEANER		MIL-L-23699 SYNTHETIC LUBRICATING OIL	MIL-C-5541 MIL-C-81706 ALODINE 1200S
		A	B	C	D	E	F	G	H	I	J	K	O	P
		pH 13.3	9.6	9.8	13.4	8.4	11.2	11.6	9.6	8.5	11.5	10.5	-	1.9
1	M22759/18-20-9													
2	M81044/16-20-9	1,2,3			2,3		3							
3	M81044/16-20-9	1,2,3			1,2,3									
4	M81044/18-20-9	1,2,3			1,2,3		2,3	1,2,3			2,3			
5	M81044/20-20-9													
6	M81044/25-20-9													
7	Experimental													
8	M81381/7-20-2	1,2,3			1		1,2,3	1,2,3						
9	M81381/7-20-2	1,2,3			1,2,3		1,2,3	1,2,3						
10	M81381/7-20-N	1,2,3			2,3		1,2,3	1,2,3						
11	M81381/11-20-N	1,2,3					2	1,2,3						
12	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
13	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
14	M81381/7-20-9							1,2,3						
15	M81381/7-20-9							1,2						
16	M81381/11-20-9							2						
17	M81381/11-20-9													

NOTE: No entry means all specimens passed.

1: Specimen No. 1 Fails
2: Specimen No. 2 Fails
3: Specimen No. 3 Fails

TABLE 4. DIELECTRIC WITHSTAND FAILURES, 2 WEEK IMMERSION

WIRE CODE	MILITARY PART NO.	SPECIFICATION, DESCRIPTION, FLUID CODE AND pH												
		MIL-C-43616 NAVY AIRCRAFT SURFACE CLEANER					TT-R-248 PAINT AND LACQUER REMOVER		MIL-R-81294 EPOXY PAINT REMOVER		MIL-C-25769 AIR FORCE AIRCRAFT SURFACE CLEANER		MIL-L-23699 SYNTHETIC LUBRICATING OIL	MIL-C-5541 MIL-C-81706 ALODINE 1200S
		A	B	C	D	E	F	G	H	I	J	K	O	P
		pH 13.3	9.6	9.8	13.4	8.4	11.2	11.6	9.6	8.5	11.5	10.5	-	1.9
1	M22759/18-20-9													
2	M81044/16-20-9	1,2,3					1,2	1,2,3						
3	M81044/16-20-9	1,2,3					1,2	1,2,3	**					
4	M81044/18-20-9	1,2,3					1,2,3	1,2,3						
5	M81044/20-20-9													
6	M81044/25-20-9													
7	Experimental													
8	M81381/7-20-2	1,2,3			1,2,3		1,2,3	1,2,3						
9	M81381/7-20-2	1,2,3			1,2,3		1,2,3	1,2,3						
10	M81381/7-20-N	1,2,3					1,2,3	1,2,3						
11	M81381/11-20-N	1,2,3					1,2,3	1,2,3						
12	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
13	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
14	M81381/7-20-9						1,2,3	1,2,3						
15	M81381/7-20-9						1,2,3	1,2,3						
16	M81381/11-20-9						1,2,3	1,2,3						
17	M81381/11-20-9						*,2,3	2,3						

NOTE: No entry means all specimens passed.

1: Specimen No. 1 Fails
2: Specimen No. 2 Fails
3: Specimen No. 3 Fails
* Specimen No. 1 exhibited low DC resistance (12 X 10^6 MΩ)
** Specimen No. 2 exhibited low DC resistance (20 MΩ)

TABLE 5. DIELECTRIC WITHSTAND FAILURES, 3 WEEK IMMERSION

WIRE CODE	MILITARY PART NO.	SPECIFICATION, DESCRIPTION, FLUID CODE AND pH												
		MIL-C-43616 NAVY AIRCRAFT SURFACE CLEANER					TT-R-248 PAINT AND LACQUER REMOVER		MIL-R-81294 EPOXY PAINT REMOVER		MIL-C-25769 AIR FORCE AIRCRAFT SURFACE CLEANER		MIL-L-23699 SYNTHETIC LUBRICATING OIL	MIL-C-5541 MIL-C-81706 ALODINE 1200S
		A	B	C	D	E	F	G	H	I	J	K	O	P
		pH13.3	9.6	9.8	13.4	8.4	11.2	11.6	9.6	8.5	11.5	10.5	-	1.9
1	M22759/18-20-9													
2	M81044/16-20-9	1,2,3					1,2,3	1,2,3						
3	M81044/16-20-9	1,2,3					1,2,3	1,2,3	1,2					
4	M81044/18-20-9	1,2,3					1,2,3	1,2,3						
5	M81044/20-20-9													
6	M81044/25-20-9													
7	Experimental													
8	M81381/7-20-2	1,2,3			1,3		1,2,3	1,2,3						
9	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
10	M81381/7-20-N	1,2,3					1,2,3	1,2,3						
11	M81381/11-20-N	1,2,3					1,2,3	1,2,3						
12	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
13	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
14	M81381/7-20-9						1,2,3	1,2,3						
15	M81381/7-20-9						1,2,3	1,2,3						
16	M81381/11-20-9						1,2,3	1,2,3						
17	M81381/11-20-9						1,2,3	1,2,3						

NOTE: No entry means all specimens passed.

1: Specimen No. 1 fails
2: Specimen No. 2 fails
3: Specimen No. 3 fails

TABLE 6. DIELECTRIC WITHSTAND FAILURES, 4 WEEK IMMERSION

WIRE CODE	MILITARY PART NO.	SPECIFICATION, DESCRIPTION, FLUID CODE AND pH												
		MIL-C-43616 NAVY AIRCRAFT SURFACE CLEANER					TT-R-248 PAINT AND LACQUER REMOVER		MIL-R-81294 EPOXY PAINT REMOVER		MIL-C-25769 AIR FORCE AIRCRAFT SURFACE CLEANER		MIL-L-23699 SYNTHETIC LUBRICATING OIL	MIL-C-5541 MIL-C-81706 ALODINE 1200S
		A	B	C	D	E	F	G	H	I	J	K	O	P
		pH13.3	9.6	9.8	13.4	8.4	11.2	11.6	9.6	8.5	11.5	10.5	-	1.9
1	M22759/18-20-9													
2	M81044/16-20-9	1,2,3			3		1,2,3	1,2,3						
3	M81044/16-20-9	1,2,3			1,2,3		1,2,3	1,2,3	*					
4	M81044/18-20-9	1,2,3			1,2,3		1,2,3	1,2,3	**		3			
5	M81044/20-20-9								***					
6	M81044/25-20-9								****					
7	Experimental													
8	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
9	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
10	M81381/7-20-N	1,2,3					1,2,3	1,2,3						
11	M81381/11-20-N	1,2,3					1,2,3	1,2,3						
12	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
13	M81381/7-20-2	1,2,3					1,2,3	1,2,3						
14	M81381/7-20-9						1,2,3	1,2,3						
15	M81381/7-20-9						1,2,3	1,2,3						
16	M81381/11-20-9						1,2,3	1,2,3						
17	M81381/11-20-9						1,2,3	1,2,3						

NOTE: No entry means all specimens passed.

1: Specimen No. 1 Fails
2: Specimen No. 2 Fails
3: Specimen No. 3 Fails
* Specimen No.1 exhibited low DC resistance (22 MΩ)
** Specimen No.1 exhibited low DC resistance (40 MΩ)
*** Specimen No.1 exhibited low DC resistance (50 MΩ)
**** Specimen No.1 exhibited low DC resistance (90 MΩ)

TABLE 7. RANKING OF FLUID ACTIVITY BASED ON TOTAL NUMBER OF WIRE FAILURES

MILITARY SPECIFICATION	FLUID CODE	TOTAL NUMBER OF FAILURES	MANUFACTURER	pH (CONC.)
TT-R-248	G	146	c	11.6
	F	133	b	11.2
MIL-C-43616	A	122	a	13.3
	D	33	c	13.4
	C	0	b	9.8
	B	0	b	9.6
	E	0	d	8.4
MIL-C-25769	J	5	b	11.5
	K	0	c	10.5
MIL-R-81294	H	2*	b	9.6
	I	0	c	8.5
MIL-C-5541/MIL-C-81706	P	0	f	1.9
MIL-L-23699	O	0	e	N.A.

* Also low D.C. resistance on some wires

TABLE 8. RANKING OF WIRES INTEGRITY BASED ON TOTAL NUMBER OF WIRE SPECIMEN FAILURES

WIRE NO.	SPECIFICATION	TOTAL NUMBER OF FAILURES	MANUFACTURER
9	MIL-W-81381/7-20-2	45	i
8		43	i
12		38	j
13		36	j
10	MIL-W-81381/7-20-N	41	i
14	MIL-W-81381/7-20-9	21	j
15		20	j
11	MIL-W-81381/11-20-N	34	i
16	MIL-W-81381/11-20-9	19	j
17		18	j
3	MIL-W-81044/16-20-9	40	h
2		37	h
4	MIL-W-81044/18-20-9	55	h
5	MIL-W-81044/20-20-9	0*	h
6	MIL-W-81044/25-20-9	0*	h
7	Experimental	0	h
1	MIL-W-22759/18-20-9	0	g

* No dielectric withstand failure, but exhibited low D.C. resistance at 4 weeks in Fluid H.

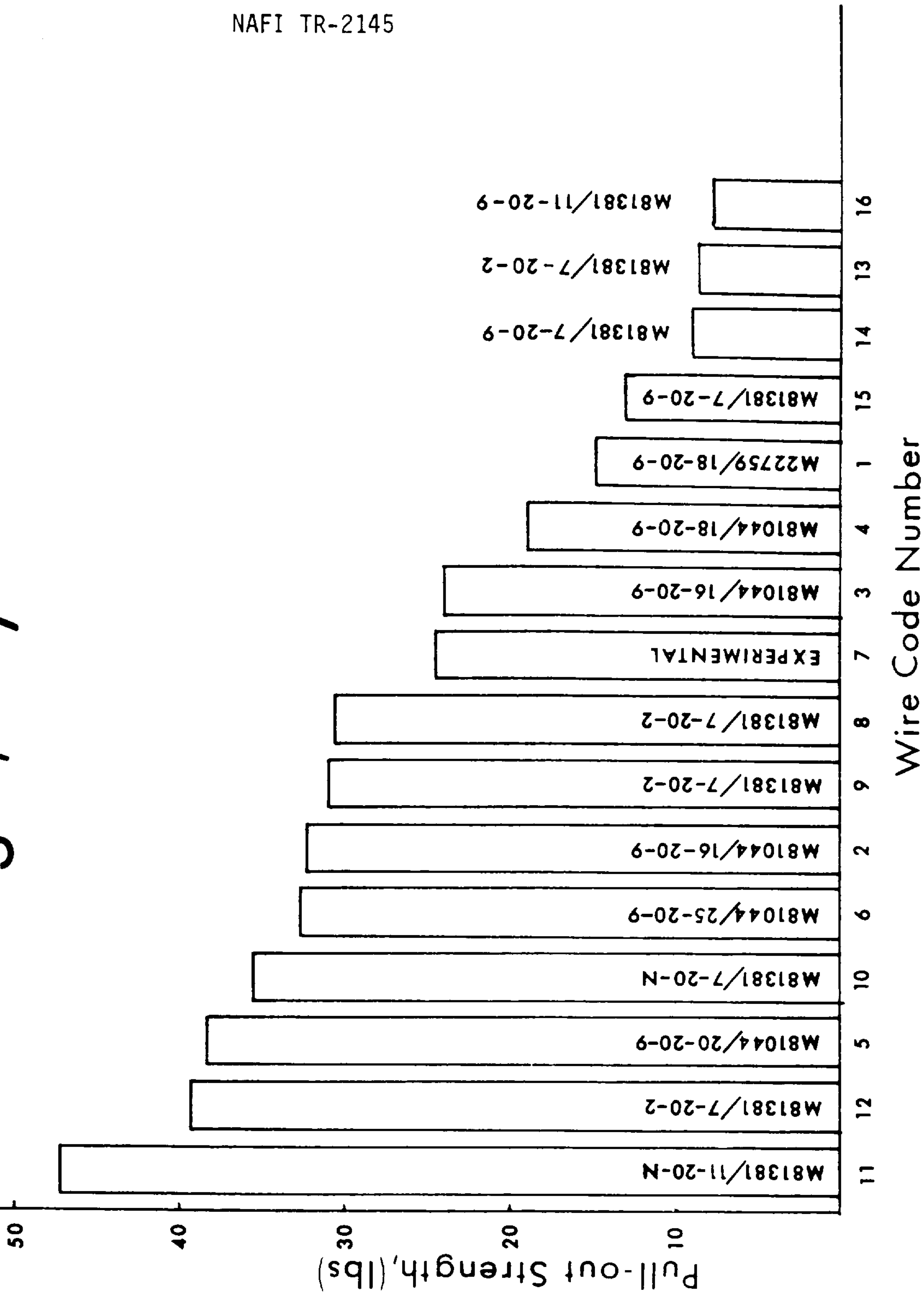
TABLE 9. POTTED WIRE PULL-OUT STRENGTH, POLYURETHANE

WIRE CODE	MILITARY PART NO.	PULL-OUT STRENGTH (LBS)						N	$\overline{X}$	σ
1	M22759/18-20-9	16.5	11.8	16.8	15.8	15.5	13.2	6	14.9	1.812
2	M81044/16-20-9	33.5	32.0	32.0	32.5	31.2	31.8	6	32.2	0.702
3	M81044/16-20-9	24.8	24.0	24.5	23.0	23.0	24.8	6	24.0	0.075
4	M81044/18-20-9	19.5	19.8	18.0	19.8	18.2	18.0	6	18.9	0.800
5	M81044-20-20-9	39.0	44.0	35.2	40.0	39.5	33.5	6	38.5	3.399
6	M81044/25-29-9	32.2	32.5	33.0	28.0	38.0	30.8	6	32.4	2.995
7	Experimental	24.0	26.0	22.5	26.2	23.0	22.8	6	24.1	1.518
8	M81381/7-20-2	30.5	30.2	28.8	31.5	30.2	33.0	6	30.7	1.302
9	M81381/7-20-2	32.8	30.0	31.0	32.5	30.2	29.2	6	30.9	1.286
10	M81381/7-20-N	33.0	31.5	37.0	38.8	39.5	33.5	6	35.5	3.029
11	M81381/11-20-N	45.8	44.0	47.0	47.5	40.0	59.0	6	47.2	5.824
12	M81381/7-20-2	46.0	39.2	37.8	34.0	35.8	41.8	6	39.1	3.952
13	M81381/7-20-2	9.5	7.8	9.6	7.5	7.9	8.9	6	8.5	0.846
14	M81381/7-20-9	8.8	9.5	9.8	6.5	9.5	9.0	6	8.8	1.096
15	M81381/7-20-9	12.5	10.2	13.8	12.8	15.2	13.5	6	13.0	1.514
16	M81381/11-20-9	6.8	7.2	9.8	8.0	8.5	6.6	6	7.8	1.095
17	M81381/11-20-9	DATA LOST								

TABLE 10. POTTED WIRE PULL-OUT STRENGTH, POLYSULFIDE

WIRE CODE	MILITARY PART NO.	PULL-OUT STRENGTH (LBS)						N	$\overline{X}$	σ
1	M22759/18-20-9	5.5	9.5	5.5	8.8	7.8	6.5	6	7.2	1.541
2	M81044/16-20-9	26.0	14.2	23.1	18.2	20.2	24.0	6	20.9	3.918
3	M81044/16-20-9	11.8	7.8	11.2	15.0	12.5	11.5	6	11.6	2.134
4	M81044/18-20-9	14.0	14.0	15.0	16.0	14.8	11.5	6	14.2	1.387
5	M81044/20-20-9	10.8	13.8	13.0	11.5	12.5	10.0	6	11.9	1.296
6	M81044/25-20-9	10.2	11.5	10.5	9.5	10.8	13.0	6	10.9	1.106
7	Experimental	9.8	9.5	11.8	9.0	9.2	8.5	6	9.6	1.028
8	M81381/7-20-2	14.8	18.0	16.0	19.5	17.2	12.0	6	16.2	2.415
9	M81381/7-20-2	17.3	15.4	21.5	16.8	23.0	16.2	6	18.4	2.838
10	M81381/7-20-N	19.2	15.0	13.5	12.5	17.0	10.5	6	14.6	2.886
11	M81381/11-20-N	11.1	11.1	16.0	20.8	24.5	20.0	6	17.2	4.993
12	M81381/7-20-2	25.0	24.5	24.0	15.8	19.5	11.8	6	20.1	4.960
13	M81381/7-20-2	4.5	4.2	3.5	3.1	3.0	3.7	6	3.7	0.552
14	M81381/7-20-9	7.5	7.5	8.0	7.5	3.5	3.5	6	6.2	1.953
15	M81381/7-20-9	6.8	8.5	6.5	6.6	9.8	8.4	6	7.8	1.216
16	M81381/11-20-9	5.1	5.4	5.0	5.5	5.2	7.5	6	5.6	0.852
17	M81381/11-20-9	DATA LOST								

Bar Chart 1
Potted Wire Pull-out Strength, Polyurethane



APPENDIX B

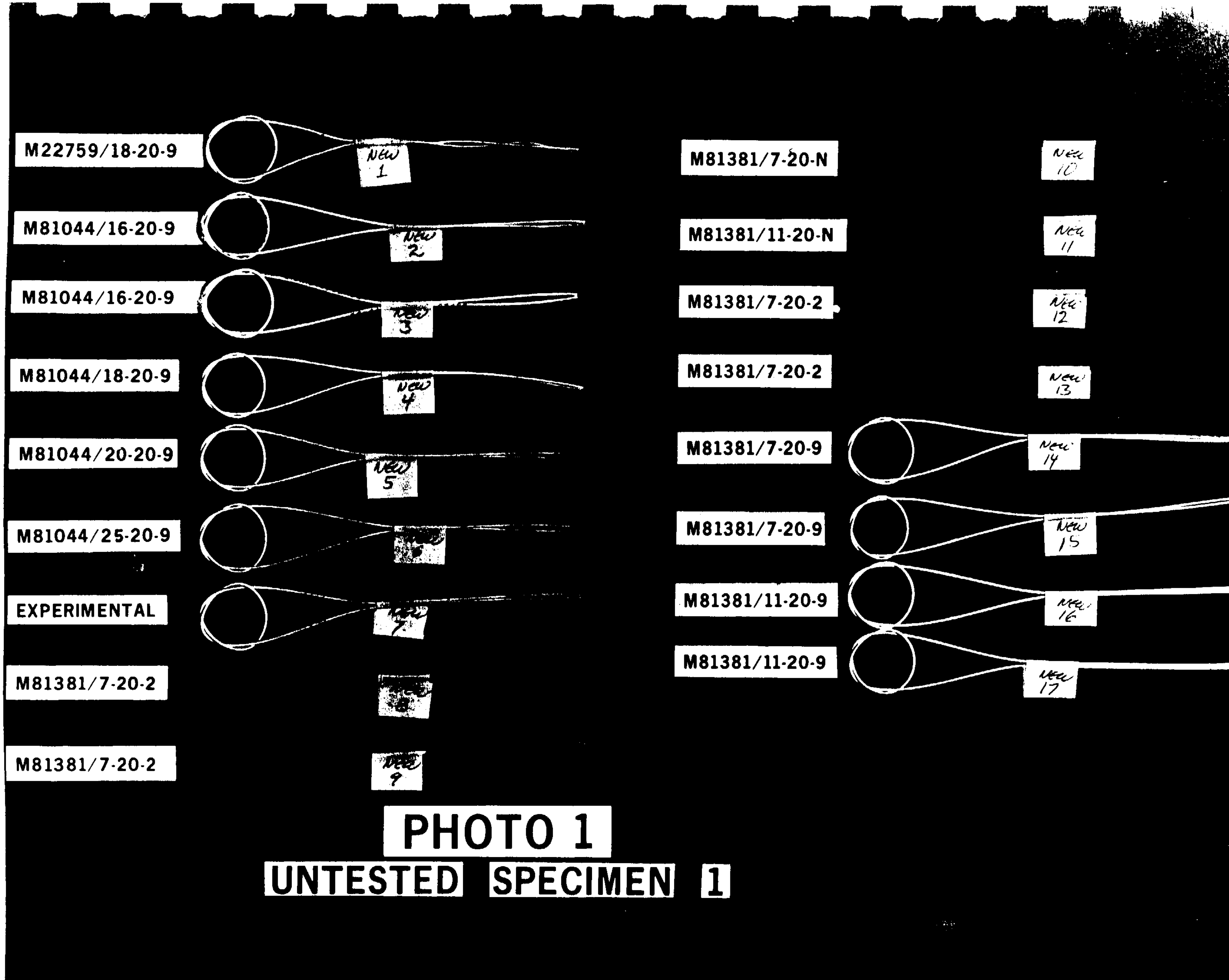


PHOTO 1
UNTESTED SPECIMEN 1

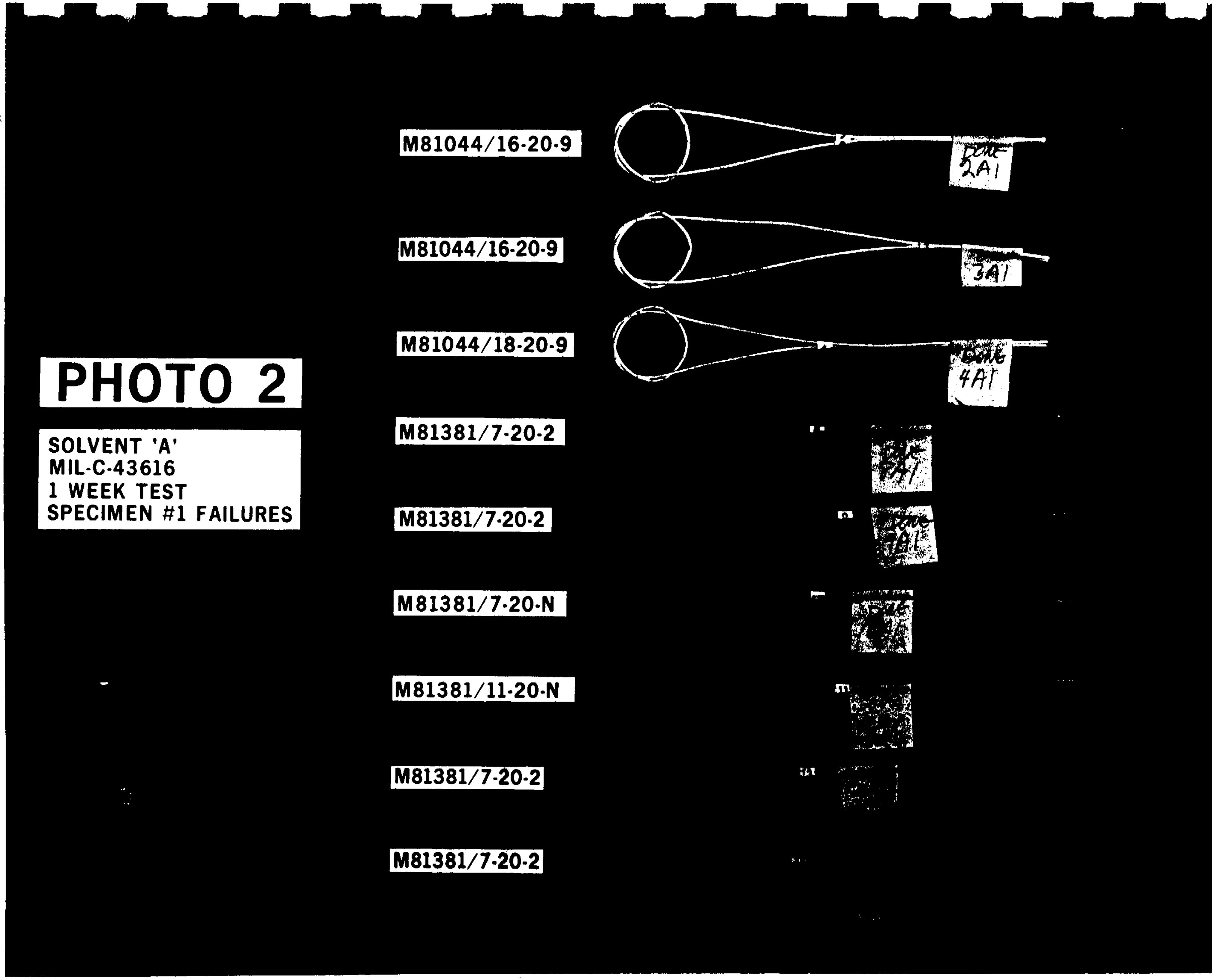


PHOTO 2
SOLVENT 'A'
MIL-C-43616
1 WEEK TEST
SPECIMEN #1 FAILURES
M81044/16-20-9
M81044/16-20-9
M81044/18-20-9
M81381/7-20-2
M81381/7-20-2
M81381/7-20-N
M81381/11-20-N
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M81381/7-20-2
2A1
3A1
4A1

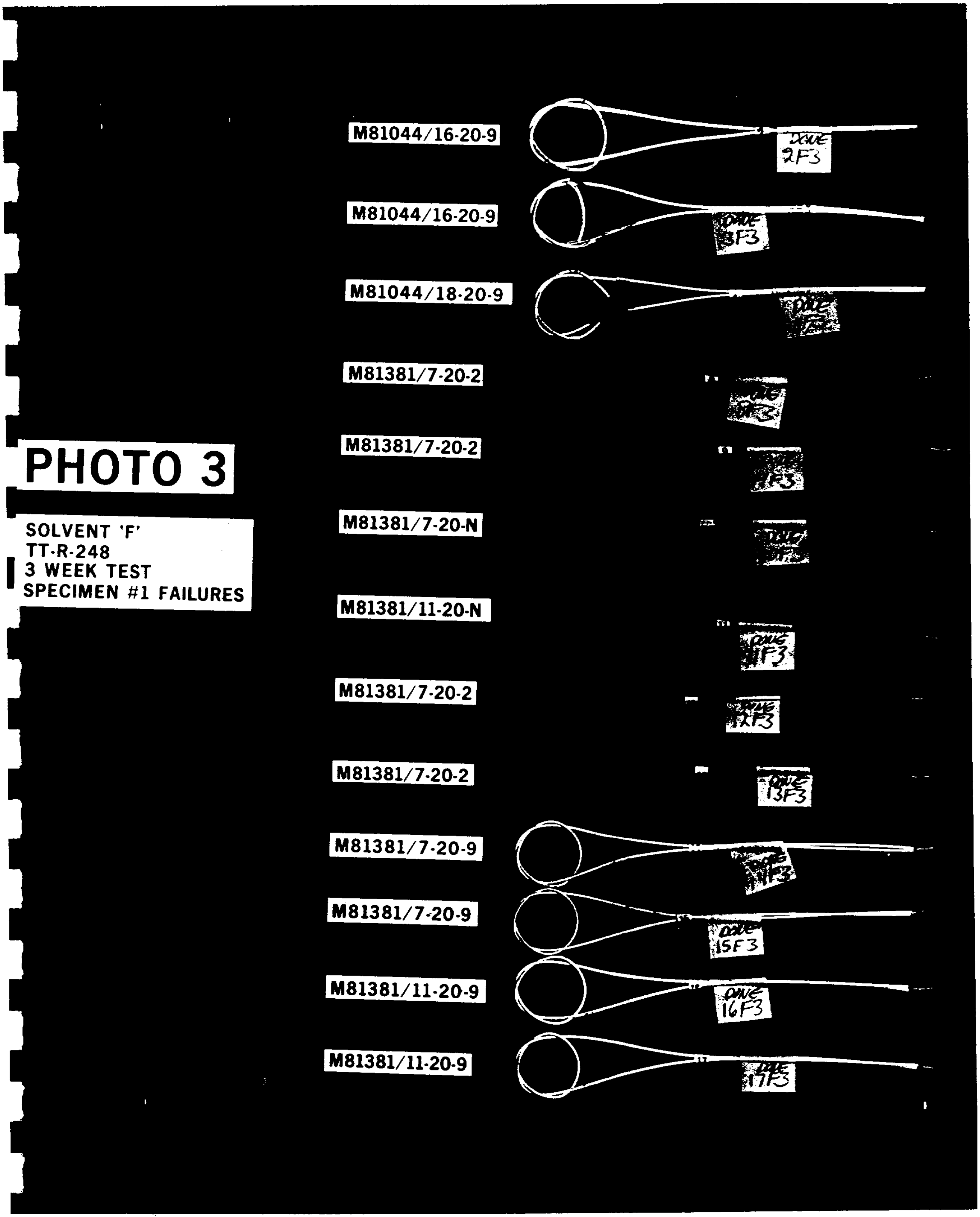
PHOTO 3
SOLVENT 'F'
TT-R-248
3 WEEK TEST
SPECIMEN #1 FAILURES
M81044/16-20-9
M81044/16-20-9
M81044/18-20-9
M81381/7-20-2
M81381/7-20-2
M81381/7-20-N
M81381/11-20-N
M81381/7-20-2
M81381/7-20-2
M81381/7-20-9
M81381/7-20-9
M81381/11-20-9
M81381/11-20-9

APPENDIX C

DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
NAVAL AIR SYSTEMS COMMAND HEADQUARTERS
47123 BUSE ROAD, UNIT #____
PATUXENT RIVER, MARYLAND 20670-1547

5000
PAO
16 Dec 99

Robert L. Swaim
Systems Group Chairman, TWA 800 Investigation
National Transportation Safety Board
490 L'Enfant Plaza, E, SW
Washington, DC 20594

Note: Letter inserted to cover supplies information.
R. Swaim

Mr. Swaim,

Your request to place four NAFI reports concerning testing and aging properties of different types of wire that were released in the 1970s in the public docket as background for your investigation is approved.

You may place the reports listed below, and their appendices, in the public docket as background for your investigation, provided you redact names of suppliers in the appropriate places as previously discussed:

Naval Avionics Facility (now the Wiring Qualification Group of Raytheon Systems Company) reports titled "Fluid Resistance Testing Of Electrical Wire Used in Aircraft And Missiles" comprised of:

NAFI-TR-2145
NAFI-TR-2199
NAFI-TR-2201
NAFI-TR-2210

Your point of contact in this matter is John Milliman who may be reached at the address above, by phone at (301) 757-6638 or by email at millimanjc@navair.navy.mil Please feel free to contact him if you need any further assistance.

Thank you,

Lola Hilton

Lola R. Hilton
Director of Corporate Communications

TOTAL P.01

NAFI TR-2145

APPENDIX C

FLUID CODE	MILITARY SPECIFICATION	PRODUCT IDENTIFICATION	MANUFACTURER
A	MIL-C-43616		
B	MIL-C-43616		
C	MIL-C-43616		
D	MIL-C-43616		
E	MIL-C-43616		
F	TT-R-248		
G	TT-R-248		
H	MIL-R-81294		
I	MIL-R-81294		
J	MIL-C-25769		
K	MIL-C-25769		
O	MIL-L-23699		
P	MIL-C-5541/MIL-C-81706		

WIRE CODE	
1	MIL-W-22759/18-20-9
2*	MIL-W-81044/16-20-9
3	MIL-W-81044/16-20-9
4	MIL-W-81044/18-20-9
5	MIL-W-81044/20-20-9
6	MIL-W-81044/25-20-9
7	Experimental
8*	MIL-W-81381/7-20-2
9	MIL-W-81381/7-20-2
10	MIL-W-81381/7-20-N
11	MIL-W-81381/11-20-N
12	MIL-W-81381/7-20-2
13	MIL-W-81381/7-20-2
14	MIL-W-81381/7-20-9
15	MIL-W-81381/7-20-9
16	MIL-W-81381/11-20-9
17	MIL-W-81381/11-20-9

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Avionics Facility Indianapolis, Indiana	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP

3. REPORT TITLE
Fluid Resistance Testing of Electrical Wire Used In Aircraft and Missiles

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Report - 11 August 1976

5. AUTHOR(S) (Last name, first name, initial)
Watkins, Willard D.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
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8a. CONTRACT OR GRANT NO. N001976WR68881 BCN AKA11 APPN.1761595.45BF b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TR-2145 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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13. ABSTRACT

Electrical wiring in Navy aircraft often is subjected to inadvertent exposure to solvents and chemicals used to clean the aircraft surfaces in the course of maintenance operations. Wire types purchased to MIL-W-22759, MIL-W-81044 and MIL-W-81381 are used in aircraft wiring. These specifications are under NAVAIR cognizance. Each has solvent resistance requirements employing liquids such as jet fuel, hydraulic fluid, etc., which are used by the aircraft. The testing reported herein employs thirteen cleaners or solvents which are purchased to military or federal specifications and used on aircraft surfaces. The insulation on seventeen electrical wire samples purchased to the above wire specifications was evaluated after immersion in the cleaners or solvents.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Insulated Wire Cleaning Fluids Dielectric Withstand Potting Adherence						

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TR 2199
11 AUGUST 1977

NAFI publication

FLUID RESISTANCE TESTING OF ELECTRICAL WIRE USED IN AIRCRAFT AND MISSILES
PART II

NAVAL AVIONICS FACILITY
INDIANAPOLIS, INDIANA 46218

PREFACE

This report describes an investigation into the ability of the insulation on aircraft electrical wire to withstand exposure to cleaners and paint removers which are used on aircraft surfaces. It is a continuation of work reported in NAFI TR-2145[1].

This work was performed for NAVAIR under Work Request No. 68E95.

PREPARED BY: W. D. WATKINS

APPROVED BY: F. H. GAHIMER, Head
Organic Materials Branch

B. C. VAUGHN, Director, Materials
Laboratory and Consultants Division

ABSTRACT

Several types of insulated electrical wire purchased to MIL-W-5086, MIL-W-81044 and MIL-W-81381 were immersed in solvents purchased to MIL-C-43616 and TT-R-248. The ability of the insulation to withstand degradation by the solvents was determined by subjecting the conditioned wire to a dielectric withstand voltage test. On some wire types the electrical insulation DC resistance was also determined.

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I. CONCLUSIONS

1. Kapton insulated wire is superior to Poly-X insulated wire in solvent resistance at room temperature. The wires tested herein are ranked in the order of decreasing resistance to solvent damage as follows.

Wire Code	Military Part No.	Insulation Type
16	M81381/17-20-9	Double Wrap Kapton*
14	M81381/7-20-9	Single Wrap Kapton*
11	M81381/11-20-N	Double Wrap Kapton
3	M81044/16-20-9	Double Extruded Poly-X
10	M81381/7-20-N	Single Wrap Kapton
4	M81044/18-20-9	Single Extruded Poly-X

* Topcoat is white fluorocarbon polymer.

2. Kynar jacketed polyalkene insulated wire is superior to nylon jacketed PVC in solvent resistance at room temperature. However, both insulations exhibit low electrical insulation DC resistance after solvent immersion. The Kynar jacketed polyalkene takes longer to be affected and the values observed are higher than on nylon jacketed PVC.

3. The new MIL-C-43616 cleaning fluid (with a pH of 9.2) produced only one failure in all the wires tested. This is a definite improvement over previous types with pH of 11 and over.

II. RECOMMENDATIONS

1. All Navy aircraft currently in service and wired with Poly-X wire to MIL-W-81044/16 through /19 should be inspected on a regular basis

for insulation damage. Particular attention should be given MIL-W-81044/18 and /19 wire.

2. Electrical wire insulated with newly developed polymers should not be used in Navy aircraft until its resistance to solvents has been determined.

3. Only electrical wire which is resistant to solvents and cleaners should be used in high performance aircraft.

III. INTRODUCTION

Electrical wiring in Navy aircraft is often subjected to inadvertent exposure to solvents and chemicals used to clean the aircraft surfaces in the course of maintenance operations. Previous testing[1,2] had indicated that some wire purchased to MIL-W-81044 and MIL-W-81381 were particularly prone to damage by MIL-C-43616 cleaners and TT-R-248 paint removers.

Teflon® (TFE) and Tefzel® (ETFE) insulated wire specified by MIL-W-22759 were not degraded by immersion in any of the test fluids for periods up to and including 28 days.

Stilan® (Polyarylene) insulated wire specified by MIL-W-81044/20 through /29 was shown to be prone to stress cracking or crazing when immersed in alcohol, glycol-water solutions and highly acid solutions. This wire is no longer manufactured.

Poly-X® (Alkane-imide) insulated wire specified by MIL-W-81044/16 through /19 was damaged by highly alkaline cleaning solutions and paint removers. Kapton® (polyimide tape) insulated wire specified by MIL-W-81381 was also shown to be prone to insulation damage by the same solutions. Unfortunately, the time periods used previously to test the wire were such that the investigation did not indicate which would withstand damage the longest. Although Poly-X is no longer available, there is a considerable amount installed in the Navy F-14 aircraft. Kapton wire is currently available and is used in commercial aircraft and the Air Force F-15.

Kynar® jacketed polyalkene insulated wire (often referred to as "Spec 44" wire) which is specified by MIL-W-81044/2 through /15 was not previously tested. Nylon jacketed PVC insulated wire specified by MIL-W-5086 also was not previously tested. The latter wire was previously allowed for use in aircraft wiring but is now prohibited.

It is the purpose of this investigation to:

1. Compare the solvent resistance of Poly-X and Kapton insulated wire.

2. Compare the solvent resistance of Kynar jacketed polyalkane, nylon jacketed ~~PCV~~ PVC and the insulations previously tested.

3. Compare the degree of damage caused by the new MIL-C-43616 cleaning fluid (pH $\leq$ 10) to that caused by high pH cleaners previously tested.

IV MATERIALS

A. FLUIDS

Three fluids were chosen for use in this investigation. Fluid A (MIL-C-43616 cleaner) and Fluid G (TT-R-248 paint remover) are the same as Fluids A and G used in TR-2145[1]. Fluid N is a new MIL-C-43616B cleaning fluid with a pH less than 10 in accordance with Amendment 2. A complete description of the fluids used is given in Appendix C.

B. WIRES

Ten different insulated wires were used. Wires with code numbers 3, 4, 10, 11, 14 and 16 are the same as those used in TR-2145[1] and identified therein by the same code numbers. Four new wires were added; wire codes I, II, III and IV. The wires are listed by code number and military specification in Tables 1-3. A complete description appears in Appendix C.

V. PROCEDURE

The fluids were used in the concentrated "straight from the can" form. This is the usual procedure for using the paint removers. While the cleaning solutions are sometimes used in the concentrated condition, they are usually diluted for use. Specifications requiring pH to be measured use a 1:4 dilution with water. For this investigation, pH of the solutions was measured in concentrated,1:4 dilution and 1.9 dilution form.

Three specimens from each of the ten wire samples were tested in each of the three fluids for immersion times of 1 though 7 consecutive days, 2 weeks, 3 weeks and 4 weeks.

The wire samples were cut to 2 foot lengths with the ends stripped on an automatic Eubanks wire cutting machine. The specimens were formed from the 2 foot lengths by making a single turn loop with the ends of the wire run through the loop twice to secure the loop. The loop was formed to a 1 inch diameter on a rod of that size and the stripped conductor ends twisted together. Identification tags were placed upon each specimen indicating the wire and fluid code and the time of immersion.

All specimens (#1, #2, and #3) were immersed in the test fluid in the "as looped" condition.

After immersion, specimen #1 was rinsed in tap water and allowed to dry one hour at room ambient conditions. It was then immersed for 1 hour in tap water containing an anionic wetting agent. While still in the tap water the insulation was subjected to a 1 minute dielectric withstand test of 2500 volts rms.

After immersion, specimen #2 was rinsed in tap water, uncoiled and allowed to dry for 1 hour at room ambient conditions. It was then subjected to the "double reverse wrap" on a 0.125" diameter mandrel as specified in the solvent resistance test procedure of the wire specifications. Following this, the specimen was formed into a loose coil and immersed in tap water for 1 hour before being subjected to a 1 minute dielectric withstand test of 2500 volts rms.

After immersion, specimen #3 was rinsed in tap water, uncoiled, and allowed to dry for 24 hours at room ambient conditions. Next, it was subjected to the "double reverse wrap" on a 0.125" mandrel, formed into loose coil, and immersed in tap water for 1 hour. The insulation was then subjected to a 1 minute dielectric withstand test of 2500 volts rms.

Note: The mandrel diameter was 0.250" for wire code IV due to its large finished diameter.

During dielectric withstand testing some specimens exhibited excessive current leakage but maintained the voltage without breakdown. These specimens were subjected to insulation resistance testing using 500 VDC applied for 1 minute.

VI. RESULTS AND DISCUSSION

A. pH TESTING

The pH of the fluids was as follows:

Fluid Code	Specification	pH		
A	MIL-C-43616	Conc.	1:4	1:9
		13.3	11.9	11.6
G	TT-R-248	11.6	11.2	11.0
N (New)	MIL-C-43616B, Amend. #2	9.2	9.2	9.1

B. FLUID IMMERSION

The dielectric withstand failures are shown in Tables 1-3 for each period of immersion. Also shown are the values of electrical resistance (in M Ω - 1000 ft.) of specimens exhibiting current leakage during the dielectric withstand test.

Electrical resistance values of the wire insulation after drying and subsequent immersion in water are shown in Table 4.

There were no dielectric withstand failures of either Kynar jacketed polyalkene or nylon jacked PVC wire (wire codes I, II, III and IV). However several of these wires exhibited low insulation resistance. Subsequent drying restored some of the electrical resistance, but upon reimmersion in water the values again were lowered (see Table 4). "Low insulation resistance" for the purposes of reporting was arbitrarily chosen to be those values below 500 M Ω - 1000 ft. This is at least one order of magnitude less than the specification requirement for Kynar jacketed polyalkene but an order higher than that specified for nylon jacketed PVC.

Note: Finished cable harnesses before installation into an aircraft generally must provide 100 M Ω (min.) between one wire and all others electrically tied together.

Fluid G (paint remover) lowered the electrical resistance of both Kynar jacketed polyalkene and nylon jacketed PVC. Both fluids A and N lowered the electrical resistance of nylon jacketed PVC, but did not lower the resistance of Kynar jacketed polyalkene below 500 M Ω - 1000 ft. Thus, Kynar jacketed polyalkene is superior to nylon jacketed PVC.

Two methods of analyzing the data were used to rank the solvent resistance characteristics of the wire. One method involves summing up all dielectric withstand failures for each wire and then ranking them according to that number, as shown in Table 5. The other method involves computing the percent failures for each wire for each immersion time and plotting the results as shown in Graph 1. The rank is the same in both methods.

Graph 1 gives some additional information. The curves should be shaped like those shown for wire codes 4 and 10, but wire code 3 is not. The initial failures of wire code 3 (double extruded Poly-X) in Fluid G were probably caused by a combination of alkali and methylene chloride, while the later failures were due to alkali alone (after the methylene chloride had evaporated).

It is concluded that double extruded Poly-X is superior to single extruded Poly-X. Double wrap Kapton is superior to single wrap Kapton. Kapton with a fluorocarbon topcoat is superior to Kapton with a modified imide topcoat. Kapton is superior to Poly-X.

The new MIL-C-43616 cleaner with a pH of 9.2 caused only one dielectric withstand failure and that was on single extruded Poly-X after 28 days immersion. It lowered the insulation resistance of nylon jacketed PVC but had no effect on the electrical resistance of any other. Since Kapton wire and Kynar jacketed polyalkene wire are the only wire types currently available (of those tested herein) and since MIL-C-43616B Amend. #2 fluid has no adverse effect on them, both of these wire types look promising for use.

REFERENCES

[1] "Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles", NAFI TR-2145, 11 Aug 1976

[2] "Fluid Immersion Testing of Aircraft Electrical Wire", Report No. 03-76, NARF-NORIS, 13 Feb 1976

APPENDIX A

TABLE 1.

DIELECTRIC WITHSTAND FAILURES, FLUID A (pH = 13.3)

WIRE CODE	MILITARY PART NUMBER	DAYS OF TEST										TOTAL NO. OF FAILURES	NO. OF SPECIMENS TESTED
		1	2	3	4	5	6	7	14	21	28		
3	M81044/16-20-9			3	2	1		1,2,3	1,2,3	1,2,3	1,2,3	15	30
4	M81044/18-20-9	1	3	2	2,3	2	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	21	30
10	M81381/7-20-N							1,2,3	1,2,3	1,2,3	1,2,3	12	30
11	M81381/11-20-N							1,2,3	1,2,3	1,2,3	1,2,3	12	30
14	M81381/7-20-9											0	30
16	M81381/11-20-9											0	30
I	M81044/12-20-5											0	30
II	M81044/12-20-6											0	30
III	M81044/2-20-9											0	30
IV	M5086/2-18-9								31.7*	26.9*	14.6*	0	30
											Grand Total	= 60	300

Note: No entry: All three specimens passed.
1: Specimen No. 1 fails
2: Specimen No. 2 fails
3: Specimen No. 3 fails

* Insulation resistance of Specimen No. 1 (M Ω - 1000 ft.).

TABLE 2.

DIELECTRIC WITHSTAND FAILURES, FLUID N (pH = 9.2)

WIRE CODE	MILITARY PART NUMBER	DAYS OF TEST 1	2	3	4	5	6	7	14	21	28	TOTAL NO. OF FAIL-URES	NO. OF SPECI-MENS TESTED
3	M81044/16-20-9											0	30
4	M81044/18-20-9										2	1	30
10	M81381/7-20-N											0	30
11	M81381/11-20-N											0	30
14	M81381/7-20-9											0	30
16	M81381/11-20-9											0	30
I	M81044/12-20-5											0	30
II	M81044/12-20-6											0	30
III	M81044/2-20-9											0	30
IV	M5086/2-18-9								13.9*	111*		0	30
											Grand Total =	1	300

Note: No entry: All three specimens passed.
1: Specimen No. 1 fails
2: Specimen No. 2 fails
3: Specimen No. 3 fails

* Insulation resistance of Specimen No. 1 (M Ω - 1000 ft.).

TABLE 3.

DIELECTRIC WITHSTAND FAILURES, FLUID G (pH = 11.6)

WIRE CODE	MILITARY PART NUMBER	DAYS OF TEST 1	2	3	4	5	6	7	14	21	28	TOTAL NO.OF FAIL-URES	NO.OF SPECI-MENS TESTED
3	M81044/16-20-9	2	3				3		1,2,3	1,2,3	1,2,3	12	30
4	M81044/18-20-9	1,2	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	29	30
10	M81381/7-20-N				3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	19	30
11	M81381/11-20-N				2		2,3	1,2,3	1,2,3	1,2,3	1,2,3	15	30
14	M81381/7-20-9							1,2,3	1,2,3	1,2,3	1,2,3	12	30
16	M81381/11-20-9							2	1,2,3	1,2,3	1,2,3	10	30
I	M81044/12-20-5								0.356*	0.689*		0	30
II	M81044/12-20-6									0.689*		0	30
III	M81044/2-20-9								0.275*	0.168*		0	30
IV	M5086/2-18-9							0.395*	0.010*	0.372*	0.006*	0	30
										Grand Total =		97	330

Note: No entry: All three specimens passed.
1: Specimen No. 1 fails
2: Specimen No. 2 fails
3: Specimen No. 3 fails

* Insulation resistance of Specimen No. 1 (M Ω - 1000 ft.).

TABLE 4.

ELECTRICAL INSULATION RESISTANCE OF SPECIMEN #1 AFTER IMMERSION (M Ω - 1000 FT)

WIRE NO.	INSULATION RESISTANCE REQUIREMENT	FLUID NO.	DAYS OF IMMERSION IN FLUID	AFTER IMMERSION IN FLUID	PLUS 5 DAY DRY	SUBSEQUENT WATER IMMERSION							
						1 hr.	2 hr.	3 hr.	4 hr.	5 hr.	6 hr.	24 hr.	48 hr.
I	5,000	G	14 21	.356 .689	8.39	7.52	7.12	-	7.12	7.40	-	18.6	51.3
II	5,000	G	21	.689									
III	10,000	G	14 21	.275 .168	4.51	4.00	3.80	-	3.60	3.56	-	4.31	5.15
IV	40	G	7 14 21 28	.396 .010 .372 .006	25.3	22.1	14.2	15.7	-	11.9	11.6	11.3	19.6
		N	14 21	13.9 111	206	202	190	-	182	162	-	131	127
		A	14 21 28	31.7 26.9 14.6	57.0	57.0	49.1	-	45.9	40.8	-	43.5	45.1

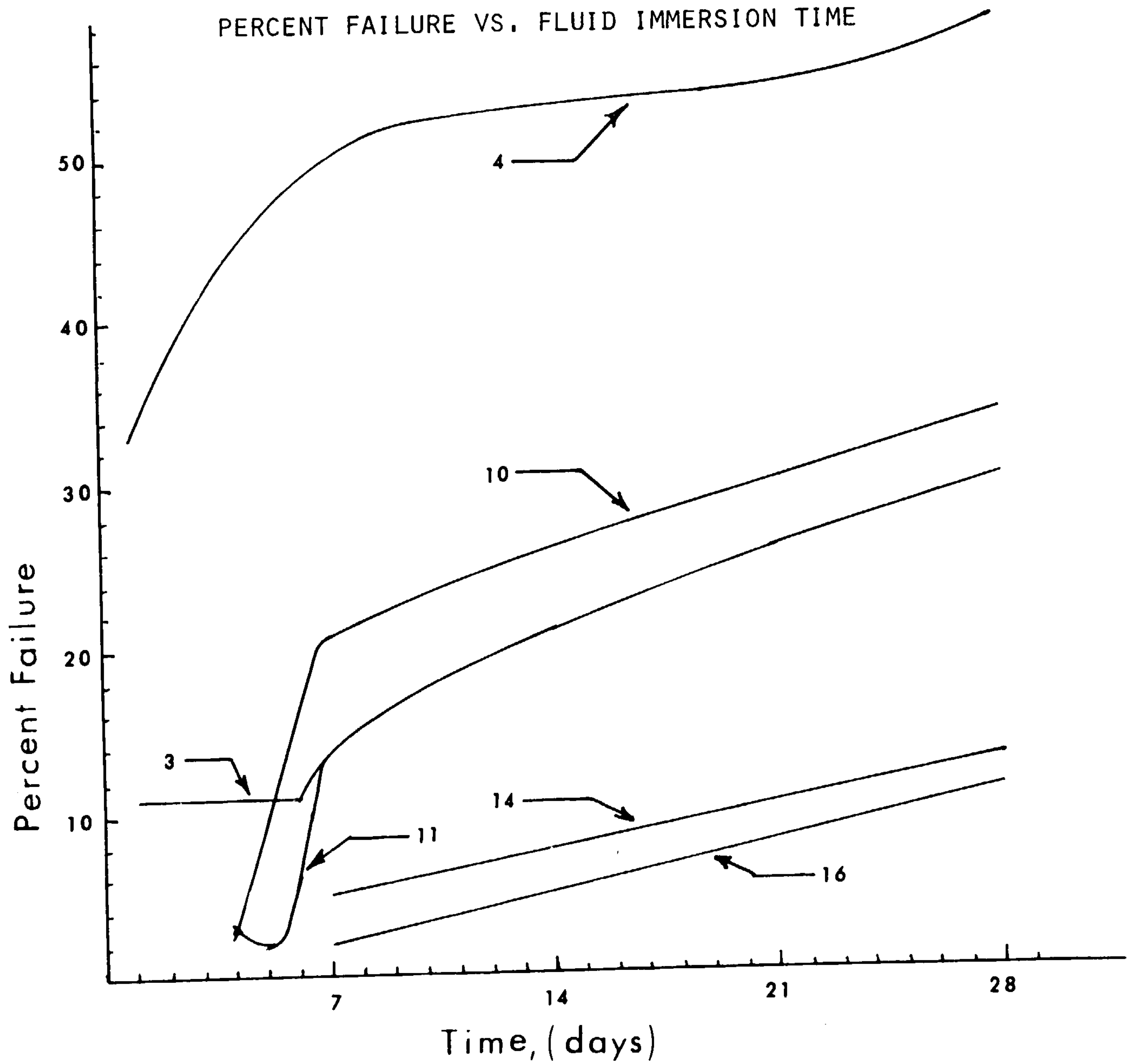
TABLE 5.

RANKING OF WIRE IN ORDER OF DECREASING RESISTANCE TO FLUID

RANK	WIRE CODE	SPECIFICATION	TOTAL NUMBER OF FAILURES
1	I	MIL-W-81044/12-20-5	0
	II	MIL-W-81044/12-20-6	0
	III	MIL-W-81044/2-20-9	0
	IV	MIL-W-5086/2-18-9	0
2	16	MIL-W-81381/11-20-9	10
3	14	MIL-W-81381/7-20-9	12
4	3	MIL-W-81044/16-20-9	27
	11	MIL-W-81381/11-20-N	27
5	10	MIL-W-81381/7-20-N	31
6	4	MIL-W-81044/18-20-9	51

GRAPH 1.

PERCENT FAILURE VS. FLUID IMMERSION TIME



APPENDIX B

APPENDIX B

MATERIAL CODES

FLUID CODE	MILITARY SPECIFICATION	PRODUCT IDENTIFICATION	MANUFACTURER
A	MIL-C-43616		
G	TT-R-248		
N	MIL-C-43616		
WIRE CODE			
3	MIL-W-81044/16-20-9		
4	MIL-W-81044/18-20-9		
10	MIL-W-81381/7-20-N		
11	MIL-W-81381/11-20-N		
14	MIL-W-81381/7-20-9		
16	MIL-W-81381/11-20-9		
I	MIL-W-81044/12-20-5		
II	MIL-W-81044/12-20-6		
III	MIL-W-81044/2-20-9		
IV	MIL-W-5086/2-18-9		

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PA(
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Robert L. Swaim
Systems Group Chairman, TWA 800 Investigation
National Transportation Safety Board
490 L'Enfant Plaza, E, SW
Washington, DC 20594

Mr. Swaim,

Your request to place four NAFI reports concerning testing and aging properties of different types of wire that were released in the 1970s in the public docket as background for your investigation is approved.

You may place the reports listed below, and their appendices, in the public docket as background for your investigation, provided you redact names of suppliers in the appropriate places as previously discussed:

Naval Avionics Facility (now the Wiring Qualification Group of Raytheon Systems Company) reports titled "Fluid Resistance Testing Of Electrical Wire Used in Aircraft And Missiles" comprised of:

NAFI-TR-2145
NAFI-TR-2199
NAFI-TR-2201
NAFI-TR-2210

Your point of contact in this matter is John Milliman who may be reached at the address above, by phone at (301) 757-6638 or by email at milliman@navair.navy.mil Please feel free to contact him if you need any further assistance.

Thank you,

Lola Hilton

Lola R. Hilton
Director of Corporate Communications

Note: The inserted letter covers the supplier information cited.
R Swaim

TOTAL P.

APPENDIX C

APPENDIX C.

DESCRIPTION OF FLUIDS AND WIRES USED

A. FLUIDS

The fluids chosen for this investigation are as follows:

1. MIL-C-43616, "Cleaning Compound, Aircraft Surface". This cleaning compound used by the Navy is water rinsable and required to be 90% biodegradable. The flash point is 142°F (min) and the pH of a 1:4 water dilution must fall between 8.0 and 12.0. The specification does not limit the composition of the cleaner; however, it does list a comparison formula with which to compare the cleaning effectiveness, and a recent amendment (2) limits the pH to 10 max. Two fluids were used: Fluid A (previously tested) with a pH of 13.3, and a new fluid (N) with a pH of 9.2 (both pH's measured in the concentrated form).

2. TT-R-248, "Remover, Paint and Lacquer, Solvent Type". This is a non-flammable, water rinsable solvent type paint and lacquer remover. It must not contain phenol, cresol, creosote oil, cresylic acid, benzene, carbon tetrachloride, perchloroethylene, trichloroethylene, or dichlorethylene. It may contain other chlorinated hydrocarbons if shown to have no deleterious effect on the aircraft. There is no requirement for pH. The specification does not contain a comparison formula. Fluid G (previously tested), containing methylene chloride and having a pH in concentrated form of 11.6, was used.

B. WIRES

The wires chosen for this investigation are as follows:

1. MIL-W-81044/16-20-9. This is a double extruded alkane-imide with an imide topcoat. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). This wire was tested in TR-2145[1] and identified by wire code #3.

2. MIL-W-81044/18-20-9. This is a single extruded alkane-imide with an imide topcoat. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). This wire was tested in TR-2145[1] and identified by wire code #4.

3. MIL-W-81281/7-20-N. This is a fluorocarbon/polyimide insulated wire with imide topcoat. It has a silver coated 19 strand copper conductor (AWG 20) and is natural color (-N). This wire was tested in TR-2145[1] and identified by wire code #10.

4. MIL-W-81381/7-20-9. This wire is the same as 3 above except that the color is white (-9). This wire was tested in TR-2145 and identified by wire code #14.

5. MIL-W-81381/11-20-N. This is a fluorocarbon/polyimide insulated wire with imide topcoat. It is the same as MIL-W-81381/7-20-N wire except that the insulation is thicker. It is natural (-N) color. This wire was tested in TR-2145[1] and identified by wire code #11.

6. MIL-W-81381/11-20-9. This is the same as 5 above except that the color is white (-9). This wire was tested in TR-2145[1] and identified by wire code #16.

7. MIL-W-81044/12-20-5 and -6. This is a crosslinked polyvinylidene flouride (Kynar) jacketed polyalkene. Two colors were used because they were available. This wire was not previously tested. The finished diameter is 0.055 inches.

8. MIL-W-81044/2-20-9. This is the same as 7 above except the color is white and the finished diameter is 0.078 inches.

9. MIL-W-5086/2-18-9. This wire is nylon jacketed PVC with a glass fiber braid beneath the nylon jacket. The color is white and the

finished diameter is 0.095 inches. It would have been preferable to test AWG 20 but AWG 18 was all that was immediately available.

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DOCUMENT CONTROL DATA - R&D

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Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles, PART II.

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical Report - 11 August 1977

5. AUTHOR(S) *(Last name, first name, initial)*

Watkins, Willard D.

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13. ABSTRACT

Several types of insulated electrical wire purchased to MIL-W-5086, MIL-W-81044 and MIL-W-81381 were immersed in solvents purchased to MIL-C-43616 and TT-R-248. The ability of the insulation to withstand degradation by the solvents was determined by subjecting the conditioned wire to a dielectric withstand voltage test. On some wire types the electrical insulation DC resistance was also determined.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Insulated Wire Cleaning Fluids Dielectric Withstand						

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by W.D.Watkins 11 Aug 1977 26p
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Several types of insulated electrical wire purchased to MIL-W-5086,MIL-W-81044 and MIL-W-81381 were immersed in solvents purchased to MIL-C-43616 and TT-R-248. The ability of the insulation to withstand degradation by the solvents was determined by subjecting the conditioned wire to a

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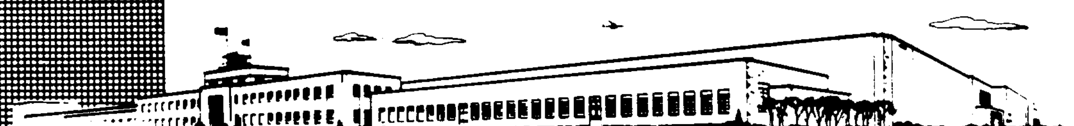

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PREFACE

This report describes an investigation into the ability of the insulation on aircraft electrical wire to withstand exposure to cleaners and paint removers which are used on aircraft surfaces. It is a continuation of work reported in NAFI TR-2199[1] and TR-2145[2].

This work was performed for NAVAIR under Work Request No. 68E95.

PREPARED BY: W. D. WATKINS

APPROVED BY: F. H. GAHIMER, Head
Organic Materials Branch

B. C. VAUGHN, Director, Materials
Laboratory and Consultants Division

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I. CONCLUSIONS

1. The wires tested herein are ranked in the order of decreasing resistance to solvent damage as follows:

Wire Code	Military Part No.	Insulation Type
1*	M22759/18-20-9	Tefzel
23*	55A0811-20-9	Irradiated Modified Tefzel
11	M81381/11-20-N	Double Wrap Kapton
3	M81044/16-20-9	Double Extruded Poly-X
12	M81381/7-20-2	Single Wrap Kapton
4	M81044/18-20-9	Single Extruded Poly-X

* No difference in rank.

2. Both Tefzel (M22759/18-20-9) and irradiated modified Tefzel (55A0811-20-9) insulated wires are superior in solvent resistance to all other types tested. Kapton insulated wire has better solvent resistance than Poly-X insulated wire.

3. The new MIL-C-43616, Amend. 2, cleaning fluid with a pH of 9.2 will cause far less solvent attack on wire insulation than previous types with a pH ≥ 11.

4. Elevated temperatures increase the activity of the MIL-C-43616 fluids used. Of the wire types susceptible to damage, the damage occurs faster at 75°C than at room temperature.

II. RECOMMENDATIONS

1. Of the wires tested herein, serious consideration for use should be given to both M22759/18-20-9 (Tefzel) and 55A0811-20-9 (irradiated modified Tefzel) wire.

III. INTRODUCTION

Previous testing[1] had established the time-to-failure of wires No. 3, 4, 11 and 12 when immersed in fluids A and N. It was concluded that Kapton insulated wire performed better than Poly-X insulated wire in similiar wall thicknesses.

The temperatures within the aircraft can be as high as 75^{O}C (higher in engine compartments). If a wiring harness is inadvertently contaminated with cleaning solutions or paint remover, it may be degraded faster than expected due to the elevated temperature.

It is the purpose of this investigation to:

1. Compare the solvent resistance of Poly-X and Kapton insulated wire by immersion in fluids at 75^{O}C.

2. Compare the solvent resistance of Tefzel and Irradiated Modified Tefzel insulated wire by immersion in fluids at 75^{O}C.

3. Compare the relative degree of damage caused by MIL-C-43616 cleaning solutions at room temperature and at 75^{O}C.

IV. MATERIALS

A. Fluids

Three fluids were chosen for use in this investigation. Fluids A and N are MIL-C-43616 cleaning compounds and Fluid G is a TT-R-248 paint remover. All three were previously used[1,2] and are identified in the same manner as in the previous reports. A complete description of the fluids used is given in Appendix C.

B. Wires

Six different insulated wires were used. Wires with code numbers 1, 3, 4, 11 and 12 are the same as those used in TR-2145[2]. One new wire was added. It is identified as wire code number 23. The wires are listed by code number and military specification in Tables 1 through 3. A complete description appears in Appendix C.

V. PROCEDURE

The fluids were used in the concentrated "straight from the can" form. This is the usual procedure for using the paint removers. While the cleaning solutions are sometimes used in the concentrated condition, they are usually diluted for use. Specifications requiring pH to be measured use a 1:4 dilution with water. For this investigation, pH of the solutions was measured in concentrated 1:4 dilution and 1.9 dilution form.

Three specimens from each of the six wire samples were tested in each of the three fluids for immersion times of 1 through 7 consecutive days, 2 weeks, 3 weeks and 4 weeks. The fluids were maintained at 75°C during immersion.

Testing in TT-R-248 (Fluid G) was discontinued after two days due to the condition of the fluid. A hard gum-like material formed which was difficult to remove from the wire specimens without damage to the insulation. However, test results to that point were similar to those obtained with MIL-C-43616 (pH = 13.3), Fluid A.

The wire samples were cut to 2 foot lengths with the ends stripped on an automatic Eubanks wire cutting machine. The specimens were formed from the 2 foot lengths by making a single turn loop with the ends of the wire run through the loop twice to secure the loop.

The loop was formed to a 1 inch diameter on a rod of that size and the stripped conductor ends twisted together. Identification tags were placed upon each specimen indicating the wire and fluid code and the time of immersion.

All specimens (#1, #2, and #3) were immersed in the test fluid in the "as looped" condition.

After immersion, specimen #1 was rinsed in tap water and allowed to dry one hour at room ambient conditions. It was then immersed for 1 hour in tap water containing an anionic wetting agent. While still in the tap water the insulation was subjected to a 1 minute dielectric withstand test of 2500 volts rms.

After immersion, specimen #2 was rinsed in tap water, uncoiled and allowed to dry for 1 hour at room ambient conditions. It was then subjected to the "double reverse wrap" on a 0.125" diameter mandrel as specified in the solvent resistance test procedure of the wire specifications. Following this, the specimen was formed into a loose coil and immersed in tap water for 1 hour before being subjected to a 1 minute dielectric withstand test of 2500 volts rms.

After immersion, specimen #3 was rinsed in tap water, uncoiled, and allowed to dry for 24 hours at room ambient conditions. Next, it was subjected to the "double reverse wrap" on a 0.125" mandrel, formed into loose coil, and immersed in tap water for 1 hours. The insulation was then subjected to a 1 minute dielectric withstand test of 2500 volts rms.

VI. RESULTS AND DISCUSSION

A. pH TESTING

The pH of the fluids was as follows:

	Fluid Code	Specification	pH		
			Conc.	1:4	1:9
As Received	A	MIL-C-43616	13.3	11.9	11.6
	G	TT-R-248	11.6	11.2	11.0
	N (New)	MIL-C-43616B,Amend#2	9.2	9.2	9.1
After 28 days at 75°C (tested at room temp.)	A	MIL-C-43616	10.4	10.1	10.2
	G	TT-R-248	not tested		
	N	MIL-C-43616B,Amend#2	8.7	8.8	8.9

Aging for 28 days at 75°C significantly lowers the pH of Fluid A and only slightly lowers the pH of Fluid N.

B. Fluid Immersion

The dielectric withstand failures are shown in Tables 1 through 3.

There were no failures of either Tefzel (M22759/18-20-9) insulated wire or Irradiated Modified Tefzel (55A0811-20-9) insulated wire in any of the fluids tested. Both of these are promising for such applications.

Table 4 contains the results obtained in previous testing[1,2] as well as those obtained in current testing. The wires are listed in order of decreasing resistance to solvent damage.

It is concluded that double extruded Poly-X is superior to single extruded Poly-X. Double wrap Kapton is superior to single wrap Kapton. Single wrap Kapton is slightly better than single extruded Poly-X. Double wrap Kapton is not different from double extruded Poly-X.

The results also indicate that if cleaning were restricted to the use of fluids no more active than the new MIL-C-43616, Amend. 2 (pH = 9.2) fluid, only the single extruded Poly-X insulation would likely be attacked.

REFERENCES

[1] "Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles, Part II", NAFI TR-2199, 11 Aug 1977

[2] "Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles", NAFI TR-2145, 11 Aug 1976

APPENDIX A

TABLE 1.

DIELECTRIC WITHSTAND FAILURES, FLUID A

WIRE CODE	MILITARY PART NUMBER	DAYS OF TEST (75°C)										TOTAL NO.OF FAIL-URES	NO.OF SPECI-MENS TESTED
		1	2	3	4	5	6	7		21	28		
1	M22759/18-20-9											0	30
3	M81044/16-20-9	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	30	30
4	M81044/18-20-9	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	30	30
11	M81381/11-20-N	3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	28	30
12	M81382/7-20-2	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	30	30
23	55A0811-20-9											0	30

Grand Total = 118 180

Note: No entry: All three specimens passed.
1: Specimen No. 1 failed.
2: Specimen No. 2 failed.
3: Specimen No. 3 failed.

TABLE 2.

DIELECTRIC WITHSTAND FAILURES, FLUID N

WIRE CODE	MILITARY PART NUMBER	DAYS OF TEST (75^oC)										TOTAL NO. OF FAILURES	NO. OF SPECIMENS TESTED
		1	2	3	4	5	6	7	14	21	28		
1	M22759/18-20-9											0	30
3	M81044/16-20-9											0	30
4	M81044/18-20-9				2		3	1,2	2,3	2,3	2,3	10	30
11	M81381/11-20-N											0	30
12	M81381/7-20-2										1,2,3	3	30
23	55A0811-20-9											0	30
	Grand Total =											13	180

Note: No entry: All three specimens passed.
1: Specimen No. 1 failed.
2: Specimen No. 2 failed.
3: Specimen No. 3 failed.

TABLE 3.

DIELECTRIC WITHSTAND FAILURES, FLUID G

WIRE CODE	MILITARY PART NUMBER	DAYS OF TEST (75°C)		
		1	2	
1	M22759/18-20-9			TEST TERMINATED DUE TO CONDITION OF TEST FLUID
3	M81044/16-20-9	2		
4	M81044/18-20-9	2,3	2,3	
11	M81381/11-20-N			
12	M81381/7-20-2		1,2,3	
23	55A0811-20-9			

Note: No entry: All three specimens passed.
1: Specimen No. 1 failed.
2: Specimen No. 2 failed.
3: Specimen No. 3 failed.

TABLE 4.

SUMMARY OF RESULTS TO DATE *

WIRE CODE	INSULATION	SPECIFICATION	DAYS TO FIRST FAILURE IN FLUID					
			MIL-C-43616				TT-R-248	
			A(pH = 13.3)		N(pH = 9.2)		G(pH = 11.6)	
			RT	75°C	RT	75°C	RT	75°C**
1	Tefzel	M22759/18-20-9	> 28	> 28	> 28	> 28	> 28	> 2
23	Irradiated Modified Tefzel	55A0811-20-9	***	> 28	***	> 28	***	> 2
11	Kapton, Double Wrap	M81381/11-20-N	7	1	> 28	> 28	4	> 2
12	Kapton, Single Wrap	M81381/7-20-2	7	1	> 28	28	7	2
3	Poly-X, Double Extruded	M81044/16-20-9	3	1	> 28	> 28	14	1
4	Poly-X, Single Extruded	M81044/18-20-9	1	1	28	4	1	1

* Also contains data from TR-2199[1] and TR-2145[2].

** Test terminated after two days.

*** Not tested at RT.

APPENDIX B

APPENDIX B

MATERIAL CODES

FLUID CODE	MILITARY SPECIFICATION	PRODUCT IDENTIFICATION	MANUFACTURER
A	MIL-C-43616		
G	TT-R-248		
N	MIL-C-43616		
WIRE CODE			
1	MIL-W-22759/18-20-9		
3	MIL-W-81044/16-20-9		
4	MIL-W-81044/18-20-9		
11	MIL-W-81381/11-20-N		
12	MIL-W-81381/7-20-2		
23	55A0811-20-9		

DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
NAVAL AIR SYSTEMS COMMAND HEADQUARTERS
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PAO
16 Dec 99

Robert L. Swaim
Systems Group Chairman, TWA 800 Investigation
National Transportation Safety Board
490 L'Enfant Plaza, E, SW
Washington, DC 20594

Mr. Swaim,

Your request to place four NAFI reports concerning testing and aging properties of different types of wire that were released in the 1970s in the public docket as background for your investigation is approved.

You may place the reports listed below, and their appendices, in the public docket as background for your investigation, provided you redact names of suppliers in the appropriate places as previously discussed:

Naval Avionics Facility (now the Wiring Qualification Group of Raytheon Systems Company) reports titled "Fluid Resistance Testing Of Electrical Wire Used in Aircraft And Missiles" comprised of:

NAFI-TR-2145
NAFI-TR-2199
NAFI-TR-2201
NAFI-TR-2210

Your point of contact in this matter is John Milliman who may be reached at the address above, by phone at (301) 757-6638 or by email at millimanjc@navair.navy.mil. Please feel free to contact him if you need any further assistance.

Thank you,

Lola Hilton

Lola R. Hilton
Director of Corporate Communications

Note: The inserted copy of this letter covers the cited supplier information.
R Swaim

TOTAL P.01

APPENDIX C

APPENDIX C.

DESCRIPTION OF FLUIDS AND WIRES USED

A. FLUIDS

The fluids chosed for this investigation are as follows:

1. MIL-C-43616, "Cleaning Compound, Aircraft Surface". This cleaning compound used by the Navy is water rinsable and required to be 90% biodegradable. The flash point is 142°F (min) and the pH of a 1:4 water dilution must fall between 8.0 and 12.0. The specification does not limit the composition of the cleaner; however, it does list a comparison formula with which to compare the cleaning effectiveness, and a recent amendment (2) limits the pH to 10 max. Two fluids were used: Fluid A (previously tested) with a pH of 13.3, and a new fluid (N) with a pH of 9.2 (both pH's measured in the concentrated form).

2. TT-R-248, "Remover, Paint and Lacquer, Solvent Type". This is a non-flammable, water rinsable solvent type paint and lacquer remover. It must not contain phenol, cresol, creosote oil, cresylic acid, benzene, carbon tetrachloride, perchloroethylene, trichloroethylene, or dichlorethylene. It may contain other chlorinated hydrocarbons if shown to have no deleterious effect on the aircraft. There is no requirement for pH. The specification does not contain a comparison formula. Fluid G (previously tested), containing methylene chloride and having a pH in concentrated form of 11.6, was used.

B. WIRES

The wires chosen for this investigation are as follows:

1. MIL-W-22759/18-20-9. This is an extruded ETFE fluorocarbon insulation on silver coated 19 strand copper conductor (AWG 20) and is white (-9). This wire was tested in TR-2145[2] and identified by Wire Code #1.

2. MIL-W-81044/16-20-9. This is a [illegible] extruded alkane-imide with an imide topcoat. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). This wire was tested in TR-2199[1] and in TR-2145[2] and is identified by wire code #3.

3. MIL-W-81044/18-20-9. This is a single extruded alkane-imide with an imide topcoat. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). This wire was tested in TR-2199[1] and TR-2145[2] and identified by wire code #4.

4. MIL-W-81381/11-20-N. This is a fluorocarbon/polyimide insulated wire with imide topcoat. It is the same as MIL-W-81381/7-20-2 wire except that the insulation is thicker. It is natural (-N) color. This wire was tested in TR-2199[1] and in TR-2145[2] and identified by wire code #11.

5. MIL-W-81281/7-20-[illegible]. This is a fluorocarbon/polyimide insulated wire with imide topcoat. It has a silver coated 19 strand copper conductor (AWG 20) and is red in color (-2). This wire was tested in TR-2145[2] and identified by wire code #12. It can be compared with wire code #10 in TR-2199[1] since it is identical except for color.

6. 55A0811-20-9. This is an irradiated modified ETFE fluorocarbon insulation on tin coated 19 strand copper conductor (AWG 20) and is white (-9). This wire was not previously tested and is being considered for inclusion into MIL-W-22759.

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3. REPORT TITLE
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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Report - 13 September 1977

5. AUTHOR(S) (Last name, first name, initial)
Watkins, Willard D.

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13. ABSTRACT

Several types of insulated electrical wire purchased to MIL-W-22759, MIL-W-81044, and MIL-W-81381, along with a new fluoropolymer insulated wire, were immersed in solvents purchased to MIL-C-43616 and TT-R-248. The ability of the insulation to withstand degradation by the solvents was determined by subjecting the conditioned wire to a dielectric withstand voltage test. This testing differs from previous testing[1,2] in that the fluids were maintained at 75°C during immersion of the wire specimens.

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	ROLE	WT	ROLE	WT	ROLE	WT
Insulated wire						
Cleaning fluids						
Dielectric withstand						

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TR 2210
19 OCTOBER 1977

NAFI publication

FLUID RESISTANCE TESTING OF ELECTRICAL WIRE USED IN AIRCRAFT AND MISSILES

PART IV

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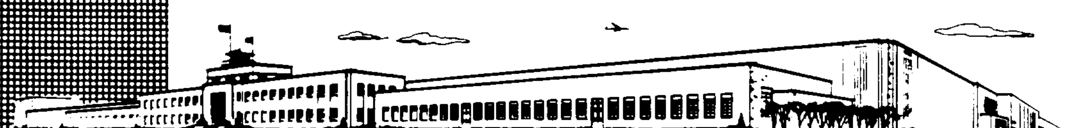

NAVAL AVIONICS FACILITY

INDIANAPOLIS, INDIANA 46218

PREFACE

This report describes an investigation into the ability of the insulation on aircraft electrical wire to withstand exposure to cleaners which are used on aircraft surfaces. It is a continuation of work reported in NAFI TR-2145[3], TR-2199[1] and TR-2201[2].

This work was performed for NAVAIR under Work Request No. 68E95.

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ABSTRACT

Several types of insulated electrical wire pu ased to MIL-W-81044 were immersed in cleaners purchased to MI -C-43616. The ability of the insulation to withstand degradation by the cleaners was determined by subjecting the conditioned wire to a dielectric withstand voltage test. The electrical insulation DC resistance was also determined.

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I. CONCLUSIONS

1. None of the insulations tested were degraded enough to cause a dielectric withstand failure.

2. Halar® and Kynar® jacketed polyalkene wire resisted the cleaners equally well as evaluated by dielectric withstand testing. However, Halar may have some superiority in regards to DC resistance testing.

3. Removing the Halar and Kynar jackets did not affect the performance in dielectric withstand testing.

4. Kapton insulated wire may fail on naval aircraft after seven to twenty-one years service. More complete field failure reports concerning both Poly-X and Kapton insulated wire are necessary in order to improve this estimate of the service life of Kapton insulated wire.

II. RECOMMENDATIONS

1. The following four wires should be considered for general use in Navy aircraft on the basis of all testing performed to date:

MIL-W-81044/30 and /33 (Proposed)
MIL-W-81044/9 and /12
MIL-W-22759/16 and /18
55A0811

2. It is recommended that a twofold evaluation program be instituted for the above wires. One part would consist of qualification testing of each wire. The second part would involve performing 28 day immersion tests in a broad spectrum of fluids as in the early evaluations done by NARF-NORIS[4].

3. The DC resistance should be determined on a 25 ft. specimen in future solvent resistance testing.

4. In order to obtain a better estimate of the Kapton service life based on the Poly-X service experience it is recommended that:

a. All failures of Poly-X insulated wire on Navy aircraft should be reported, identifying the aircraft type, aircraft BUNO, type of failure (arc-thru, low resistance, etc.), and location on the aircraft.

b. Failed Poly-X insulated wires or cables should be sent to NAFI, D/713, along with a copy of the failure report, with the failed wire tagged or otherwise marked. NAFI will perform further failure analysis and positively identify wire insulation type.

III. INTRODUCTION

In a previous report[1] it was recommended that newly developed polymers used as insulation on electrical wire be evaluated for their resistance to solvent and fluid damage. Two relatively new plastic materials have since been proposed for use in aircraft electrical wire.

One is ECTFE (Halar®) jacketed polyalkene which is radiation crosslinked. This wire is described in specifications MIL-W-81044/30 (Proposed) and /31 (Proposed). It is similar in construction to MIL-W-81044/9 and /12, which is polyvinylidene fluoride (Kynar®) jacketed polyalkene and is also radiation cross-linked.

The other is Irradiated Modified ETFE (Tefzel®) which is radiation crosslinked. This wire is described in a commercial specification and is referred to as Spec "55" wire. It is similar to MIL-W-22759/16 or /18 which are insulated with unmodified Tefzel.

Both Tefzel and Irradiated Modified Tefzel were previously tested[2] for solvent damage by immersion. Both have excellent resistance to damage by high pH fluids (pH $\approx$13) even at 75° C. There were no dielectric withstand failures after 28 days immersion. The Halar jacketed polyalkene wire was not previously tested.

It is the purpose of this investigation to:

1. Compare the solvent resistance of Halar and Kynar jacketed polyalkene wire immersed at 25°C and 75°C with and without jackets.

2. Measure the DC electrical resistance of the wire insulation during solvent immersion.

IV. MATERIALS

A. Fluids

Two fluids were chosen for this investigation. Fluids A and N are MIL-C-43616 cleaning compounds which were previously employed[1,2,3] and are identified in the same manner as in the previous reports. A complete description of the fluids is given in Appendix C.

B. Wires

Several combinations of two different insulated wires were used. The insulation systems are either Halar or Kynar jacketed polyalkene. They were also tested with the jackets removed. They are identified as follows:

Wire No.	Specification
19	MIL-W-81044/30-20-9 (Proposed)
20	MIL-W-81044/31-20-9 (Proposed)
19WO	No. 19 with jacket removed
20WO	No. 20 with jacket removed
22	MIL-W-81044/12-20-9
22WO	No. 22 with jacket removed

The wires are listed by code number and specification in Tables 1 and 2. A complete description appears in Appendix C.

V. PROCEDURE

The fluids were used in the concentrated "straight from the can" form. Periodically throughout the testing it was necessary to "reconstitute" some of the fluids by adding distilled water to compensate for loss due to evaporation. The evaporation of constituents other than water was assumed to be negligible.

Three specimens from each of the five wire samples were tested in each of the fluids (A and N) for immersion times of 1 through 7 consecutive days, 2 weeks, 3 weeks, and 4 weeks, both at 25°C and 75°C.

The wire samples were cut to 2 foot lengths with the ends stripped on an automatic Eubanks wire cutting machine. The specimens were formed from the 2 foot lengths by making a single turn loop with the ends of the wire run through the loop twice to secure the loop. The loop was formed to a 1 inch diameter on a rod of that size and the stripped conductor ends twisted together. Identification tags were attached to each specimen indicating the wire and fluid code and the time and temperature of immersion.

All specimens (#1, #2, and #3) were immersed in the test fluid in the "as looped" condition.

After immersion, all three specimens were rinsed in tap water and then immersed in 5% salt water for 1 hour. The DC resistance of the insulation was determined after one minute electrification using 500v DC.

Specimen #1 was then immersed for 1 hour in tap water containing an anionic wetting agent. While still in the tap water the insulation was subjected to a 1 minute dielectric withstand test of 2500 volts rms.

Specimen #2 was rinsed in tap water, uncoiled, and allowed to dry for 1 hour at room ambient conditions. It was then subjected to the "double reverse wrap" on a 0.125" diameter mandrel as specified in the solvent resistance test procedure of the wire specifications. Following this, the specimen was formed into a loose coil and immersed in tap water for 1 hour before being subjected to a 1 minute dielectric withstand test of 2500 volts rms.

Specimen #3 was rinsed in tap water, uncoiled, and allowed to dry for 24 hours at room ambient conditions. Next, it was subjected to the "double reverse wrap" on a 0.125" mandrel, formed into a loose coil, and immersed in tap water for 1 hour. The insulation was then subjected to a 1 minute dielectric withstand test of 2500 volts rms.

VI. RESULTS AND DISCUSSION

A. pH TESTING

The pH of the fluids was as follows:

	Fluid Code	Specification	pH		
			Conc.	1:4	1:9
As Received	A	MIL-C-43616	13.3	11.9	11.6
	N (New)	MIL-C-43616B, Amend #2	9.2	9.2	9.1
After 28 days at 75°C (tested at room temp.)	A	MIL-C-43616	10.4	10.1	10.2
	N	MIL-C-43616B, Amend #2	8.7	8.8	8.9

Aging for 28 days at 75°C significantly lowers the pH of Fluid A and only slightly lowers the pH of Fluid N.

B. Fluid Immersion

There were no failures in either Halar jacketed polyalkene wire (MIL-W-81044/30 or /31, Proposed) or Kynar jacketed polyalkene wire (MIL-W-81044/12) in either of the fluids at 25°C or 75°C.

There were no failures in the above wires with jackets removed and subjected to the same test conditions.

The averages of measured DC electrical resistance values are listed in Tables 1 and 2. The DC resistance of wires immersed at room temperature is lower at the end of 28 days immersion than at the start. This trend is clearly seen for all wires tested in Fluid A (pH = 13.3). It is also seen for wires with jackets removed and tested in Fluid N (pH = 9.2).

The DC resistance of wires immersed at 75°C in Fluid A are also lower at the end of 28 days immersion than at the start.

The daily variation in DC resistance data can be attributed to the short length of the specimen. Only 12 inches of the specimen is immersed and measured for DC resistance. When testing is performed strictly to the specification, the DC resistance is measured on a 25 ft. length. It is felt that future testing of DC resistance after fluid immersion should be done using the 25 ft. specimen.

Curve fitting (with data smoothing) was performed on some of the DC resistance data collected at room temperature and the resultant curves are shown in Graph 1. These curves are useful in showing trends and relative position, but the values of DC resistance shown are not accurate due to the variation in the original data.

It is encouraging that no individual determination of DC resistance on any of the wires was below the minimum resistance specified for cable harness assemblies at the NARFs, 100MΩ ($1 \times 10^{8}\Omega$).

The measured values of DC resistance are lowered by removing the Halar and Kynar jackets about 40% due to loss in material alone. It is obvious that the measured difference is much greater than 40%. It is concluded that both jackets enhance the insulation construction for protection against fluid degradation.

C. Summary

A summary of the results to date of dielectric withstand testing after fluid immersion is given in Table 3. Only wire types currently used or proposed for use are listed.

D. Wire Service Life

Wires 3 and 4 (Poly-X) are purchased to MIL-W-81044/16 and /18 respectively. These specifications were added to MIL-W-81044 on 2 January 1970. The wire was used on the F-4N aircraft, and in September 1975 the first malfunction due to the Poly-X degradation was recorded[6]. The wire could not have been in service more than five years.

Poly-X wire was also used on the F-14 aircraft, which has been operational for about six years. Field failures of Poly-X wire have also been reported for the F-14. While the reports have not accurately established the time of failure, it appears to be no sooner than about three years.

The laboratory tests have indicated that single extruded Poly-X will fail before double extruded Poly-X. The field failure reports do not list which of these caused the malfunction. The preponderance of the wire used in both aircraft is double extruded. But there is doubt as to which one to choose in trying to correlate the three year minumum five year maximum estimate of service life.

Most of the damaged wire found in the aircraft was in SWAMP* areas.

Wires 11 and 12 (Kapton) have been used in the S-3A aircraft, including SWAMP areas, and have been operational for about four years. No field failures have been reported.

Laboratory testing indicated that light weight Kapton (M81381/7) will fail at about the same time as normal weight Kapton (M81381/11) in high pH cleaners. Compared to Poly-X (Table 3, Column 1), Kapton insulation may last from 2.3 to 7 times longer, depending upon whether the comparison is made with single or double extruded Poly-X.

If it is assumed that there is reasonable correlation between laboratory tests and service experience, then Kapton insulated wire may fail after 7-21 years of service. The use of milder cleaning compounds to MIL-C-43616, Amend. 2 (pH ≤ 10) should extend the service life of the insulation.

It is important to be able to predict if and when Kapton insulation will fail in service to determine whether rework may be necessary in present equipment, and to make intelligent decisions in future applications of Kapton. It is necessary to obtain better failure data on Poly-X now in service so that a better estimate of Kapton service life can be made. For the present, Kapton should not be used in SWAMP areas.

In order to determine more accurately the failure history of the Poly-X in service, and thus obtain a better

* SWAMP = Severe Wind And Moisture Problem

estimate of the Kapton service life:

a. All cable harnesses which fail electrically should be reported, identifying the date of failure, the aircraft type, aircraft BUNO, location of cable in aircraft, age of aircraft (or harness) if known.

b. Failed cable harness assemblies (including connectors, if unusable) should be sent to NAFI, D/713, for further failure analysis and positive identification of wire insulation type.

REFERENCES

[1] "Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles, Part II", NAFI TR-2199, 11 Aug 1977

[2] "Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles, Part III", NAFI TR-2201, 13 Sep 1977

[3] "Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles", NAFI TR-2145, 11 Aug 1976

[4] "Fluid Immersion Testing of Aircraft Electrical Wire", Report No. 03-76, NARF-NORIS, 13 Feb 1976

[5] "Investigation of Poly-X Wire Deterioration on F-4N Aircraft", Report No. 01-76, NARF-NORIS, 30 Jan 1976

APPENDIX A

TABLE 1. D.C. RESISTANCE (Ω) AFTER IMMERSION

FLUID	WIRE CODE	MILITARY PART NUMBER	IMMERSION TIME (DAYS) AT 75°C									
			1	2	3	4	5	6	7	14	21	28
A (pH=13.3)	19	M81044/30-20-9*	1.22×10^{13}	5.67×10^{12}	5.18×10^{12}	4.72×10^{12}	3.29×10^{12}	2.68×10^{12}	2.92×10^{12}	8.53×10^{11}	2.50×10^{12}	2.05×10^{11}
	20	M81044/31-20-9*	2.28×10^{13}	1.21×10^{13}	8.64×10^{12}	3.71×10^{12}	4.65×10^{12}	6.59×10^{12}	1.51×10^{12}	2.33×10^{12}	1.56×10^{12}	4.69×10^{11}
	22	M81044/12-20-9	3.89×10^{13}	3.22×10^{12}	2.01×10^{12}	5.11×10^{12}	1.52×10^{12}	9.30×10^{11}	6.20×10^{11}	1.09×10^{11}	3.49×10^{11}	5.19×10^{10}
	19WO	No.19 W/O jacket	3.70×10^{11}	3.45×10^{11}	3.50×10^{11}	-	-	4.10×10^{11}	4.15×10^{11}	6.70×10^{10}	5.00×10^{11}	1.43×10^{10}
	22WO	No.22 W/O jacket	1.02×10^{11}	1.01×10^{11}	6.80×10^{10}	-	-	6.90×10^{10}	4.30×10^{10}	5.60×10^{9}	3.50×10^{10}	2.50×10^{9}
N (pH=9.2)	19	M81044/30-20-9	-	-	-	-	4.65×10^{12}	6.89×10^{12}	1.19×10^{12}	7.27×10^{12}	3.17×10^{12}	4.55×10^{12}
	20	M81044/31-20-9	-	-	-	-	7.64×10^{12}	9.44×10^{12}	2.41×10^{12}	7.81×10^{12}	3.03×10^{12}	1.01×10^{13}
	22	M81044/12-20-9	-	-	-	-	2.65×10^{12}	2.48×10^{12}	1.24×10^{12}	2.91×10^{12}	6.82×10^{12}	2.38×10^{12}
	19WO	No.19 W/O jacket	1.76×10^{12}	1.80×10^{12}	2.70×10^{12}	-	-	2.11×10^{12}	1.93×10^{12}	2.20×10^{12}	2.30×10^{12}	3.70×10^{10}
	22WO	No.22 W/O jacket	1.86×10^{12}	1.28×10^{12}	1.44×10^{12}	-	-	3.05×10^{11}	1.46×10^{11}	1.60×10^{10}	2.15×10^{11}	4.40×10^{9}

* Both M81044/30 and /31 are Halar jacketed polyalkene and are proposed for addition to MIL-W-81044.

TABLE 2. D.C. RESISTANCE (Ω) AFTER IMMERSION

FLUID	WIRE CODE	MILITARY PART NUMBER	IMMERSION TIME (DAYS) AT 75°C: 1	2	3	4	5	6	7	14	21	28
A	19	M81044/30-20-9*	1.12×10^{12}	-	-	-	-	1.08×10^{12}	1.42×10^{12}	6.10×10^{11}	3.71×10^{10}	3.8×10^{12}
(pH=13.3)	20	M81044/31-20-9*	5.98×10^{12}	-	-	-	-	1.98×10^{12}	2.05×10^{10}	2.09×10^{10}	1.23×10^{8}	1.75×10^{9}
	22	M81044/12-20-9	5.43×10^{11}	-	-	-	-	3.12×10^{10}	1.29×10^{11}	1.14×10^{10}	1.42×10^{8}	8.00×10^{10}
N	19	M81044/30-20-9	4.25×10^{12}	-	-	-	-	3.65×10^{12}	7.00×10^{12}	1.07×10^{12}	1.42×10^{11}	9.00×10^{12}
(pH=9.2)	20	M81044/31-20-9	6.90×10^{12}	-	-	-	-	7.25×10^{11}	4.45×10^{12}	1.84×10^{12}	8.80×10^{10}	11.8×10^{12}
	22	M81044/12-20-9	2.80×10^{12}	-	-	-	-	6.70×10^{11}	4.3×10^{12}	4.3×10^{12}	2.40×10^{10}	3.60×10^{12}

* Both M81044/30 and /31 are Halar jacketed polyalkene and are proposed for addition to MIL-W-81044.

TABLE 3.

SUMMARY OF RESULTS TO DATE*

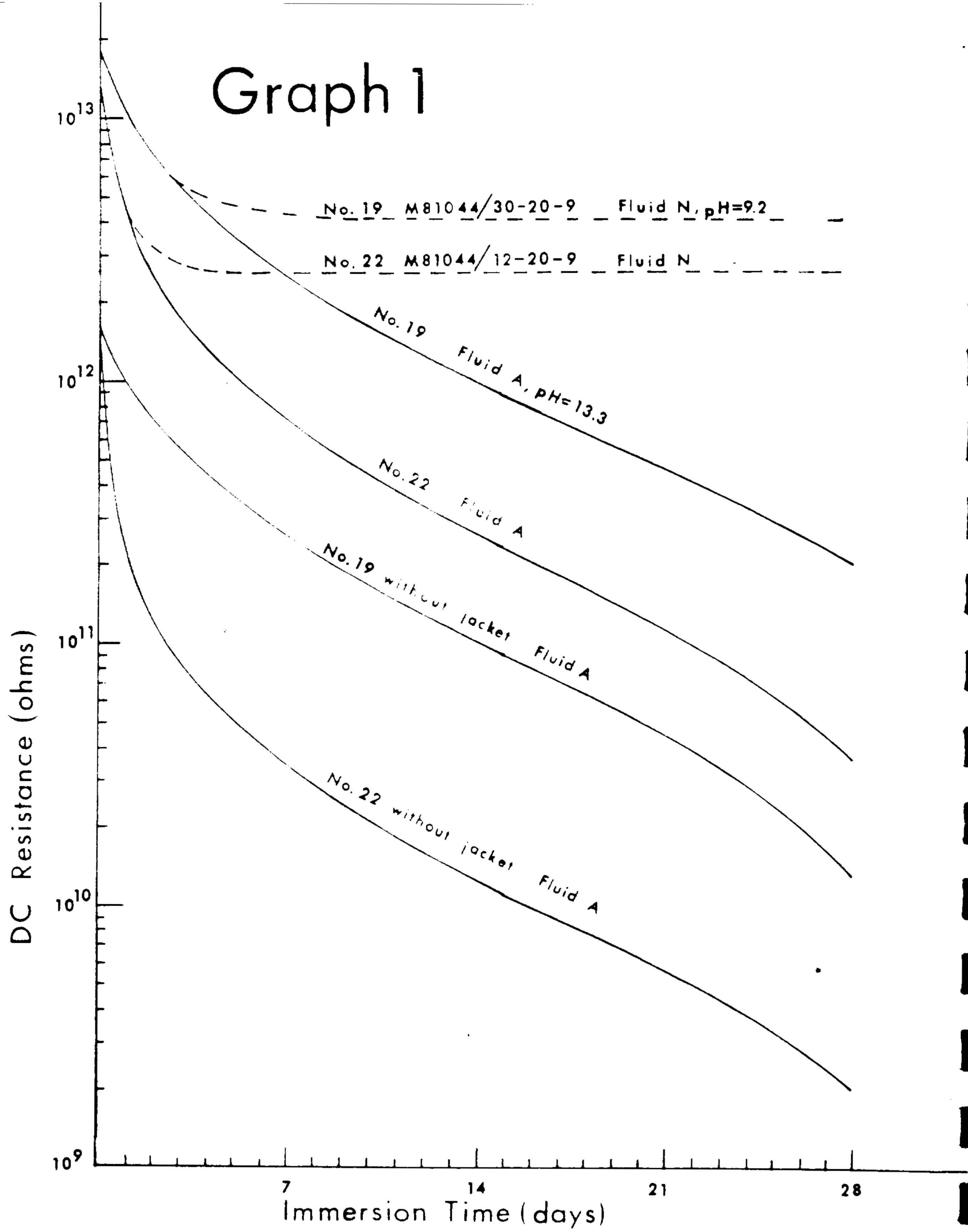
WIRE CODE	INSULATION	SPECIFICATION	DAYS TO FIRST FAILURE IN FLUID					
			MIL-C-43616				TT-R-248	
			A(pH = 13.3)		N(pH = 9.2)		G(pH = 11.6)	
			RT	75°C	RT	75°C	RT	75°C**
1	Tefzel	M22759/18-20-9	> 28	> 28	> 28	> 28	> 28	> 2
23	Irradiated Modified Tefzel	55A0811-20-9	***	> 28	***	> 28	***	> 2
19	Halar/Polyalkene	M81044/30-20-9 (Proposed)	> 28	> 28	> 28	> 28	***	***
20	Halar/Polyalkene	M81044/31-20-9 (Proposed)	> 28	> 28	> 28	> 28	***	***
22	Kynar/Polyalkene	M81044/12-20-9	> 28	> 28	> 28	> 28	***	***
11	Kapton, Double Wrap	M81381/11-20-N	7	1	> 28	> 28	4	> 2
12	Kapton, Single Wrap	M81381/7-20-2	7	1	> 28	28	7	2
3	Poly-X, Double Extruded	M81044/16-20-9	3	1	> 28	> 28	14	1
4	Poly-X, Single Extruded	M81044/18-20-9	1	1	28	4	1	1

* Also contains data from TR-2199[1], TR-2145[3] and TR-2201[2]

** Test terminated after two days.

*** Not tested

Graph 1



No. 19 M81044/30-20-9 Fluid N, pH=9.2
No. 22 M81044/12-20-9 Fluid N
No. 19 Fluid A, pH=13.3
No. 22 Fluid A
No. 19 without jacket Fluid A
No. 22 without jacket Fluid A
10^13
10^12
10^11
10^10
10^9
DC Resistance (ohms)
7
14
21
28
Immersion Time (days)

APPENDIX B

APPENDIX B

MATERIAL CODES

FLUID CODE	MILITARY SPECIFICATION	PRODUCT IDENTIFICATION	MANUFACTURER
A	MIL-C-43616		
G	TT-R-248		
N	MIL-C-43616, Amend. 2		
WIRE CODE			
1	MIL-W-22759/18-20-9		
3	MIL-W-81044/16-20-9		
4	MIL-W-81044/18-20-9		
11	MIL-W-81381/11-20-N		
12	MIL-W-81381/7-20-2		
19	MIL-W-81044/30/20-9*		
20	MIL-W-81044/31-20-9*		
22	MIL-W-81044/12-20-9		
23	55A0811-20-9		

* Proposed

DEPARTMENT OF THE NAVY
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47123 BUSE ROAD, UNIT #
PATUXENT RIVER, MARYLAND 20670-1547

16 Dec

Robert L. Swaim
Systems Group Chairman, TWA 800 Investigation
National Transportation Safety Board
490 L'Enfant Plaza, E, SW
Washington, DC 20594

Mr. Swaim,

Your request to place four NAFI reports concerning testing and aging properties of different ypes of wire tha were released in the 1970s in the public docket as background for your investigation is approved.

You may place the reports listed below, and their appendices, n the public docket as background for your investigation, provided you redact names of suppliers in the appropriate places as previously discussed:

Naval Avionics Facility (now the Wiring Qualification Group of Raytheon Systems Company) reports titled "Fluid Resistance Testing Of Electrical Wire Used in Aircraft And Missiles" comprised of.

NAFI-TR-2145
NAFI-TR-2199
NAFI-TR-2201
NAFI-TR-2210

Your point of contact in this matter is John Milliman who may be reached at the address above, by phone at (301) 757-6638 or by email at millimanjc@navair.navy.mil Please feel free to contact him if you need any further assistance.

Thank you,

Lola Hilton

Lola R. Hilton
Director of Corporate Communications

Note: The inserted copy of this letter covers the cited supplier information.
R Swaim

TOTAL P.

APPENDIX C

APPENDIX C.

DESCRIPTION OF FLUIDS AND WIRES USED

A. FLUIDS

The fluids chosen for this investigation are as follows:

1. MIL-C-43616, "Cleaning Compound, Aircraft Surface". This cleaning compound used by the Navy is water rinsable and required to be 90% biodegradable. The flash point is 142°F (min) and the pH of a 1:4 water dilution must fall between 8.0 and 12.0. The specification does not limit the composition of the cleaner; however, it does list a comparison formula with which to compare the cleaning effectiveness, and a recent amendment (2) limits the pH to 10 max. Two fluids were used: Fluid A with a pH of 13.3, and a new fluid (N) with a pH of 9.2 (both pH's measured in the concentrated form).

B. WIRES

The wires chosen for this investigation are as follows:

1. MIL-W-81044/30-20-9 (Proposed). This is a radiation crosslinked ethylenechlorotetrafluoroethylene (ECTFE, Halar®) jacketed polyalkene insulated electrical wire. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). It is similar in construction to MIL-W-81044/12-20-9. The finished diameter is 0.055 inches and is a "light weight" wire. It is identified herein as Wire No. 19.

2. MIL-W-81044/31-20-9 (Proposed). This is identical to MIL-W-81044/30-20-9 wire except the finished wire diameter is 0.070 inches and is a "medium weight" wire. It is similar in construction to MIL-W-81044/9-20-9 wire. It is identified herein as Wire No. 20.

3. MIL-W-81044/12-20-9. This is a radiation crosslinked polyvinylidene fluoride (Kynar®) jacketed polyalkene insulated electrical wire. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). The finished diameter is 0.055 inches and is a "light weight" wire. It is identified herein as Wire No. 22.

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Naval Avionics Facility (NAFI
Report TR-2210)
FLUID RESISTANCE TESTING OF ELECTRICAL WIRE USED IN AIRCRAFT AND MISSILES PART IV.
by W.D.Watkins 19 Oct 77 30p
UNCLASSIFIED

Several types of insulated electrical wire purchased to MIL-W-81044 were immersed in cleaners purchased to MIL-C-43616. The ability of the insulation to withstand degradation by the cleaners was determined by subjecting the conditioned wire to a dielectric

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical Report - 19 October 1977

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13. ABSTRACT

Several types of insulated electrical wire purchased to MIL-W-81044 were immersed in cleaners purchased to MIL-C-43616. The ability of the insulation to withstand degradation by the cleaners was determined by subjecting the conditioned wire to a dielectric withstand voltage test. The electrical insulation DC resistance was also determined.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Insulated wire						
Cleaning fluids						
Dielectric withstand						
Insulation DC electrical resistance						
Service life						

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DEPARTMENT OF THE NAVY

NAVAL AIR SYSTEMS COMMAND
NAVAL AIR SYSTEMS COMMAND HEADQUARTERS
WASHINGTON, DC 20361

IN REPLY REFER TO

10000
AIR-5304/ 4195
20 SEPTEMBER 1985

MEMORANDUM

From: AIR-530A
To: AIR-546

Subj: TECHNICAL EVALUATION OF MIL-W-81381 ELECTRICAL WIRE INSULATION

Encl: (1) Technical Review of MIL-W-81381
(2) Tabulation of Reports/Documents Reviewed
(3) NADC Technical Evaluation of 30 Aug 85
(4) Aerostructures Technical Evaluation of 16 Sep 85
(5) NASA Technical Evaluations of 9 Sep 1985
(6) NAC Technical Evaluation of 16 Sep 85
(7) Proposed Status Letter to Industry

1. A technical review, enclosure (1), of available reports/documents was conducted by AIR-5304 over the period 22 August to 13 September 1985. The objective was to assess the material performance and ballistic impact behavior of electrical wires conforming to MIL-W-81381. These wires are insulated with a polyimide film manufactured by E.I. Du Pont Company under the registered trademark of "KAPTON". The maintenance performance of these wires has been a subject of debate for years, however a new review was required because recent ballistic impact testing at NRL raised the question of aircraft survivability. This type of wire insulation is now being used on nearly all military and commercial aircraft.

2. The subject review was conducted by AIR-5304 supplemented by the personnel identified below:

Mr. K. Clark - NAVAIRDEVCEN, Warminster, PA
Mr. M. Stander - Aerostructures, Arlington, VA
Mr. E. Kelsey - NASA Langley Research Center, VA
Mr. J. Gowdey - NASA Langley Research Center, VA
Mr. R. Beach - NAC, Indianapolis, IN

The pertinent documents reviewed are tabulated in enclosure (2) and the individual technical evaluations are provided as enclosures (3) through (7).

3. This review was conducted from a materials engineering point of view, the conclusions of which are summarized below. The rationale for these conclusions is provided in enclosure (1) and forms the basis for this technical position. It should be noted that several of the conclusions are not in complete agreement with the recommendations of the support personnel, however their input was valuable in assessing the overall situation.

NAVY MEMO OF 9/20/85

DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
NAVAL AIR SYSTEMS COMMAND HEADQUARTERS
WASHINGTON, DC 20361

IN REPLY REFER TO

DRAFT

1000
AIR-5304C/4197

E.I. Du Pont De Nemours & Company, Inc.
Attn: Mr. Nicholas Pappas
Polymer Products Department
Wilmington, Delaware 19898

Gentlemen:

As indicated in our letter of 22 August 1985, we initiated a review of reports/documents pertaining to the in-service performance of KAPTON insulated wire (MIL-W-81381). This review determined that there is a basis for establishment of a Government/Industry Task Group to oversee additional testing. Of particular concern is a thorough understanding of the performance of the insulation when subjected to ballistic impact.

Membership of the group will be solicited by separate correspondence. It is estimated that it will take 3 to 4 months to complete the testing, in the interim the selection of wire insulation for new aircraft, such as the V-22, will be held in abeyance pending the results of this testing program.

Sincerely,

ENCLOSURE(7)

D. Field Reports of Kapton Performance

1. Failures on the EF-111 Kapton bundle reported in report #35 of enclosure (1) appears to have been caused by a flashover of one wire to the entire bundle. Evidence is available but not substantiated that arc-tracking initiated the failure.

2. The Air Force report, #24 of enclosure (1), from 1983 shows Kapton wire failures were seen during the inspections. The analysis shows that potential problems may exist over an extended service life. However, the conclusion is that Kapton is adequate for continued usage based on current data and reliability history.

3. Extensive data was compiled by a special task group of the Aeronautical Systems Division (ASD DAG) for the Air Force on the use of Kapton. Extensive commercial use of Kapton is shown with mostly good results for it since use it began in 1972. However, many airlines have reported Kapton bundle damage in Lockheed L-1011 aircraft. TWA has postulated fire damage of the bundles may have been caused by an arc-tracking failure and has expressed concern over the continued use of Kapton wire in their aircraft. The task groups excellent review supports the continued use of Kapton. The general feeling was that the isolated failures are few compared to the total footage used since Kapton was introduced.

4. The inspections performed by NEMA (see report #38 of enclosure 1) show that Kapton hydrolysis cracking is a potential problem in SWAMP areas. However, the inspection indicates Kapton performs well when properly installed and maintained.

Recommendations

1. Taking into account all reports, it is recommended wire insulations continue to be chosen based on their application. Before any application decision can be made for a particular insulation system, a definitive set of environmental characteristics must be established. Once all the wire's characteristics have been identified they must then be matched with each environmental characteristic, thereby defining the usage limitations. To make a decision regarding the use of Kapton, the following areas should be examined:

a. Further information is needed to determine what environmental characteristics, current-load, and bundle configurations can cause flashovers.

b. Comparison tests should be conducted on various types of wire bundles in current overload and flamability conditions.

c. To increase safety, new procedures and/or systems for circuit protection and fault detection should be considered to protect wire bundle insulations during high current overload.

d. Field data should be compiled into a data base to help predict the actual service life of Kapton (and other wires). Kapton's length of time in actual sevice is only now revealing useful service life data.

e. Evaluation of Kapton properties as a function of age should be performed.

REC'D NAC (B/714)
16 SEPTEMBER 85

ANALYSIS OF AVAILABLE DATA ON THE RELATIVE PERFORMANCE OF KAPTON INSULATED WIRES

Encl: (1) Test Reports on Kapton wire for NAVAIR Evaluation

Introduction: Concern over the use of Kapton insulated wire and cable for aerospace applications has become a priorty issue with NAVAIR over the last five years . Increased awareness of Kapton's limitations due to hydrolysis and basic cleaning fluids has resulted in scrutiny of the insulation system in field applications. The increased awareness of Kapton's chemical composition and performance differences from other wire insulation systems has led to analysis of Kapton (along with other wire insulations) in a multitude of laboratory tests. New tests have been developed in order to attempt to simulate conditions in the field. These tests were performed in the laboratory for repeatability and to compare different insulation systems. Since the NAC Test Report TR-2333 of 1983, testing has been done to analyze Kapton and other wire types to determine behavior of wire bundles to flash-over failures caused by arc tracking and the impact of projectiles.

To evaluate the properties of any wire and thus determine its applicability to a particular system, all characteristics must be examined then compared to the required environment. The purpose of this summary is to review the characteristics of Kapton which have been documented in the reports of enclosure (1) and to provide guidance on what additional data should be generated to have a full comprehension of Kapton's characteristics and limitations.

Conclusions:

A. General Purpose Wire Properties

A review of all applicable test reports indicates the NAC Test Report TR-2333 (enclosure 1 NO. 18) serves as the basic reference for the evaluation of wire characteristics, except for the flashover and ballistic phenomena. The other reports of enclosure (1) basically substantiate the results and characteristics as reported in TR-2333.

B. Carbon Tracking-Flashover Phenomenon

Reports #21, 23, and 35 of enclosure (1) were analyzed in the perspective of all reports, and the following conclusions were drawn:

1. Kapton and other similar insulations with aromatic polymer backbones and similar structures (such as PEEK) will support carbon arc-tracking making these insulations susceptible to flashover-failures in bundles under specialized conditions.
2. ETFE & X-linked ETFE are not susceptible to this phenomenon due to their chemical structure. Similar halogenated aliphalic hydro-carbon polymers are generally resistant to this phenomenon.
3. Solutions and contaminants providing carbonizing materials for "selftracking" (example sugar water) should not be used to evaluate the carbon tracking characteristics of an insulation. It may be valid to use self tracking materials to develop a laboratory test which simulate a field condition but it should not be used to categorize a particular insulation as susceptible to carbon tracking.

ENCLOSURE(6)

time. No other insulation with test results included in the review material deposited conductive carbon as a result of pyrolyzation. One case of harness fire in a civilian L-1011 was presented, attributed to this cause. Although the video was not viewed, the narrative script of a video recorded test using an actual aircraft breaker panel with a simulated harness demonstrating this effect was included in the review material. Massive damage to the harness resulted.

Several other insulating materials suitable for use in (and in use in some) aircraft were treated by the review material. In particular, a wire insulation tradenamed "RayChem Spec 55", covered by MIL-W-22759 appears from the test data presented to be the next best insulation for aircraft application, after "as-new" Kapton. This insulation, although tending to become less tough at maximum rated temperature, does not exhibit either the water absorption or the carbon tracking effects described above. It is considerably thicker than Kapton film, thus creating a bulkier harness in service.

CONCLUSIONS AND RECOMMENDATIONS

The selection of any wire insulation system is a series of engineering trade-offs, since it is unlikely that every desired characteristic will be available in a single material. Topics such as temperature range, weight, bulk, toughness, resistance to water, oils, and other materials which may act as solvents, workability, durability, age degradation, breakdown mechanisms and breakdown products, flammability, compatibility with other materials, and other factors enter into the engineering decision. Many of the considerations which enter into a decision are not addressed by the applicable specification, or may not be recognized as requirements. In retrospect, it appears that this has been the case with the application of Kapton to aircraft.

The water absorption and carbon tracking effects described in the reference material are not necessarily unique to Kapton. The water absorption was shown to be a characteristic of polyimide insulations in general. There appears from the review material to be no other polyimide insulation than Kapton currently being installed in aircraft, although a product tradenamed "Poly-X", covered by MIL-W-81044, has been used in the past and may still be in aircraft in service.

Based on the information contained in the review material, it is concluded that polyimide and polyimide film wire insulations are basically unsuitable for any long service application where exposure to water may occur. It is therefore the recommendation of this reviewer that:

1. The use of polyimide insulated wire be immediately stopped, whether in new, replacement, or retrofit aircraft installations. MIL-W-22759 wire is recommended as a substitute.

September 9, 1985

To: Naval Air Systems Command
Naval Air Systems Command Headquarters
Washington D.C. 20361

Att: AIR 5304C2/Mr. Michael Mitchell

From: National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

MS 433/Electrical Systems Section/SDB/SED
Mr. Joe C. Gowdey

Subject: Literature review of documentation pertaining to aircraft wiring systems, conducted 3 to 5 September, 1985.

BACKGROUND

Aircraft wiring systems, both military and civilian, have used wire insulated with polyimide film, tradenamed "Kapton", for many years. Reviews of the performance of this insulation in service have indicated that it may not be the best choice of available insulation systems. The Naval Air Systems Command, seeking the advice of outside agencies, assembled a collection of literature pertaining to the subject and solicited a review by knowledgeable but independent reviewers. The expected output of the review, as understood by this reviewer, is 1) an evaluation of the suitability of existing in service wiring systems for their application, 2) recommendations as to possible changes to or retrofit of wiring systems in in-service aircraft, and 3) recommendations as to changes to specifications in order to give greater assurance that wiring systems are properly applied in future procurement. Two reviewers were from NASA-LaRC. The remaining reviewers are not known to this reviewer, and no communication has taken place between the NASA and non-NASA persons involved in the review.

MATERIAL REVIEWED

A list of the reference material reviewed is attached. (Not included in the informal transmittal).

DISCUSSION

Kapton wire insulation is covered by MIL-W-81381. In general, it is selected for use because it is tough, thin, and has a high temperature

ATTACHMENT

Pertinent Documents Reviewed

#	Subject/Title	Date	Author/Affiliation
1	Aqueous Degradation of Polyimides	1971	R. DeIasi; J. Rissell Grumman Aerospace
2	Thermal Regeneration of the Tensile Properties of Hydrolytically Polyimide Film	1972	DeIasi, Grumman
3	Fluid Emersion Testing of Aircraft Electrical Wire	2/1976	NARF NI
4	Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles	1977	NAC Indiana
5	D.C. Power Wiring Harness	1977	NARF Norfolk
6	Insulation Ageing	1978	Brancate, NRL
7	Effect of MIL-C-43616 on Polyimide Insulated Wire	1978	NADC Warminster
8	Polyimide Film Insulated Wire Failures	1981	TWA
9	Fluid Resistance of Polyimide Insulated Wire	1981	NADC
10	a. Difference Infrared Spectroscopy of Stressed Polymers b. Fatigue-Induced Vibrational Shifts in Polyimide Films	1980	MCAIR
11	Minutes of SAE-AE-8D	1982	
12	Investigation of Polyimide Wire Insulation Cracking Phenomenon	1982	Raychem Corp.
13	Study of Wiring Problems in Selected Navy Aircraft	1982	Systems Associates
14	Failure Analysis of Kapton Insulated Wire in Operational Use	1982	WP, AFWAL WPAFB
15	Inspection of RF-4B Electrical Wiring Engineering Report	1983	NARF, NI
16	Long Term Thermal Aging of Raychem Specification 55A Wire	1983	Raychem
17	Correlation of Damage to Kapton Wire Insulation with Properties and Constituents of Four Aircraft Cleaners	1983	NAC, Indiana

aircraft in service. It is known from first hand experience that many of these "incidents" are considered minor and are consequently not reported. The records kept by TWA indicate that commercial aircraft are also subject.

The recently discovered potential of arc tracking or carbon tracking adds a new dimension. The molecular structure of polyimide is similar to graphite (ref. 20), in that it has a high Carbon to Hydrogen ratio. The degradation process produces free carbon. Hydrolysis effects on a wire bundle can produce small conductors on the surface of adjacent wires which, when an arc occurs, provide current paths on, and eventually in, the insulation material itself. Once a damaged wire arcs, the resulting current paths are numerous, sometimes explosive. Even after power is removed and reapplied, the paths remain and arcing is frequently continued. Efforts to produce these effects with ETFE insulation have been unsuccessful without the aid of quantities of highly conductive fluids. ETFE simply does not have this potential.

Lest it be argued that only one organization is generating the "Failure" reports on the polyimide material, it should be noted that several sources have reported the above characteristics from both field and laboratory evidence. These include separate elements of the Navy, aircraft manufacturers, unassociated Professional/Technical organiations and the manufacturer of large quantities of polyimide insulated wire (Kapton). While there are no standard tests, the range of testing has been such to show failures under a variety of conditions and does not detract from the facts.

CONCLUSIONS

1. Sufficient data exists to establish that polyimide insulated electrical wire can and will deteriorate when exposed to moisture, mild stress and a variety of aircraft related chemicals.

2. Sufficient data exists to suspect polyimide insulated electrical wire of being capable of explosive failure that could result in damage or loss of personnel and equipment.

3. The continued use of polyimides as electrical insulation should not be permitted in the aircraft environment except, possibly, in cases when no other insulation will meet special requirements, or when conditions are known to be benign.

RECOMMENDATIONS:

1. Immediate halt to use of polyimides in production aircraft.

2. Close inspection of existing aircraft cabling - particularly in areas exposed to weather and moisture.

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia
23665

Reply to Attn of 432

September 9, 1985

TO: Naval Air Systems Command
Naval Air Systems Command Headquarters
Washington, DC 20361

Attn: AIR 5304C2/Mr. Michael Mitchell
Jefferson Plaza 2 - Room 908
Crystal City

FROM: National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23665

MS 432/Aeronautical Systems Engineering Branch, SED
Eugene L. Kelsey
804-865-4666

SUBJECT: Document Review Pertaining to Aircraft Electrical Wiring, Conducted September 3 to 5, 1985

GENERAL

The following is a brief discussion and conclusions reached after a review of documentation of laboratory testing, field experience and independent surveys made available by the Naval Air Systems Command during the week of Sept. 2, 1985.

The issues to be addressed are centered around the insulation material used, or recommended for use, on electrical wiring in both present and future aircraft, military and civilian. Two materials are at the center of the issue:

1. Polimides - extruded or thin film wraps with top coat. Known in short as Poly-X and Kapton.
2. ETFE - Ethylene-Tetrafluoroethylene, (a teflon) single or double extruded - radiation crosslinked copolymer - Tefzel.

DISCUSSION

Since 1971, a variety of testing has been conducted that points to the same general conclusion: aircraft wiring insulation made of polyimide material degrades in the presence of certain fluids, including water, to the point of cracking and loss of mechanical strength. Results of testing by Grumman Aerospace attested to the aqueous degradation of the material by a measured loss in tensile strength of nearly 40% and a decrease in elongation to failure from 38% to 5%. These tests were conducted in 1971, using distilled water

ENCLOSURE(5)

Comments on above:

1) The Kapton wire insulation, because of its stiffness, is more prone to installation discrepancies then the other types. Routing and other installation methods should be reviewed to induce that good practices such as low strains are being followed. One item to review is clamp design and rubber cushion to ascertain that it does not deteriorate with age or solvent attack that would lead to wire insulation chafing.

2) There is a great deal of evidence that stress, time and temperature affect the hydrolysis of Kapton and leads to reduction in molecular weight (chain scission) and decrease in tensile strength and elongation that causes cracking. Strain levels of less than 3-4% will produce no degradation of mechanical properties. Strain level must be >9% to be significant. The above findings are based on accelerated laboratory tests under strain in warm water that are not representative of real life conditions. They do not take into consideration the facts that strains induced initially in installation are relieved and the moisture removed by repeated current-induced heating. It is likely that some hydrolysis does occur in service that has not, as yet, been precisely determined. Investigations are recommended on virgin and exposed material using repeated, alternating high humidity-dry, elevated temperature exposure. The reported annealing effects resulting from heating Kapton to temperatures of 140-180°C to eliminate hydrolysis effects are interesting but not a practical method to employ after installation in an aircraft.

3) Arc tracking of Kapton, leading to flashover, is unique to polyimide materials such as Kapton and should be further investigated as it is involved in a recently reported F-14 and F-111 failure (Item 35) and undoubtedly others in the past. Review of reported field problems at NAVAIR involving fire do not identify the causative factors. The flashovers appear to be induced initially by cracks in the insulation induced by strain/hydrolysis and/or mechanical damage.

4) The battle damage resistance tests on Kapton wire insulated bundle raise serious doubts about combat survivability. These results are related to the materials arc tracking and flashover behavior. It is essential that the NRL test be reconfirmed at the earliest possible date because of its major impact on the Fleet. Protective and modified installation methods may be implemented to overcome this deficiency if confirmed.

5) Quality control can be improved by tightening inspection and specification requirements and developing better test methods for assessing potential delamination of the outer layer.

RECOMMENDATIONS

Kapton wire insulation is implicated in many aircraft wiring failures and based on limited evidence, appears to be deficient in regard to arc tracking, flashover, and ballistic damage performance. The investigations discussed above should be implemented along with a long term approach such as an R&D program to evaluate and develop improved polymers and wire insulation systems that overcome Kapton's circuit breaker. When reset, the breakers were subsequently tripped with arcing, burning and carbon deposited on the painted aluminum surface. The other harness was shot with the ball severing at least one cable with no carbon formation and without tripping a circuit breaker. When shot with the fragment simulator, there was a bright arc and a circuit breaker was tripped. When reset there ws no arc and no tripping. The final test was conducted on a MIL-W-81381/11 wire bundle with a fragment simulator. Arcing and flaming occurred with tripping of the circuit breakers which were not reset.

35. Analyses of EF-111 Aircraft Wire Bundle Failure - AFSC -- 1985

Purpose of this report was to determine the cause of a catastrophic wire bundle failure and establish conditions under which it will occur. An aircraft was undergoing routine maintenance with external power connected to the electrical system when a flash occurred in the forward landing gear area. The circuit breaker was tripped along with its associated wire bundle whose damaged area was not in contact with the airframe or clamp. The wire bundle was connected to 115 V three phase power source and was a Kapton type.

36. NAVAIR Joint Panel/Aircraft Wiring Systems -- 1983

Cites wire size reduction from 1959 to 1972 from 22 AWG = .030" to 26 AWG = .019" and wire cross sectional area reduction of 83% and weight reduction of 72%. Fleet incidents were F-14A wheel well, S-3A wingfold wiring harness and RF-4B aft cockpit fires. Wiring affects readiness and absorbs 5-10% of direct maintenance man-hours at "O" level and little at other levels. Laboratory findings were Arrhenius effect at 50-100°C and environmental factor such as alkaline fluids, UV light, high stress and high humidity. Although hydrolysis was not a problem on all inspected aircraft, poor workmanship was indicated and, corrective actions recommended were wiring changes, emphasis on proper maintenance in publications and revisions to wiring specifications. It concluded that properly installed and maintained Kapton wire should be good for the life of the airframe except for a small number of identifiable harnesses. The recommendation was made to establish the Joint Panel on aircraft wiring systems.

30. Advanced Electrical System Investigation -- Westinghouse Electric 1982

Evaluates electrical systems in representative helicopters such as CH-47D, YAH-64, Hughes 500 M-D, UH-60 and Bell 222. Discusses problems encountered with Kapton wire such as:

a) Unraveling of the spiral wrap due to heat or solvent contamination. Care must be used to clamp the stranded insulation at the ends to minimize this.

b) Internal air passages that can hold moisture and promote corrosion.

c) Handling problems - stiffness makes the wire hard to strip, difficult to handle, difficult to route because of increased bending radii required, and hard to dress.

Price comparisons were made between Kapton and SPEC 55 wire. Insulated wire prices are as follows:

AWG No.	Kapton - Price/Ft. ($)	Spec 55 Price/Ft. ($)
20	0.20	0.105
22	0.143	0.0954

The SPEC 55 insulated wire is a double layer extruded type with inner and outer layers of contrasting colors for visual detection. Although the double layer insulation does not exhibit the cut through resistance of Kapton, its notch propagation is not nearly as high. The SPEC 55 wire is excellent for handling, routing, stamping and does not exhibit unraveling. Westinghouse recommended that SPEC 55 be used to replace Kapton or Teflon wire with little or no design change.

31. TAF Field Experience for Comparitive Analyses - Air Force Tactical Air Command -- 1984

This provides basic data collected in Dec 1983 from tactical fighter units to identify problem areas or constraints in current weapon system designs that can prevent the Tactical Air Force (TAF) from achieving its operational goals. Fifteen areas were evaluated, including one on connectors and wiring. Procedures involved in installation and maintenance are discussed in detail but little is said about the different types of wire insulation. A supplementary document refers to the Kapton wire history in the Navy and earlier AF and commercial aircraft experience that finds the insulation suitable.

32. Minutes of Military/Industry Meeting on MIL-W-22759/43A (USAF) Wire -- June 1983

Refers to sixty-four comments on proposed specification changes. It

20. Temperature Dependence of Hydrolysis of Polyimide Wire Insulation - 1983 -- NRL

Applied to Arrhenius rate equation to achieve linear extrapolation of the insulation system hydrolysis from high temperature shorter life tests.

21. Flashover Failures from Wet-Wire Arcing and Tracking - 1984 -- NRL

Flashover begins as the wire bundle deteriorates by cracking or chafing and surfaces of adjacent wires in the bundles become contaminated due to salt spray, mist, fog and high humidity. Arcing and tracking initiate and eventually localized points extend into a continuous carbon access path bridging the wire from fault to ground. Flashover occurs later without wetting on the surface of polymeric materials that readily carbonize when pyrolyzed, such as phenyl containing materials i.g. polyimide and PEEK, but not the fluoropolymers. Continuous arcing emissions produce localized surface temperature of about 1000 °C. Tefzel wires showed tracking and arcing but no flashover.

22. Wire Comparison Testing of Aircraft Electrical Wiring - 1984 -- NARF NORIS

Mechanical and electrical properties of Tefzel, Cross-linked Tefzel and Kapton insulated wire were tested for mechanical and electrical properties by the NARF, DuPont and Raychem. Tests are summarized as follows:

a) Scrape Abrasion Resistance - The Tefzels were more resistant.

b) Dynamic Cut-Through - Ranks Kapton best and unmodified Tefzel lowest.

c) Vertical Flammability - Kapton, Crosslinked Tefzel and unmodified Tefzel are ranked in order of increasing flammability.

d) Smoke Generation (Current Overload Method) - Kapton produced very little compared to the others.

e) Smoke Generation (NBS Smoke Density Method) - same as d).

f) Bending and Formability - Kapton was stiffer and produced greater spring back than the others.

g) Dielectric Strength - All exceeded minimum dielectric breakdown specification by factors of 5-10.

23. Carbon Tracking Tests - 1985 -- DuPont

Evaluated Kapton and Tefzel, under varying test conditions and both failed by tracking. Claims no standard test exists and the above requirement does not appear in military specifications. "Cut-through does happen to undamaged wire, sometimes causing extensive harness damage". Suggests research effort would be required to understand

12. Study of Wiring Problems in Selected Navy Aircraft - 1982 -- Systems Association of California

Analyzed Navy 3M data, interviewed fleet maintenance personnel and conducted on-site inspections at NAS Mirimar and NAS North Island. Aircraft consisted of F-14, S-3, H-2, H-3 and A-6. Only 20% of wiring repair actions were properly documented. Principal forms of polyimide film insulation deterioration were top coat peeling, cracking, and film delamination. Causes were apparently moisture and chafing. Unusual stiffness and springiness contributed to maintainability and reliability problems. Most broken wires occurred within six inches back of a connector. Wire induced elongation of grommet holes allowed water intrusion into connector. Identified problems in wire repair training and documentation action. Recommended improved splicing toolings and that wire systems be marked and stripped as easily as MIL-W-81044/9. Closest wire to the ideal is MIL-W-22759/32-35/41-43.

13. Failure of Kapton Insulated Wire in Operational Use - 1982 -- AFWAL

Consisted of an investigation of Kapton insulated wire on the F-15. Teflon insulated wires appeared good, however several Kapton coated wires were cracked after bending and showed separation of topcoat (manufacturing deficiency). Recommended that test method for latter be incorporated into MIL-W-81381. Extensive damage to Kapton wire found in wheel well; recommended against its use in high vibration, unprotected environment.

14. Inspection of RF-4B Electrical Wiring Engineering Report - 1983 -- NADC NI

Several cockpit electrical fires related to wire chafing were reported. Local Engineering Specification (LES) documented inspection of 21 aircraft. RF-4B Service Life Extension Program (SLEP) installed Kapton wire since Teflon wire (MIL-W-22759) was larger diameter and created "extreme wire bundle density restraints". It was reported that "variations between wire bundle routing installations contributed to various degrees of chafing". Proper repair practices and inspection were recommended. Did not criticize Kapton wire insulation.

15. Fluid Immersion Testing of Aircraft Electrical Wire - 1983 NESE NORIS

Tests conducted on Tefzel; Crosslinked Tefzel and Kapton insulated wire in 21 fluids using mandrel and "U" bend specimens. Kapton wire had a cosmetic topcoat of modified polyimide because all colors cannot be produced as per MIL-W-81381; Kapton wires failed (flaking, peeling, cracking, topcoat removal) in six of the different fluid types tested. There were no dielectric failures of the other wire types.

16. Long Term Thermal Aging of Raychem Specification 55A Wire - 1983 -- Raychem

Insulation is based on ethylene - tetrafluoroethylene (ETFE) modified by crosslinking promoters, stabilizers, flame retardants and other agents. This is extruded and then radiation crosslinked. Most

Summary of Data:

a) Teflon and Tefzel were unaffected by any of sixteen (16) fluids used in testing

b) Poly-X was affected by several fluids, especially high pH types

c) Stilan was affected by several fluids and is resistant to high pH fluids

d) Kapton was affected by all fluids, especially high pH types

5. D.C. Power Harnesses - F-14A -- NARF Norfolk - 1977

Harnesses were reported with wires having low breakdown resistance (insulation leakage). Corrosion and residue were found on connectors and respective backshell adapters. Insulation cracks and leakage in MIL-W-81044 occurred due to alkaline cleaner attack and alkaline residue was found. Recommendations were made to inspect all F-14 aircraft wheel well harnesses, limit and control cleaning materials and inspect harnesses installed in moisture prone areas for insulation leakage.

6. Effect of MIL-C-43616 on Polyimide - Insulated Wire -- NADC - 1978

The effects of above solvent emulsion cleaner on three types of polyimide insulated wire MIL-W-81044/18/16 (single and double Poly-X) and MIL-W-81381/11 (Kapton) were determined. Also, the high temperature durability (life cycle) of potential replacement wires is reported. Candidate replacements are MIL-W-81044/30 ITT Surprenant Halar, an extruded polyalkene jacketed with crosslinked extruded copolymer of ethylene and chlorotrifluoroethylene (Halar) and MIL-W-22759 (Tefzel), composed of two extrusions of ethylene and tetrafluoroethylene (Tefzel).

No cleaning compound was compatible with the three types of wire tested. Water at 75°C induces mandrel cracking of all polyimide insulated wire tested. Recommendations are made to avoid high humidity exposure and contact with cleaners and develop a more compatible cleaner. The Raychem wire was superior to the Halar type in high temperature durability after 168 hours at 200°C).

7. Fluid Resistance of Polyimide - Insulated wire. - 1981 (forwards above NADC report to NAC Indianapolis)

8. Wiring and Connectors in the SH-60B SEAHAWK -- AUG 81

Cites NAC Report TR-2201 where Tefzel and Spec 55 wire showed no failures after emmersion in three cleaning fluids. Raises questions regarding Kaptons susceptibility to cleaning agents. Chafing problem exists with Kapton based on LAMPS MK III Maintenance Engineering Inspection. A test is being conducted of vibration and heat aging. Sikorsky recommends additional investigations consisting of bend radii tests, more extensive vibration tests, controlled Fleet Tests, and

A LITERATURE REVIEW.

The following documentation related to aircraft wire investigations, identified by subject and source were reviewed:

1. Aqueous Degradation of Polyimide - Grumman -- 1971

Kapton film was soaked in distilled water at 25-100°C from one hour to several hundred hours. Ult. tensile strength decreased from 23 KSI to 14 KSI and elongation to failure from 38% to 5%. Hydrolysis is indicated that is pH dependent; high degradation rate at pH>12.

2. Thermal Regeneration of the Tensile Properties of Hydrolytically Degraded Polyimide Film -- Grumman - 1972

Heat treatments of 224°C to 310°C of degraded material regenerated tensile strength and elongation.

3. Effect of Aircraft Cleaning Fluids on MIL-W-81381 (Kapton) Wire-Mar 1976

Immersion of 16" loops of wire in fluid for 24 hour intervals plus one hour in tap water; then 2.5 KV rms and bend tests (as per spec). Fluids were DOD cleaner, deicing fluid and NaOH test (pH>12.0). Some (few) diameter changes and cracking observed.

4. Fluid Immersion Testing of Aircraft Electrical Wire -- NARF NI - Feb 1976

Problems were reported with MIL-W-81044/16/18 (Poly-X) and MIL-W-81044/20/25 (non-oriented Stilan) wire types (Raychem). Latter formerly showed "solvent stress crazing" of the insulation. In an installation on the F-4, Poly-X showed improper cure of polyimide topcoat which resulted in stress concentration when wire is flexed causing cracks. Even if properly cured, the MIL-W-81044/16/18 made by Raychem will show deterioration and cracking when exposed to ph>10 cleaning compounds. NARF NORIS plans to replace Poly-X with wire bundle assemblies containing Teflon in areas subjected to frequent exposure of cleaning solvents.

Various types of abrasion resistant wire insulations were tested:

a) MIL-W-22759/5/7/11 Teflon extruded p-tetrafluoroethylene fluoropolymer (mineral filled)

b) MIL-W-22759/16/18 Tefzel extruded ethylene tetrafluoroethylene fluoropolymer

c) MIL-W-81044/16 Poly-X dual layered crosslinked alkane-imide with modified imide topcoat

MIL-W-81044/18 as above but single layered.

d) MIL-W-81044/20 Stilan dual walled polyarylene

MIL-W-81044/25 as above but single walled

MATERIALS ENGINEERING
TECHNOLOGY EVALUATIONS

Prepared for:
AIR 5304
Materials & Process Branch
Naval Air Systems Command

Prepared by:
Max Stander
Aerostructures, Inc.

August 1985
TM85014

Conclusions

1. Kapton wire is failing in service by one or more of the following mechanisms:

a. Hydrolysis of Kapton polyimide insulation and subsequent cracking under stress

b. Nicking of wire prior to installation and subsequent propagation of the defect under stress

c. Peeling of the topcoat followed by unraveling of incompletely sealed tape wraps

d. Inadequate clamping of wire leading to chafing contact with nearby surfaces (due to the tendency of the wire to retain its shape as manufactured).

2. With the exception of insulation chafing, current laboratory tests are not able to identify the failure mechanism on wires which have failed in service.

3. High humidity, salt spray, and hot weather operations combine to make the naval aircraft environment especially hostile toward materials which are hydrolytically unstable. The high rate of failure of Kapton in naval aircraft results from environmental conditions more conducive to failure by hydrolysis.

4. Annealing by resistively heating Kapton wiring is not a practical means for preventing hydrolysis due to the high temperatures required.

5. Carbon tracking and flashover is an important consequence of Kapton wire failures. Resultant damage to surrounding wire and initiation of aircraft fires is a threat to aircraft survivability.

6. ETFE or crosslinked ETFE wire has been shown to be a suitable replacement for Kapton wire.

Recommendations

1. Kapton wire installed in SWAMP areas or in locations requiring short radius bends should be replaced with ETFE or crosslinked ETFE wire.

2. Other Kapton wiring exhibiting excessive peeling or blistering of the topcoat should be replaced if it interferes with normal inspection for wire integrity.

3. Adequate malfunction codes should be established to gain as much information from field repair actions as possible. Such information will be used to determine whether more extensive replacement programs will be necessary.

4. Unless topcoats are developed which prevent the hydrolytic effects found above, polyimide-insulated wire should not be specified in future Navy aircraft design.

Rec'd NADC (Code 6062)
30 August 85

POSITION ON KAPTON WIRING

Laboratory Data

Laboratory studies have established the following facts regarding the two major problems with Kapton -- hydrolytic instability and carbon tracking/flashover phenomena:

1. The unstressed polyimide film used in Kapton wire suffers large mechanical losses (due to hydrolysis) during immersion in water at 25° to 100°C. (R. DeIasi, J. Applied Polymer Science, Vol. 15, pp 2965-2974 (1971))

2. Kapton-insulated wire under stress suffers dielectric failures during exposure to water or water vapor at 60° to 100°C. (F. J. Campbell, NRL Memo Report 5158 of 4 Aug 83; Raychem Lab Report 5191 of Jul 82)

3. Dielectric failures occur more rapidly with:

a. Increased strain (tighter wire bend) (C. J. Wolf, IEEE Transactions on Electrical Insulation, Vol. EI-19, No. 4, Aug 84)

b. Higher temperature (Campbell 1983 above; Raychem 1982 above)

c. Water than with humid air (Raychem 1982 above)

d. Exposure to high pH cleaning compounds (W. D. Watkins, NAPI Report TR 2199 of 11 Aug 77; N. Bryant, NAC Materials Test Report No. 27-83 of 27 Jun 83)

4. Dielectric failures do not occur with ETFE or crosslinked ETFE under the same conditions in the above reports. While the chemical structures present in the Kapton polyimide are inherently sensitive to hydrolysis, no such sensitivity is present in ETFE.

5. The topcoat of most Kapton wire, also a hydrolytically unstable polyimide, exhibits wrinkling and delamination in water and severe blistering and dissolution in high pH cleaning compounds. (K. Clark, NADC Lab Reports of 18 Apr 78 and 5 Jun 78)

6. Annealing of Kapton wire under stress can increase the time to failure, but requires heating at a minimum of 140°C for 8 hours. (Wolf 1984 above)

7. Kapton wire suffers much more carbon tracking and flashovers than does ETFE or crosslinked ETFE due to the tendency of aromatic polyimide chemical structure to carbonize. (F. J. Campbell, NRL Memorandum Report 5508 of 17 Dec 84)

8. Although Kapton-insulated wire is superior to ETFE- or crosslinked ETFE-insulated wire with respect to

a. Cut through resistance

ENCLOSURE(2)

16. Long Term Thermal Aging of Raychem Specification 55A Wire	1983	Raychem
17. Correlation of Damage to KAPTON Wire Insulation with Properties and Constituents of Four Aircraft Cleaners	1983	NAC Indiana
18. Testing of Selected Aircraft Electrical Wire Insulation	1983	NAC Indiana
19. Functional Integrity of KAPTON Wire in Service	1983	AFSC, WPAFB
20. Temperature Dependence of Hydrolysis of Polyimide Wire Insulation	1983	NRL
21. Flashover Failures from Wet-Wire Arcing and Tracking	1984	NRL
22. Wire Comparison Testing of Aircraft Electrical Wiring	1984	NARF, NI
23. Carbon Tracking Tests	1985	Dupont
24. Field and Laboratory Investigation of KAPTON Insulated Aircraft Wiring	1985	AFWAL, WPAFB
25. Aircraft Wiring Problems AIR 4111 Memo	Mar 1983	NAVAIR
26. Wire & Cable Fabrication Technology Report	no date	
27. F-14 Aircraft Sparrow Umbilical Transformer Rectifier Support and Repair	1982	
28. Aircraft Wiring - KAPTON	1984	Canadian Forces CF18 Detachment
29. Review of Raychems Study of KAPTON Wire Insulation	1982	NRL
30. Advanced Electrical System Investigation	1982	Westinghouse
31. TAF Field Experience for Comparative Analysis		AF TAF
32. Minutes of Military/Industry Meeting on MIL-W-22759/43A	June 1983	

6. KAPTON has superior cut-through resistance at all temperatures tested, retaining approximately 70 percent of it's room temperature capability at 200 degrees C.

7. Tefzel is much less sensitive to slight nicks than are either Spec 55 or KAPTON, viz., a notch up to about 3 mils in depth will propagate much more slowly in Tefzel than in the other 2 wires.

*NAC Report TR-2333 "Testing of Selected Aircraft Electrical Wire Insulations" 8 June 1983.

3. The most severe degradation has resulted from laboratory tests which immerse the wire in water. Testing has shown however that small reductions in moisture absorbed have a significant effect on the rate of hydrolysis. The rate is not directly proportional; for example the rate at 50 percent relative humidity is not twice as slow as at 100 percent but rather 20 times as slow. The point is that the wire installed in an aircraft is not continuously exposed to water immersion, therefore the rate of hydrolysis is significantly different than predicted based on the laboratory immersion tests.

4. While the aircraft is in flight, the humidity is low and the wire can dry out. The current heating effect will also evaporate any moisture which condenses on the surface or has been absorbed by the insulation. Additional cyclic testing in this area is required for a better understanding.

5. There is disagreement between investigators on whether the hydrolytic deterioration of KAPTON is a first order or fifth order kinetic reaction. The difference in life prediction for 50 percent relative humidity is 4 years versus 80 respectively. This area requires additional clarification.

The conclusion which is drawn from this is that for most installations the moisture and strain levels required to induce cracking by hydrolysis do not normally exist. There is some evidence which shows that without strict adherence to good design practices (minimum strain, proper clamping etc.) in wet areas the use of KAPTON could result in electrical problems. This would account for some of the problems experienced in wing fold wheel and well areas.

B. Arc Tracking

The arc tracking characteristics of KAPTON can be demonstrated in controlled laboratory experiments. However, certain conditions must be met before arc tracking can occur.

1. The wire must be damaged (i.e. cracked insulation) such that the bare conductor is exposed. Laboratory experiments require that the insulation be cut.

2. A second conductor, such as a ground plane, must exist within a reasonable distance of the first conductor.

3. A potential difference must exist between the two bare conductors of such magnitude that a spark can initiate across the gap.

4. A liquid electrolyte must be present to effect an intermittent conductive path between the conductors.

As previously discussed the probability of cracks developing in the insulation is small, therefore one of the key conditions listed above would not normally be satisfied. The remote possibility does exist however that a wire could be mechanically damaged but again this is only one of the key conditions which would have to occur before arc tracking became a possibility. There are a few incidents referenced in the data, plus the recent F-14 incident at NAVAIREWORKFAC Norfolk, where it appears that some form of arc tracking may have occurred and it is therefore recommended that a standard test be developed to determine arc tracking resistance.

c. Preliminary ECP(s) should be prepared to restrict the use of KAPTON insulated wire in combat aircraft now in production (i.e. F-18, AV-8B etc.). If the ballistic testing in item "B" above shows that this material behaves unfavorably under ballistic impact then the contractual vehicle will be available to change the wire insulation.

d. Airframe companies should be directed to review design procedures for installation of MIL-W-81381 wire to insure proper clamping and that strain levels are kept to a minimum (less than five percent). Also clamp design should be reviewed including verification that the rubber cushion will not deteriorate with age or solvent attack which could lead to insulation chafing.

e. Wire selections for future aircraft (i.e. V-22) should be delayed until completion of the government/industry review.

f. Recommend a letter be forwarded to manufacturers, providing them with our current position. Enclosure (7) is provided as a "straw man" to be used as a basis for this letter.

g. New maintenance codes be established by AIR-04 to better define wiring problems.

5. Although numerous reports and studies have been conducted on this subject, it is very difficult to find documented data on fleet aircraft which substantiates the laboratory tests which show sensitivity to moisture, arc tracking and ballistic impact. In those instances where data is available it is inconclusive that wire failure initiated as a result of poor design, insulation degradation and/or mechanical damage, or how MIL-W-22759 insulation would have performed under the same scenario. The conclusions and recommended action previously discussed are based on the assumption that the formation of a Government/industry task group will be implemented and additional ballistic testing conducted. If however, this is not approved then more definitive direction will have to be provided to restrict the use of MIL-W-81381 in aircraft high vibration and wet areas.

6. AIR-530 point of contact for this review is Mr. Thomas White, AIR-5304C, X26025.

Ray E. Yalat

LECTROMEC RESEARCH INTO AGING OF WIRING

LECTROMEC, July 10, 1997

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Conference Chairman Dr. Joseph Gallagher
WL/XPZ Bldg 45
Wright Laboratory (AFMC)
Wright-Patterson Air Force Base, Ohio, USA

Aging Measurements of Operating Aircraft Wiring; Implications for Specification Writing & A/C Reliability

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"Structural failure" used as a discipline in conjunction with "aging failure of electrical wire" may be a strange association in the minds of most of the attendees of this conference. But Figure 1 on the next page illustrates the consequences of a **structural crack** in the electrical insulation on a conductor. And Figure 2 indicates the electrical noise caused by the electrical leakage current of Figure 1. Finally, Figure 3 shows a micro crack typical of those found in an aircraft. These micro cracks —as well as grosser damage— allow leakage current of Figure 1 between the conductor and ground or other conductors. This is typical of aging insulation used on the domain of air and space vehicles related to all three sponsors of this First DoD/FAA/NASA Conference on Aging Aircraft.

To illustrate the significance of the wiring failures, one set of published field failure data follows: These U.S. Navy statistics[1] emphasize the serious impact that aircraft wiring insulation structure system failures have on fleet readiness, as well as the significant contribution to the overall cost of ownership. A parenthetical comment may also be in order: our experience is that invariably such data has a large spread of uncertainty, and its collection and access in some organizations subject to the emotions of command structures.

In a one year period in U.S. Naval aviation --

- there were 143,641 wiring failures.
- the mean flight hours between wiring failures was 11.4 hours.
- there were 807,418 man-hours spent on unscheduled wiring maintenance. This represented 8.6% of all aircraft maintenance man-hours.

[1] from Aircraft Wiring Analysis Program, Readiness, Reliability, and Maintainability Impact Report of 15 January 1989; data for the period July 1, 1987 to June 30, 1988; issued by Fleet Readiness Engineering Branch (Code 916), Naval Avionics Center, Indianapolis, Indiana; report of comparative failure/maintenance data on wiring systems for 19 type/model/series aircraft (total of 3,158 aircraft), both fixed and rotary wing.

Figure 1: Effect of structural micro cracks allowing leakage current from a 120 volt circuit in an aircraft bundle after 4 years, 3 months service. The visual appearance of carbon arc tracking is unusual. More common is invisible leakage which causes EMI and glitches, or fully developed arcing breakdown.

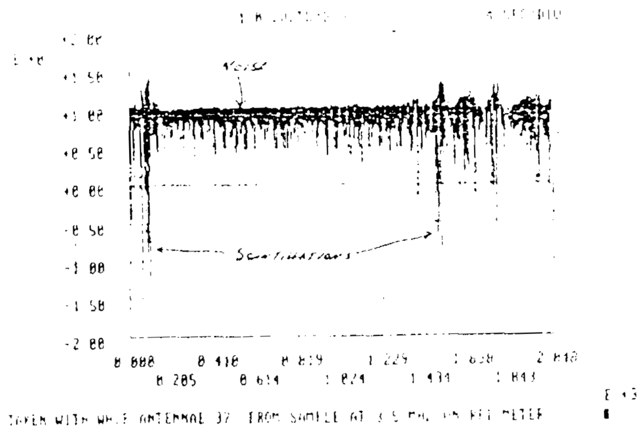

Figure 2 EMI measured one meter from a failed structure similar to Figure 1.

Figure 3 An aromatic polyimide tape substrate with micro cracks. The external fluorinated polymer coating has been removed for examination of the aged polyimide in order to show visually the concealed structure failure.

LECTROMEC, JULY 10, 1997

- aircraft averaged 0.94 flight hours per day. The same aircraft averaged 0.72 unscheduled wiring maintenance man-hours per day.

- aircraft wiring maintenance had the Navy's 3rd (based on an average of 115 systems per aircraft) highest total of unscheduled maintenance man-hours at the organizational maintenance level.

Detailed analysis of the failure data indicates these failure rates are specific to the type of aircraft. Further, based upon understanding of the fundamental thermodynamics of the process aging as well as field tests of active aircraft, wire aging is not related to flight hours, but rather to the environmental conditions. We expect to see a continuing increase in recognized aging failure of non-maritime aircraft as use of older aircraft increases, better records are kept, and access to testing for aging of active aircraft wiring is made available to persons experienced in insulation structural-material thermodynamics.

The material in this presentation is the result of work done with the services of four countries: USA, Canada, Netherlands, and Great Britain. It includes test results from well over 25 operational aircraft, as well as years of fundamental chemical thermodynamic research. Electrical insulation failures are material and wire structure design specific. Thus the details covered below are for one specific wire type where the preceding experience is greatest, but are meant to illustrate fundamental principles for all wiring structures.

There are two components of the failure process which we consider in our work. There are various visible "ultimate" failures. These can be of several forms. But prior to the obvious ultimate or final manifestation of failure, there is a proximate failure that may then lead to the final failure. That is, the failure process can be divided into two steps: (1) the proximate failure being the structural failure, and (2) the resulting ultimate form of electrical failure.

Proximate failure of insulation of aircraft wiring can be called a structural failure since the vast majority of aircraft wire insulation failures are induced by mechanical stresses. Voltage induced failure at 28 and 120 volts in aircraft installations we have examined are nonexistent. Thus structural failure is the subject of this presentation.

Description of Aging and Failure Processes

There are at least eight different insulating polymers which have been popular and widely used for some period of time since the advent of synthetic polymers in aircraft wiring, remembering that PVC was discovered in 1913. Detailed examination reveals the incidence of structural failure is related to "chemical aging" of the synthetic organic polymers.

For purposes of illustrating the principles and statistics the rest of this paper deals with one of the two more successful and widely used polymer constructions. This is illustrated in Figure 4 on the following page. The construction is a conductor on which is helically wound, thin, coated polymer tape. The coating is a fluorinated polymer which is thermally melted to bond the helical tape. In our example the tape itself is an aromatic polyimide - sometimes referred to, based upon its components by a rather long and involved name which is useful in the context of this paper only to emphasize the data is related to this specific[2] aromatic polyimide with its selective additives.

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[2] Pyromelitic dianhydride [PMDA] and 4, 4' diamino diphenyl ether [ODA]

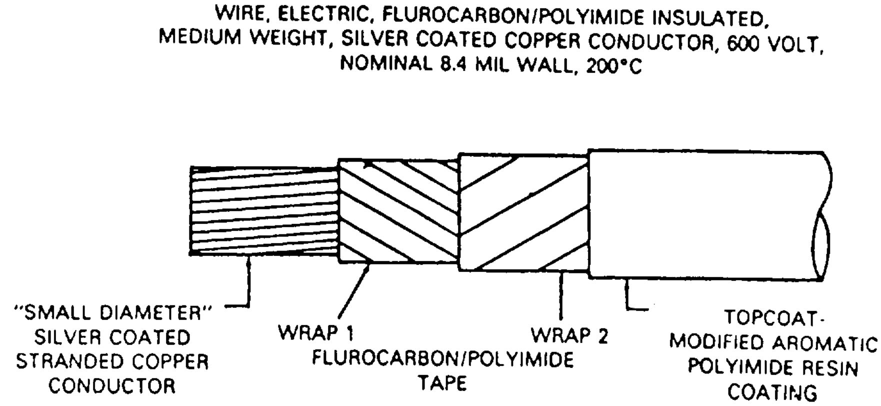
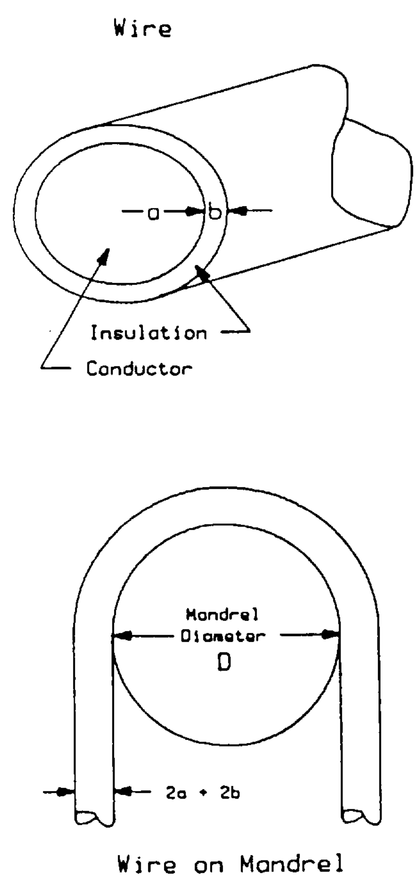


Figure 4 Structure of MIL-W-81381/11 aromatic polyimide film bonded with FEP-Teflon™



$$lo = pi/2\ (4a + 4b + D)$$

$$ln = pi/2\ (2a + 2b + D)$$

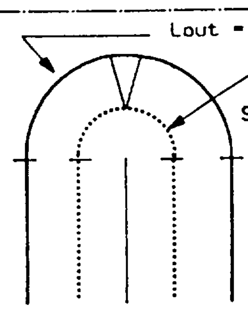
$$Strain = \frac{lo - ln}{ln}$$

$$Strain = \frac{(pi/2)(4a + 4b + D) - (pi/2)(2a + 2b + D)}{(pi/2)(2a + 2b + D)}$$

$$Strain = \frac{2a + 2b}{2a + 2b + D} = \frac{1}{1 + \frac{D}{2a + 2b}}$$

$$d \doteq 2a + 2b \quad \text{Therefor, } Strain = \frac{1}{1 + \frac{D}{d}}$$

EXAMPLE:
When D=0



$$Strain = \frac{lo - ln}{ln}$$

$$= \frac{2\frac{pi}{2}\frac{d}{2} - \frac{pi}{2}\frac{d}{2}}{\frac{pi}{2}\frac{d}{2}}$$

$$= 2 - 1 \quad \text{OK}$$

Figure 5 Classical simplistic analysis of hoop bending strain of insulated wire structure of "2a+2b" diameter bent in a loop of diameter "D".

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To emphasize the shifting character of material properties when combined in structural variations of insulation build, we have tested ostensibly the same or similar materials which have varying lifetimes under identical demanding condition. Some have life times that are as much as 50 times longer than the shortest lived presumably same material and construction. The insulating material of the MIL-W-81381 type wire treated in this paper is frequently called by its trade name, "Kapton[3]" in conflict with trademark laws, implying generic-ness of the material produced by Du Pont.

This MIL-W-81381 construction was used during the period of 1977 through 1986 on U. S. Navy planes. It also exists on many other types of aircraft so managing its aging is of practical significance for all aircraft organizations.

The structural aging and failure process for polyimide is well defined from a theoretical insight viewpoint. Application of the theory is complicated by virtue of chemical reaction rate constant relations in the fundamental aging relations, and to the structural form. The basic syllogism of the failure process for polyimide tape insulated wire is as follows:

1. The polymer is formed by an imidization of the two monomers leading to formation of a long chain polymer with the release of water during the polymerization process.

2. As a result of the lengthening of the molecular chains from this polymerization, the polymer develops increasing ability to withstand various stresses.

3. In a user aircraft environment where there may be sufficient water—characterized by the relative humidity particularly when the aircraft is on the ground, temperature, and continual strain energy, this polymerization can reverse. That scissioning leads to a deterioration of the physical properties —in other words, the material ages.

4. When the applied stresses exceed the weakening aging physical properties the material fails mechanically exposing the conductor to the outside environment.. This is the proximate failure step.

5. When and if sufficient leakage current occurs, then the visible electrical ultimate failure occurs. This failure can be RF EMI, glitches in the electronics, or occasionally arcing energy.

Note the accuracy of the above scissioning scenario is not necessary to justify the fundamental calculation of rate of loss of mechanical property. One can use the concept of transfer function without insight into the process to formulate the rate equation. But the scissioning process described in the following serves to assist in intuitive understanding of the aging process.

Some of the relevant structural failure stresses that have been identified include:

1. Hoop bending strain. Figure 5 on the preceding page is the classical illustration of this.
2. Flexing strain fatigue
3. Torsional strain.
4. Vibration
5. Cut through
6. Chafing/abrasion.

---

[3] Kapton is a trademark of the E. I. du Pont de Nemours & Company

We have chosen to use the bend breaking strain of a ½ inch diameter wire bend as the maximum strain to which the wire should be exposed as a "standard" maximum strain and associated stress. Note there is a nonlinear equivalency of other failure stresses to hoop bending. For instance insulation resistance to abrasion decreases with aging faster than resistance to bend failure.

Also, there are second order mechanisms such as adhesion between layers; and diffusion, adsorption, absorption, and chemical transport of water which have a bearing on aging rate. Some have also proposed that repolymerization may occur, although we have not been able to measure this in any of the higher temperature current carrying conductors which we have examined from operating aircraft. Further, statistical distribution of quality of polymer and the fabrication control of tape application have a large practical effect on the life of the insulation structure.

Figure 6 on the following page indicates a typical variation in failure rates for 256 contiguous specimens of polyimide wire. This large variation has a great affect on the analysis of present quality and life-remaining. Note here one sees about a two to one ratio of maximum to minimum life of insulation.

This graph also has another implication. For instance, if all the specimens were considered a single continuous specimen 256 times as long there would be only one life expectancy, the 52.5 units of time of the weakest link in the series chain of shorter specimens. From this one can infer that the probability of failure is related to the length of test specimen. This important conclusion means that MIL specifications can not provide absolute life data since they do not correlate the length of the test specimen with actual installed lengths in establishing probability of failure.

In addition to the structural stresses, the other part of the failure process —the chemical aging is pertinent. Fundamental work beginning in 1927 can be used to determine the rate at which this scissioning occurs. This work is covered in detail in an IEEE Transaction "Aging in Wire Insulation under Multifactor Stress", Bruning & Campbell, Oct 1993 V28 N5. This reference contains extensive references and the pertinent statistical thermodynamics. The principles can be illustrated by Figure 7 and Figure 8 (Figure 8 is our interpretation of data published by Du Pont in 1963). Here we see the following: B represents a typical polymerization link between the repeat units (indicated by a straight line segment). A indicates a polymerization that did not occur or scissioned from B. As the number of scissions of B reverting to A occur with aging the average molecular weight, and associated length of polymer chain decreases. The resulting effect on the physical properties is shown in Figure 8. This illustrates the decreasing strain-sustaining capability of the polymer as the chain shortens.

Since one can calculate the rate at which the polymer shortens for any combination of moisture, temperature, and aging strain, and the failure strain is defined by Figure 8, one can calculate the "life" of the insulation.

Figure 9, second page following, indicates the typical variation in age to fail at a ½ inch diameter wire bend as a function of temperature and humidity. Of course, if we are concerned about an "excessive trauma" such as a mechanical blow, chafing, etc. the polymer may reach the failure point with less shortening of the polymer chain. This can be analyzed on paper, measured in the laboratory and field, and results observed on "hard usage" aircraft. Figure 10, three pages following, is one such example. Much of some organizations' effort is aimed at this excessive trauma situation. Of course as aircraft wiring ages, amelioration of this effect becomes increasingly expensive and difficult. In addition efforts have been made to protect aircraft with polyimide insulation from moisture, as examination of the fundamental relations of the reference development reveal that the life of aromatic polyimide is very long if the material is protected from water. Practical implementation of protection from water is yet to be demonstrated, as far as we know.

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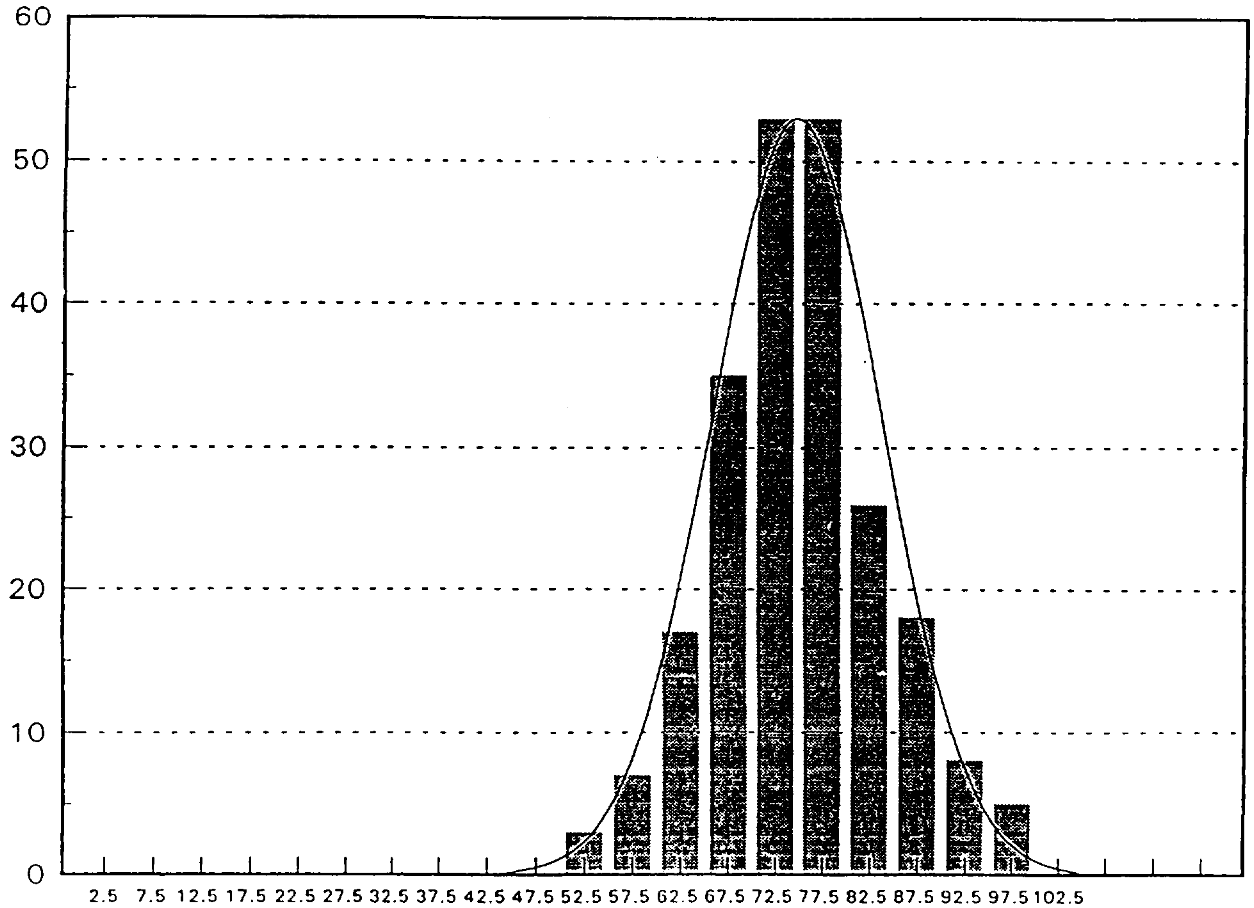

Figure 6 Failure rate curve for 256 contiguous specimens of MIL-W-81381. Abscissa shows the average test time in hours of the interval test time to indicate crack in the insulation structure progressing to the inside conductor. Ordinate is number of specimen failures per test time interval.

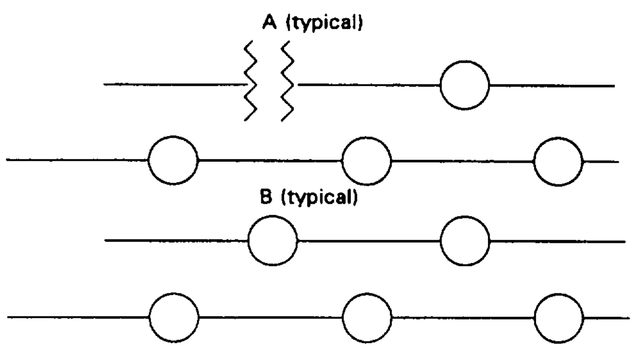

Figure 7 Schematic of repeat units (lines), polymerization points (B), and incomplete polymerization or scission points (A).

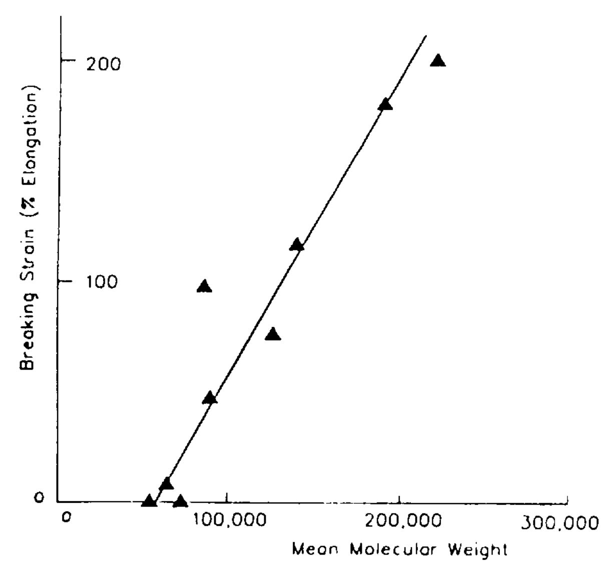

Figure 8 Breaking strain elongation vs. mean molecular weight (MMW) of Polymer.

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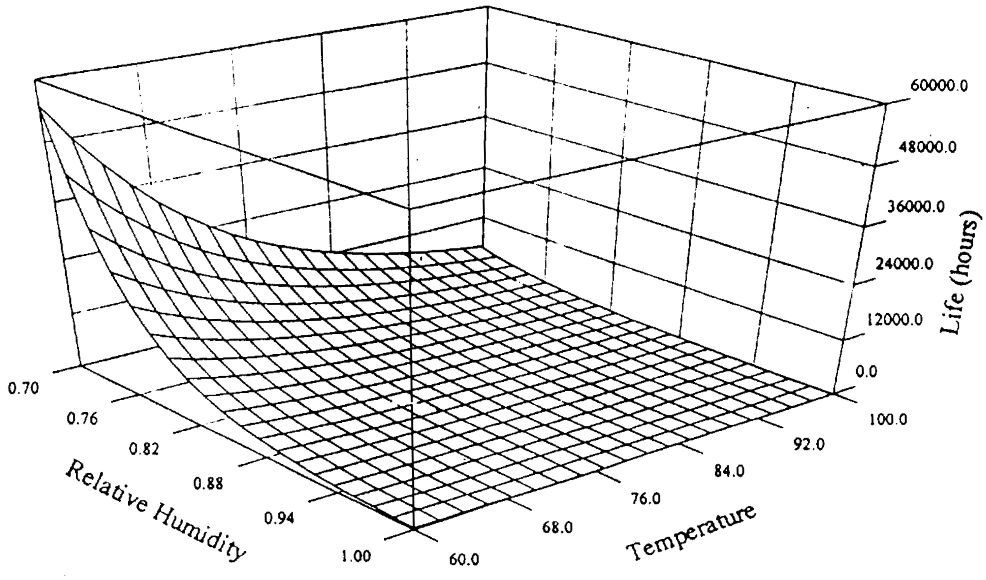

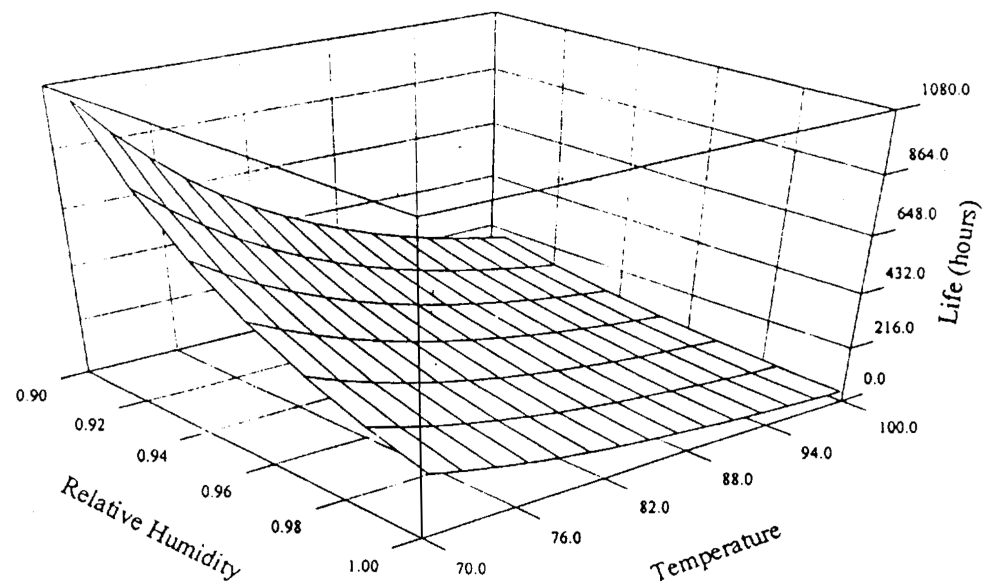

Figure 9 Variation of life in hours of one group of MIL-W-81381 as a function of the temperature (°C) and relative humidity (%). All specimens aged with a continuous ½ inch bend. Confidence limit 1% probability of any failure before time indicated. Similar curves exist for other aging bend diameters and failure stresses.

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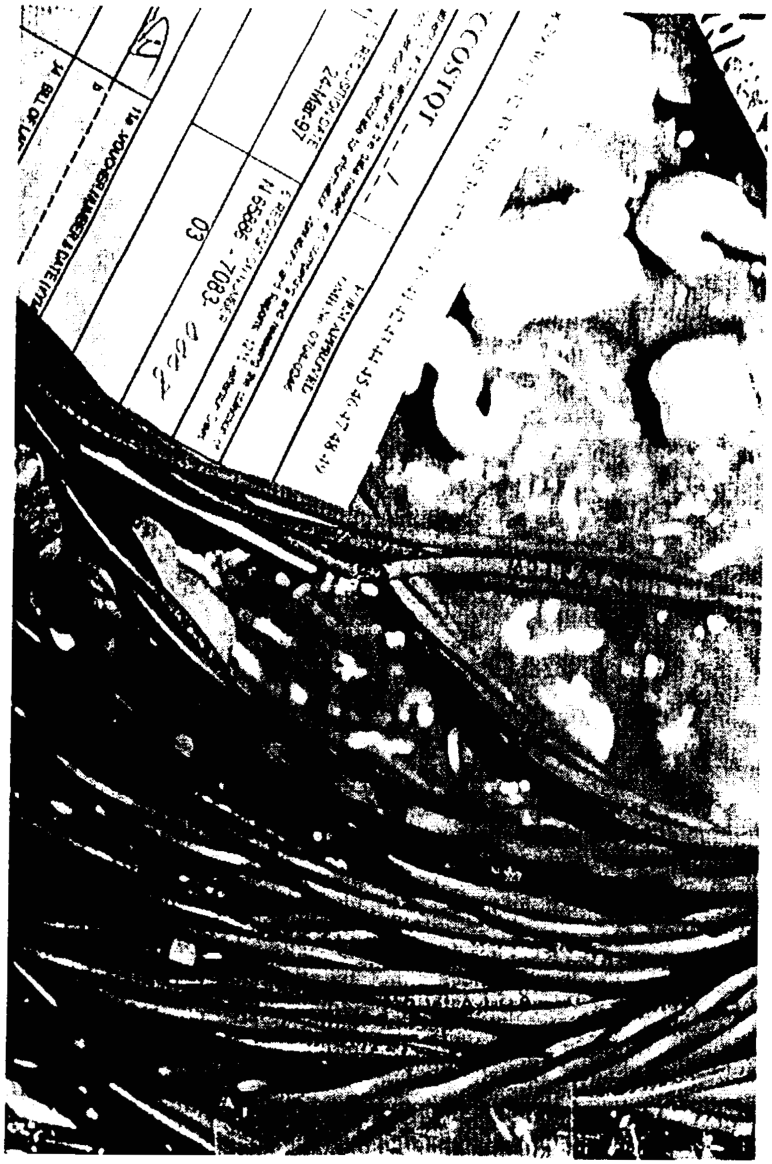

Figure 10 Typical severe trauma damage to insulation structure commonly found on many types of aircraft.

Percent Probability of Failure of the Worst
Polyimide Insulated Wire in each USN P-3C Aircraft Location
vs. Time

Location	Years 1	2	5	10	20
	% Failures				
Bomb Bay	0	0	0	24	33
Wing, Outboard Trailing Edge	0	0	0	28	53
Galley/Aft Cabin	0	0	0	41	61
Wing,Center Leading Edge	0	0	15	23	30
Forward Electrica Load Center	0	0	24	35	48
Avionics Bay C1	0	0	43	57	68
Wing, Inboard/Ro Leading Edge	15	20	32	46	60
Avionics Bay H1	21	23	40	46	78
Hydraulic Service Center, Under De	20	26	39	56	64
Main Wheel Well	38	42	50	72	100
Nose Wheel Well	31	57	89	100	100
Wing, Center, Trailing Edge	0	74	91	100	100

Lectromechanical Design Company
Sterling, VA 20166

As of May 7, 1995

Figure 11 Life forecast based upon measurement of length of polymer and correlation with expected maximum stress.

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Diagnostics and Cures

Most classical wiring fault detection systems depend upon monitoring the insulation to find cracks that already exist in the insulation, not for detecting material that has deteriorated sufficiently that cracks will develop in the near future nor material that has so deteriorated it is sensitive to trauma. These classical systems use such instruments as

1 DIT-MCO
2 megger
3 reflectometer
4 low current leakage

The DIT-MCO test unit has been used for many years to check wiring continuity and also leakage resistance to ground with a hipot voltage. A megger is a compact dc insulation resistance measuring device usually using 500 or 1000 volts dc. The reflectometer measures pulse voltage reflections in cable at impedance change points. Thus, if there is a break, this will be indicated by a pulse reflection voltage. The low current leakage technique uses a very low voltage to minimize test time to indicate existing breaks in insulation. All of these techniques are presently available, and are NDE in use. Other techniques are partially developed. They include sonic, optical, RF detectors, and insulation hardness testers ("indenters" similar to Brinell testers). We are not aware of any that have reached a commercial stage. Finally, the May 30, 1997 A. E. Petsche Co., Inc. "Committee Notes" indicates that Wright-Patterson AFB's Mr. George Slenski "never sounded more positive for the success" on his NDE *in situ* development program. Technical details have not been made available to this author.

All of the preceding techniques depend upon the existence of a complete break in the insulation on the wire in order to obtain a reading for the common micro crack of the insulation structure. Of course, these systems all measure the extreme trauma fault of Figure 10. These wire husbandry efforts are a reactive repair process. Further, as mentioned below, this also does not distinguish between wiring that is starting to fail because of aging of the polymer, and unusual trauma.

A system we have been using since 1991 provides data which measures the amount of remaining insulation life at the time a specimen is removed from the aircraft. From this one can infer how much time is left before the end of life is reached for any projected stress and environmental condition. The age of the polymer is determined by measuring how short the molecule has become. From this one can predict the amount of life-remaining in the polymer. This prediction follows directly from Figure 8. Figure 11 (published with premission) indicates one form of presentation of the projection of actual tests of life-remaining which can be used to schedule partial rewiring of aircraft. We note parenthetically, that managers of some aircraft types have been able to organize and implement quite economical partial repairs, contrary to common feeling this is not practical.

Recapitulation and Opinion

The process describing wire insulation deterioration is a structures failure phenomenon arising from the chemical aging of the polymer. This technical detail of the process permits quantitative analysis of the age and susceptibility of the insulation to failure **before** the onset of normal aging failure. Further, while use of the several techniques for locating existing open insulation will clearly improve reliability, the susceptibility of aging insulation to rupture by smaller and smaller stresses means that in aging aircraft the wiring will be increasingly prone to unexpected failure. By measuring the state of the polymer it is possible to black list aircraft before radical failures begin to occur.

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Note a second type of failure, distinct from normal aging failure is common in some aircraft types we have examined. This "excessive" trauma can be identified by measuring existing failures vs age of the wiring. This process can be observed in Figure 12 and Figure 13.

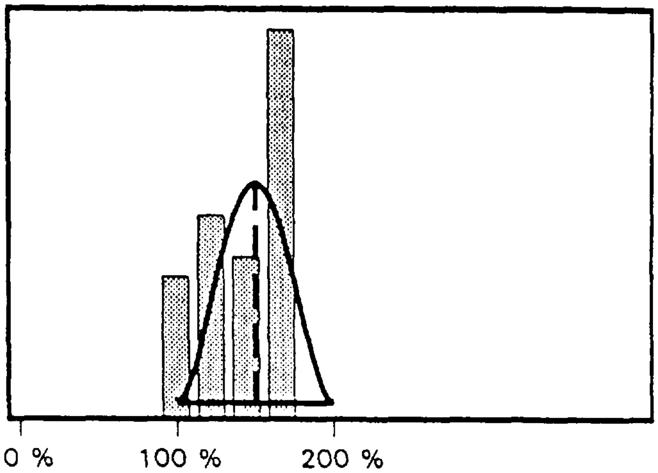

Figure 12 Age measurement of a batch of new polyimide wire. Abscissa is percent of life remaining as a percent of the shortest life expectancy of new specimens. Ordinate is the failure rate.

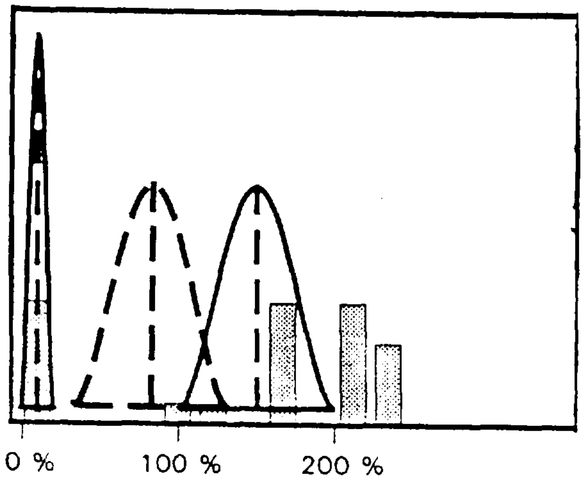

Figure 13 Measurement of the same wire from an active aircraft in maritime service since 1981. The left hand bell are the number of specimens which had already failed at the time specimens were removed. Note the bell is shown for clarity but all specimens were failed at time zero. The right hand bell is the normal aging distribution, in this case indicating essentially no aging since 1981 for this group. The dashed bell is the expected distribution of aging in more severe environmental locations. Note associated with this partially aged group is a lower resistance to trauma.

This composite report of Figures 12 and 13 provide the basis for predicting the improvement in aircraft reliability to be expected from remedial work. Partial rewiring, standard repair, and training programs will help for the two solid bell curves of Figure 13. Those actions will not cure the problem revealed by the solid left-dotted center bell, nor the dotted bell with no left bell curve.

In our opinion the informal level of wiring problem reports we receive indicate to us the insulation structure gradual deterioration process is placing our aging aircraft in a state where we will see more and more unexpected wiring failures. The process is compatible with the preceding scenario. Making "insulation structure" examinations to determine the normal aging drift can provide the information to take proactive remedial action on wiring, rather than waiting for overt failure. The molecular examination process is well defined. Examination of well over 25 active aircraft lend us this confidence.

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File: EnclA2. November 11, 1998

DESCRIPTION OF LECTROMEC WIDAS AGEING SUPPORT PROGRAM

Background

The study of a number of aircraft by the US Naval Research Laboratory (NRL), Washington, D.C. has confirmed that the deterioration of aromatic polyimide wire insulation, such as that used in MIL-W-81381 type wire, is *not* a function of the chronological age of the aircraft or the wiring but a function of the service environment. Unless all the aircraft in a series are exposed to the same environmental stresses over their operating life, no two aircraft will have the same amount of wire insulation deterioration for the same time period. There is a significant increase in the rate of insulation deterioration when there is an increase in a combination of humidity, temperature, and strain.

Since it is impractical to replace all wiring in all aircraft it would be desirable to be able to plan for wire replacement before failure occurs. There are two forms of failure. The most common is the breakdown of insulation leading to moist salt or carbon tracking. This tracking may lead to intermittent leakage current which generates electrical noise in the circuit. These "glitches" can cause intermittent failure of connected electronic equipment with particularly troublesome impact on digital equipment. These intermittent signals interfering with electronics become increasingly troublesome as polyimide ages. Occasionally, in naval environments in warm climates short circuit failure with circuit breaker tripping, destructive arcing, or wire and bundle burn through failures occurs. The Lectromechanical Design Company (Lectromec) of Sterling, Virginia has demonstrated and employed a system for determining the amount of aromatic polyimide type aircraft wire insulation deterioration that has occurred between the time the wire was installed and the present. The name of this system is the Lectromec Wire Insulation Deterioration Analysis System (WIDAS).

The goal of WIDAS is to support improved aircraft wiring reliability, availability, and productivity, with resultant reduction in maintenance cost per unit life cycle. WIDAS can be utilized to support extended operating cycles and extended life programs. It may also be used to support revised maintenance strategies in the face of budget or other resource reductions.

Knowledge of the amount of insulation deterioration that has occurred

(1) determines the criticality for managing wire replacement or wire maintenance BEFORE failure occurs. This allows aircraft maintenance personnel to identify and replace selected aircraft wiring (harnesses, bundles, etc.) before wire insulation failure results in wire failure and/or unscheduled wiring maintenance and to allocate wire repair/replacement resources (manpower or financial) efficiently.

(2) establishes a base for estimating the amount of life remaining in the insulation. Repeating this analysis periodically will give additional data points to facilitate an extrapolation of the end of insulation life.

LECTROMEC WIDAS

WIDAS Brief Description

WIDAS is a predictive technology that utilizes engineering knowledge of aircraft wiring for combining wire specimen selection, selective sampling of aircraft wires, accelerated ageing of the wire specimens in a controlled environment, and detailed analysis of the ageing test results to produce a report on the condition of the aircraft wiring. The system is designed to measure the amount of wire insulation deterioration caused by the environmental factors of temperature, moisture, and strain.

WIDAS determines the time to failure for each wire specimen taken from different locations in the aircraft. Statistically, the time until failure of each tested wire specimen compared to the time to failure of baseline (control) specimens represents the percentage of wire insulation life used. Selective sampling and testing will result in a high confidence estimate of the condition of the wire insulation for an entire aircraft.

Briefly, the WIDAS procedure:

(1) Takes wire samples removed from an aircraft.

A wire specimen is defined as a 24 inch (61 cm) in length, of statistically significant AWG diameter. Lectromec has aged polyimide insulated wire diameters of AWG 12, 16, 18, 20, 22, 24, and 26.

The choice of which aircraft to select samples from and test might be a function of scheduled depot level maintenance or the result of an age exploration or similar type program. Conversely, the results of this testing process could be the basis for the scheduling or initiation of such programs.

The wire specimens are taken from areas of the aircraft exposed to harsh environment and/or predetermined wiring maintenance problem areas. WIDAS is designed to report on the condition of wire insulation in these high wiring maintenance areas.

(2) Accelerates further insulation ageing of the specimens in a controlled environment in the Lectromec laboratory.

The wire specimens are placed in an automated wire insulation deterioration accelerator for accelerated ageing and analysis. This ageing accelerator is an environmental testing chamber capable of ageing the wire specimens under pre-established, tightly controlled and precisely defined thermodynamic physical chemistry conditions. Insulation breakdown at a specified voltage is used as the failure criterion.

Each sample is aged in the ageing accelerator until the insulation fails. The time to failure is dependent on the gage of the wire, the mechanical strain on the wire, the humidity and temperature in the environmental chamber, and condition of the wire being tested.

(3) Analyzes the specimens and test results.

WIDAS determine's the time to failure for each sample taken from the aircraft. Statistically, the time until failure of each test sample compared to time to failure of a control sample (baseline) represents the percentage of wire insulation life used, that is, its "age".

LECTROMEC WIDAS

(4) Makes conclusions about the condition of the wire insulation in the sampled aircraft.

Comprehensive WIDAS Survey

The first step in initiating an aircraft wiring evaluation program for any aircraft type/model/series is to conduct a *Comprehensive WIDAS Survey*. The purpose of this survey is to produce a profile, to the extent the information is reasonably available, of the environmental locations, circuits, cables, connecting devices, clamping points, removal and repair maintenance areas, abrasion points, and wire bends which are relevant to wire insulation ageing. A characterization will be presented for selected individual circuits, wire bundles, harness transitions, environmental zones, and for the overall aircraft. The deliverable of this first step will be a written report of the results, conclusions, and recommendations for selection of the aircraft and circuits to be sampled for testing in the second step of this proposed *Comprehensive WIDAS Survey*.

A "location" is defined as an environmental zone of the aircraft, such as the cockpit, a wheel-well, an avionics bay, engine nacelle, etc. in which the wiring in that zone is exposed to different temperatures and humidity than other zones. For each location the *Comprehensive WIDAS Survey* will identify wires to be sampled that are representative of the state of insulation deterioration for that location.

The initial activities are associated with identifying the aircraft locations and wire specimens that should be sampled and tested in subsequent activities. Following items 1-9 can be done during a working visit and inspection of aircraft of the relevant service by Lectromeand your personnel. A follow-up visit by an Lectromec engineer will be made to support service electrician(s) during sample removal. This removal is a routine process which we have supported for active duty aircraft. The following are a listing of relevant activities.

1. Comprehensive review of engineering information and drawings for selection of locations and sub-locations to be sampled and evaluated.

2. Interviewing of cognizant Tornado aircraft engineering and maintenance personnel concerning wiring system related problem experiences.

3. Identification of aircraft locations for WIDAS testing and evaluation.

4. Examine wiring bundles and wires in each aircraft location. Include in the examination the condition of the wiring insulation, clamps, ties, and connectors. Especially observe wire routing curvatures.

5. On any convenient aircraft at time of meeting of Lectromec and your personnel, make selected current leakage measurements on several wire circuits. This will require the assistance of an wireman to disconnect several cables to permit access to pins of connectors.

6. Lectromec to photograph all potential WIDAS aircraft sampling locations.

7. Identification of a minimum of 4 to 8 wire specimens, each 24 inches long, from each

LECTROMEC WIDAS

aircraft location (sub-location) for WIDAS testing and evaluation. There may be several specimens in one length of wire sample. There is some flexibility in this process. Last minute modifications can and probably will be made at the time of actual sample removal in step 2, with the assistance and advice of the Lectromec engineer that will be in attendance for this first WIDAS wire removal from an aircraft.

8. Train engineering and aircraft wiring maintenance personnel in the WIDAS program, wire specimen selection and removal process, and wiring specimen handling and shipping requirements.

9. Database compilation of data/information collected during survey.

10. Formulate interview speculations on condition of the wire insulation in each location.

11. Make recommendations as to aircraft, aircraft locations, and wire specimens to be tested and evaluated during second step of the *Comprehensive WIDAS Survey*.

12. Selection of a minimum of 4 to 8 wire specimens from each sub-location as candidates for testing and evaluation.

13. Preparation of the report of the analysis, conclusions, and recommendations.

14. The deliverable will be a written report, "Aircraft and Wiring Selection Recommendation Report", of the results, conclusions, and recommendations of the wiring samples to be taken for the second step of this *Comprehensive WIDAS Survey*.

It is expected that Lectromec engineers will work closely with the cognizant aircraft maintenance, logistic, and engineering personnel in accomplishing these first steps. Upon conpletion of these steps prodeed as follows:

15. Review of engineering information for selection of locations and wire specimens to be evaluated, including data derived from Step 1, and comparison with previous WIDAS evaluations and the Lectromec data bank from polyimide insulated wire tests (Data bank started in 1981). Analyze effect of large amounts of AWG 22 & 26 wire.

16. Selection of a minimum of 4 to 8 wire specimens from samples taken from each location for testing and evaluation.

17. Examination and preparation of the wire specimens for accelerated ageing.

18. Accelerated ageing of the wire specimens in the Lectromec Automated Wire Insulation Deterioration Accelerator (LAWIDA). The LAWIDA is a proprietary controlled ageing and testing system, designed and built by Lectromec, located at the Lectromec laboratory.

19. Post-ageing examination of the wire specimens.

20. Database compilation of the ageing test results.

LECTROMEC WIDAS

21. Data analysis.

22. Formulate conclusions about the condition of the wire insulation in the various locations.

23. Formulate Recommendations as to age implications of wire..

24. Preparation of the report of the analysis, conclusions, and recommendations on a location and overall aircraft basis.

Systematic WIDAS Evaluation

Systematic WIDAS Evaluation performs evaluation of an aircraft on a location basis. The number and identity of the locations will be a result of the *Comprehensive WIDAS Survey*. Again, a "location" is defined as an environmental zone of the aircraft, such as the cockpit, a wheel-well, an avionics bay, engine nacelle, etc. in which the wiring in that zone is exposed to different temperatures and humidity than other zones. It is a simple process may be an appropriate tool to use in the maintenance stragey.

Systematic WIDAS Evaluation of each location includes the following tasks:

1. Review of engineering information for selection of locations and wire specimens to be evaluated, including data derived from the initial *Comprehensive WIDAS Survey* for the type of aircraft of specific interest. Data from previous WIDAS evaluations are also used for comparison purposes. A significant data base of various manufacturer's wire quality, and ageing characteristics have been banked since 1982. These data are particularly useful in examining damage arising from external trauma, as compared to continuous thermodynamic ageing.

2. Selection of a minimum of 4 to 8 wire specimens from each location for testing and evaluations.

3. Examination and preparation of the wire specimens for accelerated ageing.

4. Accelerated ageing of the wire specimens in the Lectromec Automated Wire Insulation Deterioration Accelerator (LAWIDA). The LAWIDA is a proprietary controlled ageing and testing system, designed and built by Lectromec, located at the Lectromec labs.

5. Post-ageing examination of the wire specimens.

6. Database compilation of the ageing test results.

7. Data analysis.

8. Formulate conclusions about the condition of the wire insulation in the location.

9. Recommendations.

10. Preparation of the report of the analysis, conclusions, and recommendations on a

location and overall aircraft basis.

Definition of End-of-Life and Ageing

Lectromec defines the end-of-life of wiring insulation as the time at which a brief high voltage applied between the conductor, through the insulation, to a close ground plane (outside of the insulation) will lead to excessive leakage current (greater than 2.5 ma$_{rms}$). As a practical matter, the precise magnitude of the test voltage and leakage current make little difference in the total quantitative life measurement of polyimide type wire insulation. This end-of-life is defined for our purposes as 100% age point.

As the wire insulation reaches the end of its life at 100% age it becomes increasingly susceptible to cracking when moved by bending, such as occurs during maintenance. Although we know of no reliable quantitative fretting and abrasion correlation with polyimide type insulation ageing, our experience is that polyimide type insulation becomes much more susceptible to abrasion as it ages.

Many examples have been seen where insulated wiring which did not indicate visible cracking did develop conduction path(s) from the conductor to the outside of the wire. As salt and cleaning fluid deposits accumulate, with humidity these microscopic path(s) conduct current which leads to wire failure.

The following analogy may also help to understand the terms "age" and "life remaining" of wire insulation:

> Polyimide insulation has a specific number of good molecules at the time of material production and wire wrapping. This number of good molecules can be thought of as analogous to a starting balance of a bank account. That is, a new aircraft with new wire insulation has a starting balance of, let us say, 100% (or $100) life available and age of 0% corresponding to a certain number of good molecules which we also call 100 %. The stresses and strains of aircraft usage withdraw over time from the "insulation life account", or use up the good molecules. The dollars withdrawn (or number of molecules used) is related to the amount of stress over a period of time. For instance, 95°C for ten hours at 100 % relative humidity might withdraw $10 from our life account, leaving us with only $90 (aged 10%, leaving us with 90 % of insulation life still available). Each type or combination of use stress such as moisture, strain from bending or abrasion or vibration, and temperature makes its own $ withdrawal per period of time from the "life" account (uses a specific number of good molecules). Note that all polyimide insulation molecular usage is sequentially additive. Also, the life remaining account is a one-way bank account, in the aircraft environment; i.e.: we can use the good properties of insulation but cannot restore the insulating properties --we can make a cash withdrawal but can not make a redeposit. There is an opposite viewpoint that it is possible to "anneal" polyimide insulation. We do not believe this is possible in the aircraft application.

Definition of Baseline Life

WIDAS does not use "new wires" as the baseline (control group). Laboratory tests from 1982 to present by the Naval Research Laboratory and Lectromec have demonstrated large variations within MIL-W-81381 type (polyimide) insulation quality. Thus, for any given aircraft, the length of life to be expected from a given wiring installation (i.e., the number of "good" molecules available) is highly variable. To measure how much the wiring has aged as a percentage of the original life available, it is not possible to compare the life remaining as a per cent of an industry average. WIDAS, instead, measures the original amount of life available in the specific aircraft which is being tested.

Fundamental thermodynamic development and experimental data indicates that polyimide deterioration rate is negligible with low relative humidity, low strain, and moderate temperature. This fact is utilized to determine the actual life duration capability of the wire as originally installed on the tested aircraft. As part of the WIDAS process, an area of the aircraft will be identified which has relatively low humidity and moderate temperature from which wiring samples with low strain will be selected as representative "unaged" wires (baseline specimens).

ECONOMIC AIRCRAFT WIRE MAINTENANCE, INSPECTION & REPAIR: *PERFORMANCE IMPLICATIONS*

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Abstract

Maintenance is one of the more costly elements of aircraft operation. Wiring as an element of that maintenance cost that has been regarded as of relatively little importance. In addition to wire maintenance cost, wiring is today receiving a high level of attention because of the perception that it may also have a significant impact on reliability of operation. It would be well to be aware of economic impact of any changes in wire maintenance if this new interest in wiring (and thermal blanket insulation changes) can lead to increased wire costs. We explore the economic aspects based upon our experience, particularly drawing lessons from our military experience to raise questions, and suggest some answers and options for extension to the commercial jet fleet.

The senior author of this paper was the Director of Logistics and Fleet Support for U.S. Navy and Marine Corps Aviation for a period of 4 years. That included command of six Naval Aviation Depots caring for wiring of a fleet 5,400 aircraft. The depots either performed this work or directed the work of civilian contractors. The number of unscheduled field wire events was reduced from an annual rate of 143,641 in 1987-1988 to an expected total in 1999 of 62,200 (extrapolated from the first five months of 1999). Our report relies on that experience.

In addition to the reduction in cost associated with this improvement there was a corresponding decrease in the number of A/C wire fires. On one specific A/C type/series the rate of in-service A/C fires was reduced by 88%, resulting from a proactive wire management program.

The major components of the tools to improve maintenance that have lead to the cited improvement in unscheduled outages and reduction of A/C fires include: Continued use of the classical techniques of professional dedicated visual inspection teams, hi-pot and leakage resistance test devices, improved husbandry practices and sensitization of the non-electrical mechanics as to special needs of wiring. Recognizing the tendency to report all wiring problems as a charge against the connected device, work unit codes were established to more accurately reflect the under reported wire events. The junior author cooperated in the development of two novel maintenance techniques. He has applied these broadly across the fleet. For some types of

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A/C significant improvement resulted, both with the U.S. Navy and cooperating military forces in Canada, the Netherlands, and Great Britain. The two techniques provide (1) actuarial life prediction of wiring aging by zones of many types of aircraft, used to plan proactive maintenance. (2) In addition nondestructive examination (NDE) of high risk zones permit 100% correction of wiring that has breached insulation.

Background

Study of wiring care economics and impact on reliability is at an early stage of development. The available data is frequently of questionable validity, having both possible military intelligence and adverse commercial impact potential which leads to proprietary treatment. We expect to continue the investigation of the material presented here with some of you in this audience and solicit your communications, particularly with respect to increasing accuracy and as to new viewpoints and models. We note several caveats:

- While the question of safety and loss of aircraft can have severe economic impact we have chosen not to attempt to assign our judgement of liability personal injury dollars to wire derived events. We note the statement by Mr. Robert Baker, American Airlines Executive Vice-President for Operations: "If it is a safety issue, there isn't such a thing as too much money.[1]"
- Costs associated with loss of an in-flight aircraft consist of two major elements: The value of lost hull can be handled from several viewpoints including depreciated value or replacement cost. Consequential cost includes or excludes lost passenger fare and liability costs. At the early stage of this work we have little basis on which to choose. We have chosen to use the underwriters's coverage as an indication of the value placed on the equipment by commercial operator for the hull and liability loss.

  Such numbers do not exist for military aircraft. The "dollar value" of a military aircraft is a complicated number, subject to the question of quantity in the order chain, assignment of development costs, etc. We can only recognize there are substantial costs associated with loss of availability and hull loss in the military. Military maintenance costs are therefor handled as a cost avoidance opportunity.

We treat in this paper the following categories:

- Background
- Cost Scenarios
- Technical aspects affecting economics
- Initiatives

As background we present estimates of maintenance costs for A/C wiring in the USN and for commercial jet transports. As far as the Air Force we can only quote[2] that about half of the Air Force personnel are reported to be assigned to maintenance activities. The junior author has had a number of anecdotal comments made to him by Air Force personnel about wiring events that leads him to believe that the portion of this maintenance effort for wiring is not negligible.

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As to the U.S. Navy wire maintenance costs, we estimate the Navy will spend $20.1 million on unscheduled wiring maintenance in 1999. This leads us to Figure 1.

Figure 1. Yearly unscheduled US Navy maintenance costs, 1999 estimated.

- Naval Air Logistics Data Analysis (NALDA) indicates 5.2% of all naval unscheduled maintenance hours is on electrical power systems. Projecting 1 Jan – 21 May 1999 data implies 62,213 wire repairs for 1999.
- Estimated cost of labor, material and overhead (but no burden) is $20.1 million. This is a cost of $323 per wire event.

A sidelight to this number: The senior author's logistics group at the Naval Postgraduate School has developed data that indicates a sharp difference in maintenance economics for the navy and one major commercial airline: The navy's incidence of unscheduled maintenance is 4.5 times the amount of scheduled wiring maintenance. On the other hand, in the case of one studied commercial airline the unscheduled maintenance is only 0.3 times their scheduled maintenance. The reasons for this difference have yet to be positively identified.

We estimate commercial jet wire maintenance costs by the following process: Figure 2 indicates the distillation from 1998 DOT aircraft operating cost data. And complete data sheet for the 727-200 is shown in Figure 3. Figure 4 compares the navy and commercial wire maintenance costs.

Figure 2. Operating vs. maintenance data. Overheads included, but no burdens.

727-200 (Based on 1998 DOT data)				
Block Hour Costs: 1998 Dollars per Block Hour:				***Total Maint.***
Carrier	**# A/C Operated**	**Flying Operation $**	**Direct $ Maintenance**	**Block hrs. / Maint. $**
American Airlines	78	$ 1,282	$ 509	238,266 / $ 121,000,000
Delta Airlines	129	$ 1,496	$ 336	424,608 / $ 143,000,000
United Airlines	75	$ 1,206	$ 386	231,974 / $ 90,000,000

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Figure 3. Complete DOT data for all US commercial jet transports.

Aircraft Block Hour Operating Costs and Operations

727-200

The Year 1998

Dollars Per Block Hour

Carrier	Aircraft Operated	Crew Cost	Fuel and Oil	Rentals	Insurance	Taxes	Total Flying Operations	Airframe Maintenance	Engine Maintenance	Direct Maintenance	Maintenance Burden	Depreciation	Other	Total Aircraft	Block Hours
American Airlines	78	$700	$532	$0	$0	$50	$1,282	$321	$188	$509	$368	$68	$33	$2,260	238,266
American Trans Air	25	$423	$815	$285	$7	$0	$1,551	$382	$67	$449	$117	$402	$15	$2,534	78,939
Continental Airlines	30	$534	$532	$121	$2	$51	$1,240	$339	$154	$492	$193	$17	$16	$1,958	96,492
Continental Micronesia	13	$503	$532	$265	$1	$34	$1,315	$529	$172	$701	$0	$17	($1)	$2,032	30,918
Delta Air Lines	129	$746	$653	$21	$1	$75	$1,496	$181	$155	$336	$222	$123	$19	$2,196	424,608
Northwest Airlines	40	$565	$524	$75	$1	$72	$1,237	$341	$94	$435	$61	$43	$5	$1,781	108,609
Sun Country Airlines	11	$238	$638	$351	$34	$0	$1,357	$361	$231	$592	$117	$34	$1	$2,101	32,731
Trans World Airlines	25	$422	$455	$78	$2	$59	$1,018	$199	$108	$307	$348	$9	$5	$1,687	76,052
United Air Lines	75	$568	$556	$1	$0	$81	$1,206	$277	$108	$386	$300	$50	$35	$1,977	231,974
USAir Shuttle	12	$853	$504	$21	$0	$0	$1,379	$570	$506	$1,076	$151	$142	$0	$2,748	24,440
TOTAL	437	$624	$588	$58	$2	$60	$1,335	$279	$149	$428	$238	$92	$21	$2,114	1,343,029

Aircraft Utilization Per Day

	Total Fleet Operations						Average Aircraft Operations										
Carrier	Departures	Block Hours	Flight Hours	Miles	RPMs	ASMs	Departures	Block Hours	Flight Hours	Miles	RPMs	ASMs	Average Seats Per Flight	Average Stage Length	Operating Cost Per ASM	Gallons Per Hour	Cents Per Gallon
American Airlines	271	653	540	243,486	25,171,641	36,521,510	3.5	8.4	6.9	3,122	322,713	468,224	150	898	4.04 ¢	1,325	0.40
American Trans Air	78	216	185	86,323	10,999,356	14,933,795	3.1	8.7	7.5	3,491	444,778	603,874	173	1,111	3.67 ¢	1,376	0.59
Continental Airlines	103	264	220	99,756	11,346,773	14,863,597	3.4	8.8	7.3	3,319	377,471	494,464	149	969	3.48 ¢	1,398	0.38
Continental Micronesia	39	85	71	33,043	2,486,378	3,882,386	3.1	6.7	5.6	2,618	197,019	307,638	117	840	4.43 ¢	1,080	0.49
Delta Air Lines	675	1,163	923	380,933	40,213,427	56,705,932	5.2	9.0	7.2	2,953	311,732	439,581	149	564	4.50 ¢	1,279	0.51
Northwest Airlines	139	298	239	101,135	10,532,310	14,956,118	3.5	7.5	6.0	2,537	264,166	375,122	148	728	3.54 ¢	1,265	0.41
Sun Country Airlines	35	90	75	38,203	4,885,811	6,193,079	3.2	8.2	6.9	3,473	444,165	563,007	162	1,097	3.04 ¢	1,424	0.45
Trans World Airlines	104	208	165	68,464	6,928,885	9,893,279	4.2	8.3	6.6	2,744	277,711	396,524	145	658	3.55 ¢	1,257	0.36
United Air Lines	317	636	524	234,227	25,102,641	34,407,482	4.2	8.5	7.0	3,123	334,702	458,766	147	739	3.65 ¢	1,373	0.40
USAir Shuttle	58	67	43	11,600	837,699	1,872,178	4.8	5.6	3.5	962	69,461	155,239	161	199	9.83 ¢	1,092	0.46
TOTAL	1,819	3,679	2,985	1,297,170	138,504,921	194,229,356	4.2	8.4	6.8	2,966	316,735	444,166	150	746	4.08 ¢	1,311	0.45

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Figure 4. Comparison of wire maintenance costs.

- **Wire Maintenance Cost on all 437 Commercial 727-200s (DOT data from Figure 3)**
  - **$1.8 billion operating**
  - **$0.57 billion maintenance (no burden)**

  If 5% of maintenance is wiring, then:
  - **$29 million/437 A/C = $66,000 per A/C per year**
  - **$29 million/1.34 million block hr = $21/block hr**
- **In comparison: Wire Maintenance Cost on USN Air Fleet**
  - **$21 million/390,245 flight hours = $52/flight hr**

In addition to the maintenance costs of wiring we need to have a measure of the costs of loss of A/C, as attributed to wiring, to estimate savings from improvement in aircraft wire maintenance. This is, of course, quite controversial. We will not try to adjudicate the difference in opinions as to whether failing electrical insulation has caused the loss of commercial A/C. We know conclusively this has happened in our naval service. With the reports of smokers and fires in commercial jets we take the position of bracketing with an upper and lower bound the cost of lost commercial A/C averaged over the complete inventory of 3,972 U.S. jet transports (based on the 1998 DOT A/C data count, Figure 3). We use the loss associated with an A/C at Peggy's Cove, Halifax recently, as a measure of what a single large modern loss could cost. Of course, in the U.S. fleet there were no fatalities related to A/C loss in 1998. We emphasize that we pick the Halifax loss in order to establish a measure of average loss that is a reasonable estimate.

For those that argue that this is an unreasonable approach we could cite a number of aircraft fires or smokers that came very close to causing similar U.S. A/C losses in 1998. *Business Insurance* magazine quotes the responsible underwriter for Swissair 111 that the "incurred hull and liability losses...totaled...$641 million"[3].

Figure 5 presents two prorated costs per A/C which for this analysis we attribute to electrical wire insulation failure. The average cost is, of course, calculated by dividing the one event cost by the total number of A/C in the US population at risk. We divide this over the U.S. fleet for one event per year and one event per ten years. This costing is the equivalent to a 100% efficient insurance pool payment by all operators, completely spreading the loss risk.

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Figure 5. A "straw man" estimate of range of hull loss and liability cost prorated over all U.S. aircraft.

- **Insurance Trade Journal *Business Insurance* indicates Swiss Air 111 "incurred hull and liability losses ....totaled...$641 million". For purposes of calculating an average hull loss cost use this loss for an electrical US carrier hull and liability loss.**
- **DOT indicates there are 3,972 U.S. jet hulls.**
- **Averaging, this would be $161,000 per hull per year for each US aircraft.**
- **If this unusual wire event occurs once per decade, the cost per hull would be $16,100 per year.**

Another number which may give some feeling as to magnitude of the assumed loss: According to the same reference 4, "in 1998, total; aviation insurance losses topped $1.8 billion...there were 26 Western built jet losses..."

In addition to basic cost of wire maintenance, and wire related hull loss economic costs, there are other cost factors. These include flight diversion costs for which we have estimates ranging from $10,000 to $50,000 per diversion, a large number of smaller items such as necessity to repeat a deicing because of flight delay from electrical repair, etc. More serious are loss of reputation with customers from delay or canceled flights, a major economic impact from deterioration of employee moral, and diversion of management attention from creative tasks.

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Cost Scenarios

Figure 6 is the diagram of a simple wire repair sequence in response to an unscheduled wire failure event. The event could have been a ramp, taxiing, or in-flight event. We have used input data appropriate to our military experience.

Figure 6. Standard wire repair sequence from ramp, taxiing, or flight insulation wire breach.

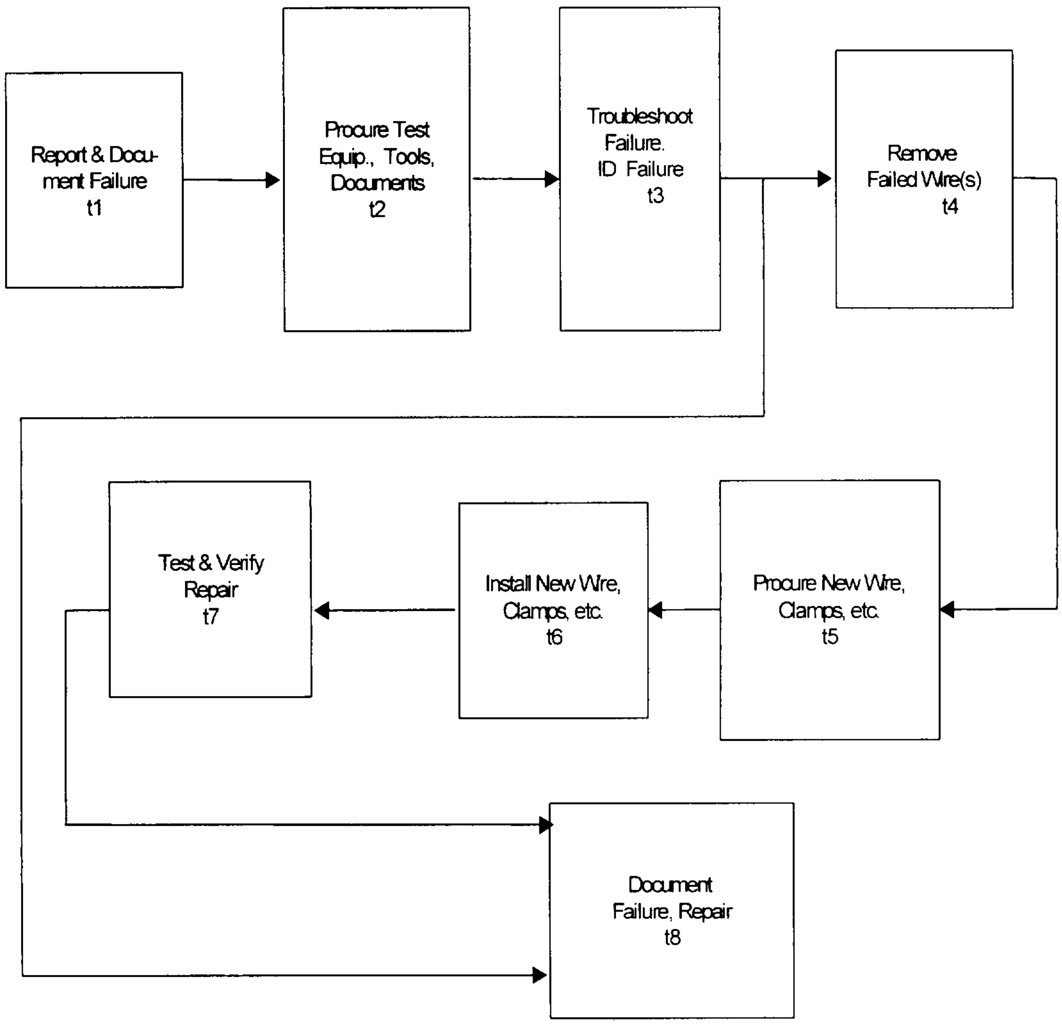

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Figure 7. Sensitivity analysis of a naval wire repair sequence.

	2 hour Diagnosis		10 hour Diagnosis	
	Labor $ 40/hr.	Labor $ 50/hr.	Labor $ 40/hr.	Labor $ 50/hr.
Report and Document Failure	0.5 hours	0.5 hours	0.5 hours	0.5 hours
Procure Test Equipment	1 hour	1 hour	1 hour	1 hour
Trouble Shoot Failure and I.D. the Failure	**2 hours**	**2 hours**	**10 hours**	**10 hours**
Remove Failed Wires	1 hour	1 hour	1 hour	1 hour
Procure New Wire and Accessories	0.5 hours	0.5 hours	0.5 hours	0.5 hours
Install New Wire	0.5 hours	0.5 hours	0.5 hours	0.5 hours
Test and Verify Repairs	1 hour	1 hour	1 hour	1 hour
Document Findings and Repairs	2 hours	2 hours	2 hours	2 hours
Cost of Parts	200 $	200 $	200 $	200 $
Labor Rate (Unburdened)	**40 $ per hour**	**50 $ per hour**	**40 $ per hour**	**50 $ per hour**
Total Yearly Cost (Unburdened)	**33.6 million $**	**38.9 million $**	**53.5 million $**	**63.8 million $**

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Figure 8. Summary of wire repair cost logic flow and sensitivity analysis.

NALDA USN data indicated 5.2% wire maintenance resulting in $20.1 million maintenance costs for 1999.

Model calculations in preceding slide imply USN cost for 62,213 NALDA wire event costs ranging from $33.6 million to $63.8 million. At the lower number this is $540 per wire event.

Estimate from NALDA may be low. Difficult not to submerge wire repair time into code for connected device.

Emphasizes critical nature of quick identification of fault.

There are several comments about the results of this analysis: First, even the lower cost of $33.6 million for the navy experience is above our NALDA based cost estimate of $20.1 million for 1999, made above. But we consider the results are within what we feel is the accuracy range of our present data input.

A second result is not apparent from the table. That is the effect if one were to include the cost of lost revenue in the case of commercial flights, or some "cost" for an adversely affected mission for military operations. It would not take many "lost fares" because of diversion of passengers, to amount to many millions of dollars over the year for an airlines' operations.

There are many other scenarios which it will be useful to cost. While it is beyond the scope of this presentation to analyze the many cost scenarios that are a part of aviation operations we list a few of them in Figure 9.

Figure 9. Other economic scenarios.

- **Ramp Events**
  - **EMI**
  - **Smokers**
  - **Fires**
  - **Flight Delays**
- **Taxiing Events**
  - **ditto**
- **Flight Events**
  - **ditto**
- **Associated Economics**
  - **Loss of Customers/Fares**
  - **Loss of Military Mission**
  - **Loss of reputation**
  - **Punitive liability costs**
  - **Management diversion**
  - **Employee demoralization economic impact**
- **A/C Purchase/Resale Value affected by Wire Condition**
- **Age/Type of Insulation Past maintenance quality**

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A selection chart for identifying each of the cost options for in-flight wire failure is shown in the following Figure 10.

Figure 10. Wire penetration caused failure results possibilities; In-flight failure.

	A	B	D	E
1	OK			
2	Insulation Break	OK		
3		Electronic Noise	OK	
4			Diverted Flight	
5			Loss of A/C	
6			Abnormal Landing	OK
7				Loss of A/C
8		Failed Power Device	Ditto	Ditto
9		Smoke or fire	Ditto	Ditto

Examination of the probability chart indicates there are a number of routes to the following abnormal situations which each have their cost consequences. Note we have not presented our probability estimates for each branch point because of their great variation and uncertainty. The results include:

- diverted flight
- damaged aircraft
- loss of aircraft

Probabilities and cost for similar unscheduled wiring event options exist for A/C on a ramp (or deck), or in the process of taxiing.

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Technical Aspects

For economic calculations, a deterministic model confirmed by field data and laboratory experiments, can provide the means to make probability estimates to be used in the summation of the results derived from the processes of the preceding section. There are two fundamental phenomenon relating to wire insulation failures. The first is the actual process of penetration of the wire insulation. The second technical process is the impact on the aircraft of a wire breach which *may occasionally* result in an aircraft event.

We document some of the types of insulation penetrations. These exist on all types of aircraft we have examined, even some with only a few years of use. The vast majority of these penetrations are benign with respect to aircraft operation:

- Fractures from bending as when removing equipment, design of cable routing, etc.
- Chafing against other wires, structure, clamps
- Crushing
- Cutting
- Wire tension

Each of the insulation penetrations is affected by the aging of the polymer as well as the force intrinsic to various force "insults". The aging factors for the various polymers are well documented in the voluminous polymer literature. Further it appears to your authors there is one overriding factor dominating the longevity of wire insulation. This is the thickness, or perhaps we should say "thinness" of the insulation. This is illustrated in the following Figure 11. And to define types of penetration we illustrate some in the following Figure 12. Note the more common types of wire presently installed have their "favorite" failure modes. We commonly find all of these in military and Coast Guard aircraft.

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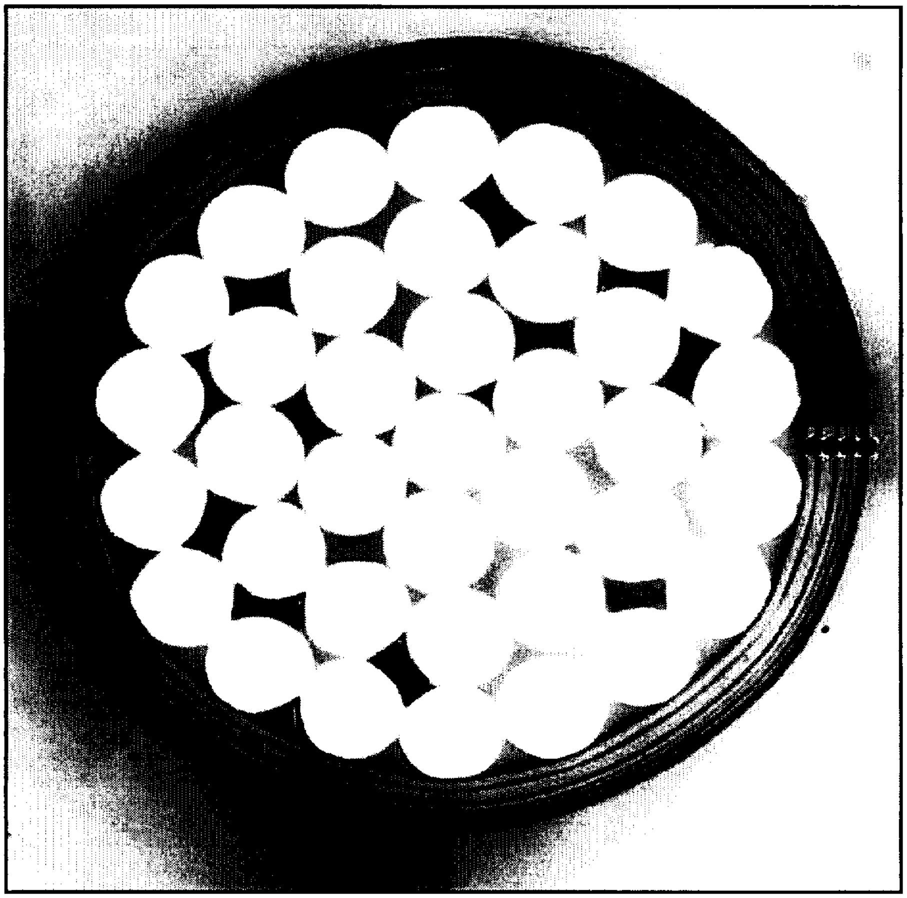
Figure 11. Fundamental Challenge; Wire cross section illustrating 3½ hair "thinness" of insulation.



The 4 human hair cross sections on the right indicate the implied delicacy of much of the insulation on our A/C. The probability of encountering a force, and insulation aging, in the 25-150 miles of wire found on our aging transport appears to the authors to be high. The probability, forecast, and finding these before the insulation breach that can lead to an aircraft event is at the heart of realistic economic maintenance and consequential damage economic challenge.

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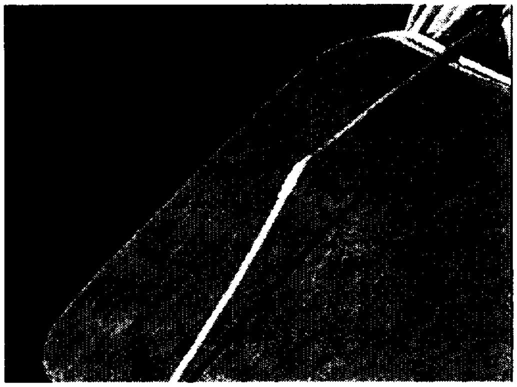
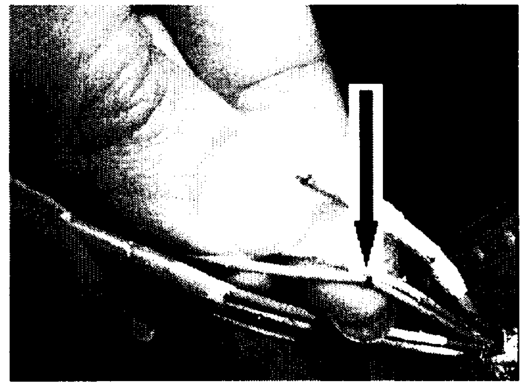
Figure 12. Four types of failures in four different widely applied types of insulation.

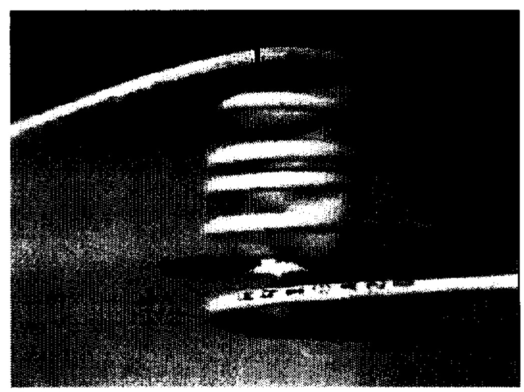


Mil-W-22759/34
(X-ETFE)
Flowing



Mil-W-81381 (Aromatic
Polyimide) Fracturing
from age

Mil-W-5086/2 (PVC/Nylon)
Compression split



Mil-W-81044/16 (Aliphatic
Polyimide) Spalling

The authors have widely discussed in various military publications, transactions, and previous FAA-DOD-NASA conference the principles of Figures 13, 14, and 15. The underlying fundamentals to insulation breaching are illustrated:

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Figure 13. Time to first insulation fracture of aromatic polyimide for a one half inch diameter bend as a function of temperature and humidity.

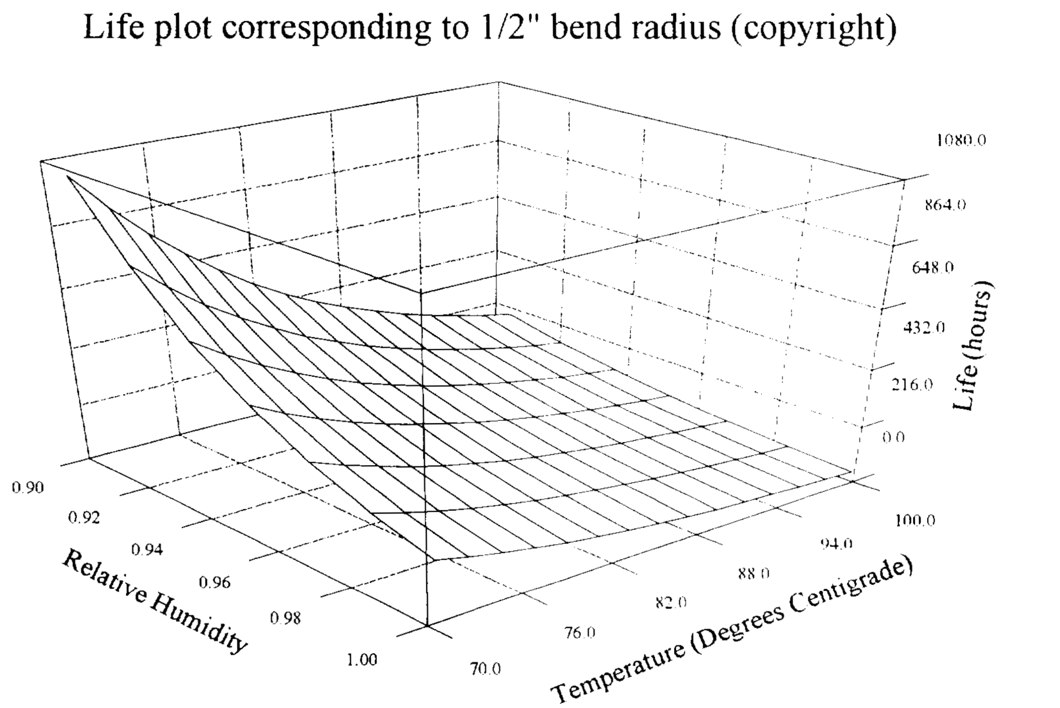

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Figure 14. Insulation breaching probability in a specific aircraft zone (zone 32) of a fighter, based upon sampling tests of active aircraft wire (thirty feet of removed wire from 100,000 feet in an active aircraft). Similar projections have been verified by field follow up of projections initiated in 1990 on other A/C.

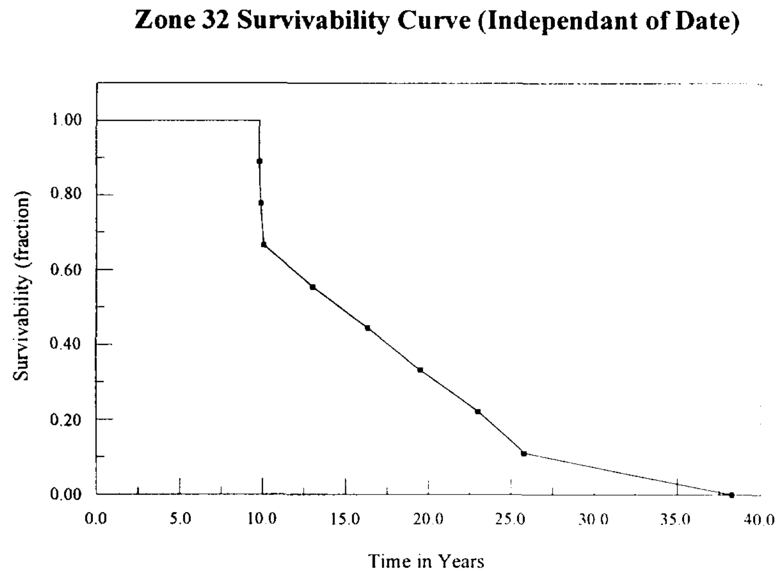

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Figure 15. Wire actuarial breaching probability chart. Used to proactively load level wire maintenance scheduling, avoid emergency flight delay repairs, and avoid in-flight events.

Location	Years: 1	2	5	10	20
	% Failures				
Bomb Bay	0	0	0	24	[illegible]
Wing, Outboard Trailing Edge	0	0	0	[illegible]	53
Galley/Aft Cabin	0	0	0	[illegible]	61
Wing,Center Leading Edge	0	0	15	23	[illegible]
Forward Electrical Load Center	0	0	24	[illegible]	[illegible]
Avionics Bay C1	0	0	43	57	68
Wing, Inboard/Root, Leading Edge	15	20	[illegible]	[illegible]	60
Avionics Bay H1	21	23	[illegible]	46	[illegible]
Hydraulic Service Center, Under Deck	20	[illegible]	39	56	64
Main Wheel Well	[illegible]	[illegible]	50	72	100
Nose Wheel Well	[illegible]	57	89	100	[illegible]
Wing, Center, Trailing Edge	0	74	91	100	[illegible]

P-3 Four Engine	% Probability of failure	As of May 17th, 1995

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At this point we have defined wire insulation penetration phenomena. Insulation penetrations, fortunately, do no always lead to adverse economic and safety consequences. There is a second step that must occur before we have an adverse A/C event. This is the fact that at the dominant 120/208 volt system most threatening on jet A/C *there will be no adverse effect of wire insulation breaching* unless a (partial) short circuit develops. Broadly speaking, there are two types of short circuits. The first is the bared electrical conductor directly contacting metal of the airframe (ground) or another conductor at a different potential. In our experience this "dry arcing" is the more common form of troublesome failure.

The second type of failure affecting cost probability projections is the so called wet arc tracking failure. Here low level current "creeps" through the insulation fracture to dirt and moisture on the surface of the insulation, along this path to a ground return. This current can carbonize lint, dirt, and insulation, sometimes over long periods of time, and occasionally leads to a violent final arcing and severe electrical fire.

The key economic impact question, for which the final answers are not yet in but for which we have the fundamental techniques to determine the answer is:

> *What is the quantitative connection between the occurrence of an insulation breach and a serious consequence for operation of the aircraft?*

The forms of serious consequences include:

- Electronic noise interfering (intermittently) with electronic and power equipment operation by EMI and noisy circuits.
- Tripped circuit breakers dropping loads.
- Reclosing circuit breakers without a simple pre-thought out failure action card (we have seen recommendations that a flight crew should "analyze the flight fire problem which may take as much as one half hour" with the associated probability of economic impact of loss of the A/C).
- Fire; arc cutting of structures, control cables, other wires ,hydraulic lines; generation of blinding smoke; and ignition of gasoline and other combustibles.

Using wire age measurement sampling techniques we have identified severely aged wire insulation in a group of a 100 A/C at the cost of $3000 per aircraft, Figure 15 above. Where action has been taken by services in various countries to correct this problem there has been no reported further wire induced failures. Where corrective actions have not been taken there are written reports of wire associated flight fires. Follow-up 100% non destructive examination (NDE) at a cost of $20,000 located all insulation breaches and repaired them in a period of two days. (Laboratory staged blind fault location tests have demonstrated essentially 100% reliability of the proprietary tests combined with use of standard commercial test equipment.)

On one specific A/C type/series use of the new techniques reduced the rate of in-service A/C fires by 88% over a five year period. We believe the same techniques would markedly reduce unscheduled wire events for every type of military and civilian aircraft for all types of insulating materials. These techniques are particularly important to protect against the

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characteristic of aromatic polyimide burning in the presence of the very high electric arc temperature, the economic impact of which can be severe if this aspect is not properly managed.

Economic Impact Initiatives

The preceding findings indicate several guiding thoughts.

- Two of the lower cost estimates for unscheduled repair were $323 and$550 per repair. This is well over twice the cost of the NDE repair described in the text.
- The overall proactive NDE cost rate is low for the detection and repair of faults as compared to even the $16,000 for loss of A/C and liability for one loss each ten years. The safer we can operate, the more economical it is.

Quoting Dr. David Huntzinger, Vice President of Safety, America West: "Prevention is *always* cheaper than investigation"[4]. In that spirit we list some of the actions that can be initiated, or perhaps deserve further economical investigation:

- Generate a whole new husbandry attitude in all mechanical trades, engineering design, and management personnel about the delicacy of wire insulation and possible consequences of ignoring the problem.
- Recognize that visual inspection locates only about 25% of insulation breaches. Consult with and use newly emerging and existing inspection equipment.
- Decide on a management philosophy: 1. Attempt to maintain an insulation system with minimal insulation breaches; or 2. analyze and recognize for one's particular type/age/maintained aircraft the cost of reactive maintenance.
- Particularly recognize the high cost associated with the severe arc burning propensity of aromatic polyimide. Either check engineering aspects to minimize arcing fault impact or replace wire with other materials *if the engineering application environment will permit use of materials with different weaknesses*.
- Consider retiring A/C with severely chemically aged (not necessarily correlated with chronological aged) wire. This has been very effective in reducing severe accidents with some Navy type A/C.
- Consider the feasibility of arc fault detector circuit breakers to prevent possibility of arcing faults.
- Investigate possibility of arc suppression fire extinguisher systems.
- Accelerate replacement of signal wires with multiplexed and fiber optic information and control systems. Note the authors believe this will take significant support structure development so that interim wire care would be beneficial for a period of years, near term.
- Utilize developing techniques to audit occurrence of work practice induced trauma vs. unavoidable age related insulation failures. Refine existing husbandry training and

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practices, some of which we have seen that do not account for some fundamental materials properties.

- Recognize severe challenge identified by FAA of ensuring that practices in some 4,500 certified A/C repair stations do not mistreat wire. To the authors that are familiar with managing the work of six repair depots, this appears to us to be an awesome management challenge.
- Recognize that we have seen the navy achieve an 88% reduction in wire events in one type/model US Navy A/C. Based on our examination of the civilian and Air Force situation it appears that if a decision is made that proactive wire maintenance is economically and safety wise justified, the phenomena would be responsive to the new inspection techniques in combination with standard practices to a similar degree of improvement.
- Investigate tracer wire insulation fault detectors.

In conclusion, we believe air transportation is the vital enabling factor in a robust global economy and a safe effective air force is a guarantor of national security. The demonstrated safety and economy of commercial and military aircraft is awesome today, but it can be made better. The adoption of the wire maintenance strategy recommended by the authors will ensure wire will never compromise safety or revenue.

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References

1. Lunsford, J.; *The Dallas Morning News*, 24 June 1999.

2. O'Bryon, J; Deputy Director, Office of Secretary of Defense, Live Fire Test & Evaluation; 10 June 1999 Aircraft Wiring & Inert Gas Generator Working Group.

3. Roberts, S; Record Losses in Aviation; *Business Insurance*, June 7, 1999; p43

4. Huntzinger, D. May 10-20, 1999, Introduction to Aviation Safety and Security Management; Aviation Safety and Security Management Certificate Program, The Aviation Institute, The George Washington University, Virginia Campus.

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WIRE PROTECTION

VOLTAGE BREAKDOWN

1963 DOUGLAS PAPER 1661

SWPM HARNESS SEPARATION

BOEING LETTER OF OCT 12, 1999

BOEING LETTER OF NOV 3, 1999

BFGoodrich FQIS

SMITHS FQIS

NPRM 97-NM-272-AD

BOEING LETTER OF MAY 26, 1998

UNITED LETTER, MAY 26, 1998

AD 98-20-40

FAA LETTER, APRIL 7, 1999

AIRBUS LETTER NOV 2, 1998

BOEING LETTER OF MAY 25, 1999

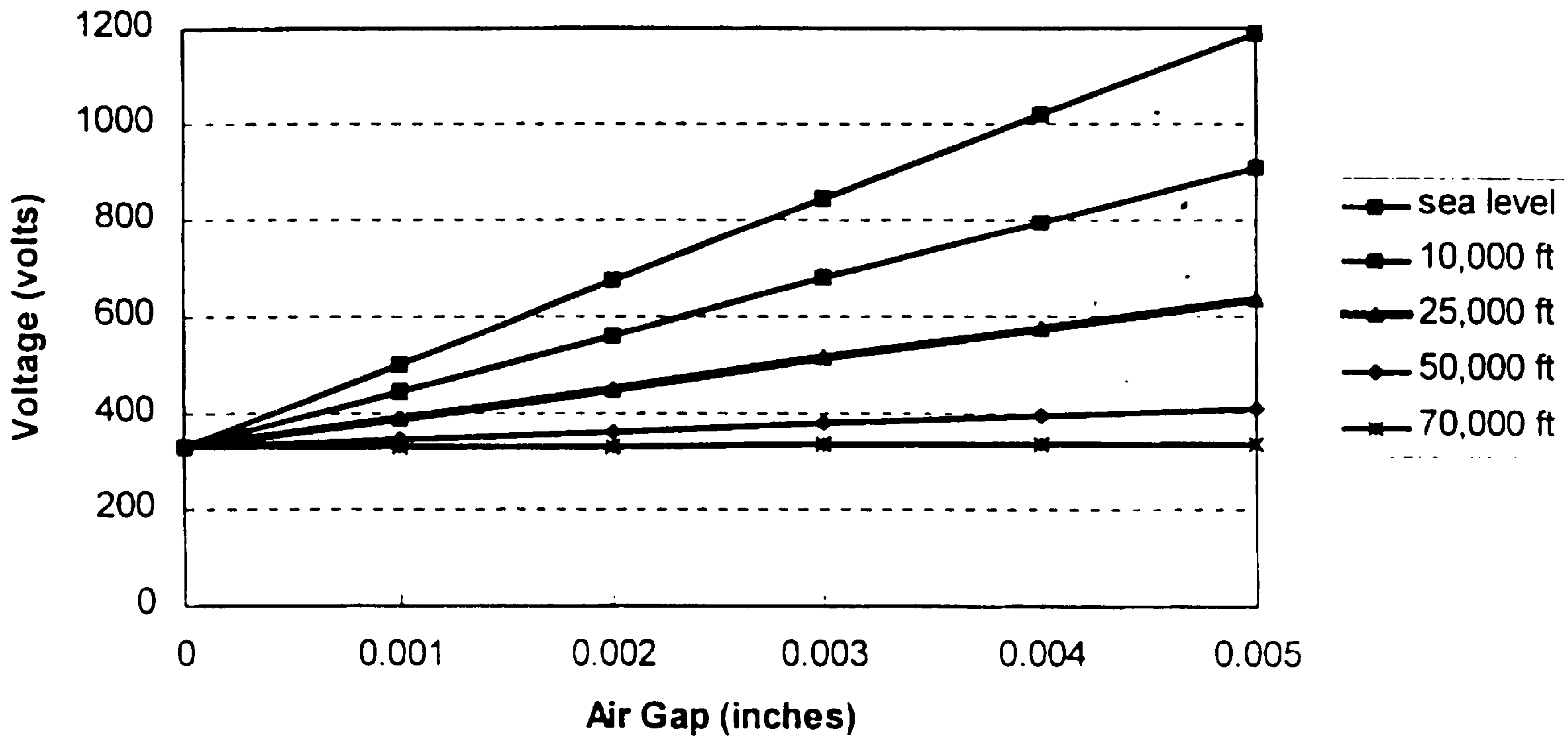
BOEING LETTER OF OCTOBER 12, 1999

BOEING LETTER OF JANUARY 10, 2000

AFRL EMAIL MAY 6, 1999

AFRL EMAIL JULY 28, 1999

Voltage Breakdown vs Air Gap (source ..... Appendix C p 245, Engineer's Relay Handbook)



VOLTAGE BREAKDOWN

Douglas Paper No. 1661

ACHIEVING ELECTROMAGNETIC COMPATIBILITY BY CONTROL OF THE WIRING INSTALLATION

By
G. J. King
Communications/Electrical Section
Engineering Department

Presented to
The Ninth Tri-Service Conference on Electromagnetic Compatibility
Chicago, Illinois
October 15 - 17, 1963

DOUGLAS AIRCRAFT COMPANY, INC. □ AIRCRAFT DIVISION □ LONG BEACH, CALIFORNIA

ACHIEVING ELECTROMAGNETIC COMPATIBILITY BY CONTROL OF THE WIRING INSTALLATION

G. J. King
AIRCRAFT DIVISION
Douglas Aircraft Company, Inc.
Long Beach, California

Abstract - Control of the wire routing and grouping of the many equipments and systems that are installed in modern aircraft is necessary to assure the electromagnetic compatibility of the ultimate system. Controlled classification of the wiring and the bundles reduces the interaction of equipments caused by the inadvertent coupling resulting from random installation. Wire routing control is mandatory to prevent the interaction of individual systems and may also be required with wiring associated with systems that are susceptible to self-interference. The minimum design concept for adequate wiring isolation is defined in this paper. Definitive grounding of systems and the attendant grounding methods, including the bonding of all equipment installations, is a significant part of the overall compatibility of the electrical/electronic environment. Emphasis is directed towards this area.

I. INTRODUCTION

For many years aircraft have been increasingly burdened with electrical and electronic equipment. These equipments have been evolved from the simple dc systems, of not so many years ago, to the modern integrated complexes operating entirely on an ac power source. As a result, the modern environment is one that is dynamic in nature where the equipments are subjected to an ambient electromagnetic field of complex shape and frequency. It is not strange that some of this ambient energy will appear on the wiring.

Much has been done to reduce interference at the component, equipment and system levels. Little information is available concerning the installation of equipment inter-connecting wiring. Sporadic interest has occurred in wiring compatibility where the various schemes vary from the custom installation (the reference is to "build-it" and "fix-it" methods) to the over-designed brute-force technique. The airframe manufacturer is confronted with the installation problem in which the interconnecting wire coupling effects upon any of the equipments can only be estimated. Few equipment manufacturers are prepared to indicate the necessary installation precautions required for compatibility. The precautions would include requirements for special wiring (other than single conductor), threshold susceptibility values over a specified frequency range, and the characteristics of the conducted and radiated energy over a broad frequency range. The fact remains that special installation requirements of wiring is necessary because most equipments radiate, and almost all equipments are susceptible somewhere in the electromagnetic spectrum.

The method of wiring control to be described classifies all of the interconnecting wiring in accordance with the energy carried by each wire and the probability of that wire becoming either a "transmitter" or a "receiver." A high degree of compatibility is achieved by physical separation of the categories of bundles and by grouping only the wires of similar characteristics and voltage levels.

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For example: a wire carrying 28 volts to a lamp would not be susceptible to a wire carrying 115 volts to a motor. However, if the 28 volt wire is connected to a servo amplifier then a degree of susceptibility might exist. Therefore, the first problem is the inductive susceptibility of a wire. The induced voltage is dependent upon the separation distance of the wires and the coupling area or parallel distance. There are many other factors, but if the spacing between the wire is infinite and the parallel length is zero a coupling problem will not exist.

The other factors are modifiers useful to the design engineer to determine the minimum required separation versus the maximum parallel distance before the threshold susceptibility is exceeded.

The other problem of wire coupling is that experienced from electro-static fields (voltage) usually associated with the radio frequency spectrum. Physical isolation will reduce some of the voltage coupling but not as effectively as for magnetic field coupling. Generally, electrostatic coupling is associated with high impedance circuits. Many low impedance circuits can become carriers of electrostatic energy that is conducted directly to a susceptible circuit. Such circuitry is adversely affected by external coupling. Frequently, the reduction of external coupling does not alleviate the problem. Many of these were found to be caused by coupling between the internal wiring. The usual precautions are employed for electrostatic isolation such as shielded wiring and, equally important, the proper grounding of the shield. The grouping of susceptible wires away from "transmitter" wiring frequently reduces the requirements for shielding.

The wire classification methods, described in this paper, have evolved over a number of years. However, it was only a few years ago that the environment reached the degree of complexity where the extensive use of classified wiring was required.

An analysis was conducted on one model of aircraft to determine what could be done to control the interference caused by the interconnecting wiring. All of the empirical and theoretical data colected over the years was evaluated and a logical model of the proposed method was developed. The aircraft was completely remodeled with the new system. After testing the aircraft, it was found necessary to change one wire from a single braid coaxial to a double braid. Filters that had been installed on the original aircraft to reduce interference were found to be unnecessary after implementation of the classification technique. The aircraft was a complex military type that had a history of multiple interferences. Once the wire classification had been implemented, several of the more vexing problems were revealed as being self-induced.

A second model airplane had a similar history of severe and subtle interferences that were subdued by the usual costly rework and loss of time. The entire system was carefully categorized by detailed evaluation of each equipment. After test, one fix was required - the installation of a diode to quiet down the inductive kick of a relay. The subtle interferences were resolved to be self-induced within specific systems.

The latter aircraft has been in current production for one year without any interference problems. Wire classification will make the product like "peas in a pod" as compared to others without wire classification which may exhibit wide variance of interference from unit to unit.

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II. DESIGN FOR INTERWIRING COMPATIBILITY

Design Concept - The minimum design concept for adequate wiring isolation is based upon classification according to the energy and power that the wire carries. A second consideration is that of the impedance of the wire that may carry spurious energy. This will indicate whether the interference may be induced by either magnetic or electrostatic fields or both. The third consideration is the division according to the susceptibility of a given wire to either inductive or electrostatic coupling. For example: a wire to the input of an amplifier is more susceptible to spurious energy than a wire connected to a motor.

Category I - Power Wiring - Category I is comprised of the following examples:

1. Three Phase distribution wiring (115/200 volts ac)
2. Single phase distribution wiring (115 volts ac)
3. Other wiring carrying 115 volts ac

There are two sources of coupled energy that can cause interference into numerous systems: the magnetic field and the electrostatic field. Of the two, the magnetic field is the most difficult to handle since shielding is ineffective. The practical method for magnetic field isolation is physical separation where the current-carrying wires are isolated from other wiring that is susceptible to magnetic coupling. Power systems are insensitive to coupled magnetic fields from other power lines. Motors, relays, most power transformers, actuators, and other power devices are inherently insensitive to induced voltages, induced phase shift, transients, etc. Therefore, it is possible to group all distribution power lines into one category. Primary, or feeder wiring, is not grouped with distribution wiring to minimize damage in the case of fault currents.

All of the noted wires may be bundled into groups dependent upon the installed wiring configuration.

Category II - Secondary Power - Secondary power wiring is grouped into Category II. Secondary power wiring is generally classed as wiring carrying watts of power at voltages less than 115 volts (ac/dc). Secondary power wiring can be troublesome in restricted areas such as cockpits, radio racks, conduit runs, and other areas requiring dense wiring runs. Since the magnetic field is directly related to the current, and secondary power lines are found in sensitive equipment wire bundles, it has been necessary to create this category. Secondary power lines are usually associated with interior lighting circuits, synchro circuits, small motors, actuator circuits, etc. Therefore, Category II is comprised of the following examples:

1. Low-voltage power circuits
2. Low-voltage lighting circuits
3. Synchro and servo circuits not in Category IV
4. Includes wiring from an equipment power supply to other equipments within the same system for dc voltages up to 5000 volts.

Category III - Control Wiring - Reference was made in Category I on the coupling effects of the magnetic and electrostatic fields. In Category III, the wiring is grouped according to the transient fields that exhibit both characteristics. Line

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transients occasioned by operating characteristics of the equipment can produce transient magnetic fields associated with a fast rise time of the current. High voltage transients, caused by the familiar "inductive kick-back" can produce broad-band RF voltages. Therefore, Category III is similar to Category II except that it also carries transient energy. Category III is comprised of the following examples:

1. All wiring that involves the operation of relays (solenoid), stepper switches, automatic homing switches, intermittent pulsing energy, etc.
2. Any other wire that can produce pulse energy caused by operating characteristics of the system or equipment such as wiring to flashing incandescent or fluorescent exterior lights.

Note: Category III can be converted to a Category II by reducing or eliminating transient energy. Category III could be eliminated entirely by use of transient suppressors at each relay or inductive device. Other wiring could be placed in Category II by determining the frequency of occurrence of transient energy that could affect other equipment. If the transient does not affect a critical circuit or an equipment listed under safety of flight, then it may be changed to Category II. Eventually, by consideration of these elements in the design stage, the need for this category may not be required.

Category IV - Sensitive Wiring - Sensitive wiring is somewhat of a misnomer since sensitiveness is directly related to susceptibility in this case. There are many wires within a system or complex that would appear under this category. Most of the wiring in this category is susceptible to electrostatic types of energy because of high impedance circuits. Low impedance circuits are susceptible to magnetic fields. However, a low impedance circuit can act as a carrier of electrostatic energy that will conduct spurious energy directly into a sensitive circuit such as a microphone input to an amplifier. Dual protection is usually required for these circuits.

Category IV is comprised of the following examples:

1. All microphone circuits. These invariably require twisted/shielded leads to reduce coupled magnetic fields and prevent the conduction of electrostatic RF fields.
2. All audio output and video output circuits.
3. All sensitivity control circuits and volume/gain controls.
4. All cathode and grid circuits.
5. Signal wiring requiring a "shield out" shield.
6. All metering and bridge input circuits.
7. All circuits associated with signal inputs to a computer.
8. All signal circuits associated with a demodulator.

A high percentage of the above wires are required by the designer to be shielded. To avoid ground circuit problems it is necessary to emphasize that all shielded wire shall be insulated with an external non-conductive jacket.

Category V - Susceptible Wiring - Experience has shown that certain wiring is extremely susceptible to most all levels of electrical energy. Such wiring shall be routed free of all other wiring and must not be grouped into a bundle unless associated

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with a single system. Antenna cables may be grouped provided that the shielding integrity of the entire system is good. High power antenna cables and pulse cables shall be run separately.

Category V is comprised of the following examples:

1. All radio antenna coaxial cables.
2. All wiring to electro-explosive devices.
3. Fire Warning shielded wires.
4. Fuel Quantity coaxial cables.
5. Liquid Oxygen indicator coaxial cables.
6. Other wiring pertaining to safety of flight items such as anti-skid systems, spoiler actuator circuits, etc.

Category VI - System Wiring - Category VI is a compromise designed for convenience of installation. To minimize extensive separation of system wiring bundles and to reduce the resulting wiring complexity, certain system bundles may contain wiring that otherwise would appear in Categories II, III, and IV. The category does not contain wiring that is classed as Category I or V. System groups may be installed only after careful analysis has indicated that the system is free of self-induced interference. An example would be the Automatic Flight Control System (AFCS) that is inherently susceptible. The AFCS usually has many interconnecting wires between multiple black boxes grouped in close proximity. These runs, and the long runs from the immediate area to the control center, are classed as Category VI. There may be more than one system within the complex that has been classified as a Category VI. It is suggested that each system bundle be identified and routed separately. It is not recommended that bundles of Category VI be grouped together.

Design Limits for Separation - Minimum coupling between wires of the various categories can only be controlled by specifying the minimum distances to be maintained throughout the cable run. Table I gives the minimum design data for physical isolation. Modifications to the rather rigid requirements are described in subsequent paragraphs. It must be emphasized that the design parameters noted in (Table I) are to be used as the minimum, and that the compromises suggested be used only where necessary. Compromises are the responsibility of the Electromagnetic Compatibility engineer and are useful only when the threshold susceptibility of a given wire is known.

Classifying the categories as "transmitters" and "receivers" will help in understanding why the groups are spaced and will assist in the selection of compromises where required. It will be noticed that Categories I, II, and III may be classed as transmitters and that Categories IV, and V as good broadband receivers. Category VI is in the position of proving that it will not interfere with itself since it contains potential transmitters and receivers. Another way of classification is to consider that Categories I and II carry relatively intense magnetic fields, Category III carries magnetic fields of similar intensity and transient RF fields of relatively high energy with a broadband distribution. Categories IV and V are then susceptible to these fields. The third consideration is that the groups carry similar types of energy: Category I, power line voltages (115/200 volts ac); Categories II and III carry low voltage power (28 volts ac-dc), and Categories IV and V carry signal voltages and frequencies. The method of classifying is based upon the minimum voltage gradients between wires within any given category.

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Installation Consideration - The possibility of maintaining the minimum separation distance for all categories throughout the aircraft is remote. Structural areas and design prohibit such luxuries. Requirements for the three common areas of minimum isolation are noted in the following:

Lightening Holes - Wire bundles shall maintain the minimum spacing until they immediately enter the lightening hole and shall break away at the first opportunity. Lightening hole parallel runs are added to compute the overall parallel run. Normally, there is no restriction on the category of bundles. It is preferred, however, to route Categories IV, V, and VI through adjacent holes wherever possible. The category to be routed through adjacent holes depends upon the physical size of the bundle, see Figure 1.

Common Plugs - Common equipment plugs and bulkhead plugs are treated the same as for lightening holes. Common plug wiring should break into categories as soon as possible, see Figures 2 and 3.

Conduit - Grouping of bundles in conduit will be similar to the grouping used for marriage clamping. Non-metallic conduit is preferred. Metallic conduit may be used to increase the isolation when conduits are closely nested and to take advantage of the shielding effects. Aluminum conduit should be used for electrostatic shielding and special purpose steels for magnetic "shielding." Unrestricted use of metallic conduit should be discouraged since the reflected inner fields could increase coupling between wires within the conduit, see Figure 4.

Compromises - Practical considerations for the installation of bundles require some modification of the basic rules. It must be emphasized that modification of the basic rules must be held to an absolute minimum. There will be areas where the minimum spacing of the bundles cannot always be maintained. Other areas may require that the wires originating at an equipment plug must be bundled together for a specified distance. The installation designer must control the wiring to ensure that the compromised areas do not result in an unbalance towards the interference end of the scales. What is lost on one end of the scales must be regained on the other.

Category VI - Category VI is a compromise as noted under the categories.

Marriage Clamping - The minimum design spacing may be relaxed in close areas such as cockpits, control centers, and other dense areas. This is based upon achieving separation in the rest of the aircraft that results in coupling far below threshold sensitivity. The following categories may be marriage clamped:

Category

1. II with III
2. IV with V
3. VI with either II, III or IV

It is recommended that Category I not be marriage clamped with any other category or group. Maximum distance should be maintained between Category I and Categories IV and V.

Special Wiring - Special wiring includes all types of wiring configurations other than the single-conductor-insulated wire. Special wires are always used for the control of interference and, in the wire categorization plan, they are used for isola-

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tion purposes where the minimum physical isolation distances must be reduced for practical reasons. Therefore, the special wiring would replace the single conductor wire under certain installation conditions.

There are two types of special wire: twisted wires (two or more) and shielded conductors (one or more). Twisted wires are used for control of radiated or induced magnetic fields, and the shielded wire is used for the containment or exclusion of electrostatic fields. Combinations of both are used where the circuitry may be susceptible to magnetic and electrostatic fields. Configurations recommended for use include the following: twisted pairs, shielded twisted pairs, shielded single conductor, and the various configurations of coaxial cable.

Special wiring is used only when and where necessary if not called out in the system design. Use of special wiring is an admission that the system is susceptible or radiates over some specified portion of the electromagnetic spectrum (just like a gasket is an admission that a perfect mechanical joint cannot be obtained). Requirements for extensive use of special wiring may be reduced by considering the environmental effects preliminary to the design of the electrical/electronics portion of the system. Wire categorization does not require, per se, additional requirements for the use of special wire. The necessity for the use of special wire can be reduced in many cases. Unrestricted use of shielded wire can produce more problems than it cures, and the unrestricted use of twisted wiring is frowned upon because of the increased cross sectional area. Special wiring installed for the prevention of coupling can be eliminated for the most part. Under the categorization rules, special wiring is used only in areas where the design separation distances cannot be achieved.

Special Wiring and Pigtails - Electronic and electrical equipment racks are frequently so highly congested that wire separation to the design limits is an impossibility. The problem can be resolved by considering all of the wires emanating from a single equipment plug as a pigtail to where the wires can break out into categories at a distribution center or a terminal board. Pigtail length can vary from two to ten feet. Lengths in excess of ten feet should be considered for classification into categories. Since space isolation is not possible in a pigtail, the only recourse is to specify the use of special wiring, refer to Figure 5. Power wiring should be twisted with the ground return for wires grouped under Categories I and II. Single conductor signal wiring should be shielded (Categories IV and V). Two conductor signal wirings (Categories IV and V), such as microphone circuits, should be twisted and shielded. Category II, other than power wiring, and Category III do not require special wiring. In general, the requirement for special wiring to achieve isolation in a pigtail grouping does not exist after the wiring has entered the proper categories. Figure 6 is a description of an equipment rack utilizing pigtails from the equipment plugs to the terminal junction and then to the categorized ship's wiring.

In referring to Figure 5, it will be noticed that the categorized wiring has been labeled in a definite order. When using parallel runs (where all of the categories are in the same plane) it is desirable to locate the bundles for minimum coupling. The suggested order would be: 1, 2, 3, 6, 4, and 5 where Category I is always the farthest distance from any terminal board wiring and/or Categories IV and V.

Ground Wires - Ground wires shall always take the category of the mating "hot" wire. Twisting of pairs of wires always refers to the hot wire and the (ground) return. Twisted pairs of wires may be used on circuits of either transmission (Categories

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I, II, and III) or circuits of reception (Categories IV and V). The former reduces the magnetic field coincident with current flow and the latter inhibits induced magnetic fields. Twisted wires may also be used to reduce the loop aperture where a tight twist results in minimum loop area.

Ground Studs - All ground studs will take on the category of the attaching wire. This immediately states that only one category can be connected to a given ground stud.

III. INSTALLATION CONTROL

Engineering Control - Engineering control of the wiring installation is a corollary to the wire classification plan. Previously, engineering furnished the wiring schematics and pertinent data. Actual installation of the aircraft wiring was accomplished without specific engineering requirements for a specific installation design. Wiring installations were then frequently modified by the electromagnetic compatibility group to reduce interwiring interference. If the wiring installations could not be modified for diverse reasons, efforts for interference reduction were then directed at the affected equipment. Occasionally, this resulted in equipment redesign to operate satisfactorily in an interference environment. More often, external filters were required. The desired engineering control is accomplished by carefully designing the installation on the development aircraft in accordance with the data contained in this paper. From this effort, engineering control of the actual wire runs and locations is established. Engineering documents define the classification of each bundle where each wire in the bundle is identified. Application of the engineering control made it mandatory that subsequent aircraft would be wired identical to the development aircraft.

IV. CONCLUSIONS

Application of a classification plan to all of the wiring in the aircraft will result in a considerable reduction of system interferences caused by inadvertent wire coupling. Many of the knotty problems associated with the equipment or auxiliary hardware can then be defined as having been caused by wire coupling. The reverse may also be true. Interferences, mistakenly laid to wire coupling, may be resolved as system deficiencies. Wire classification is a distinct aid in the solution and tracking down of many electromagnetic compatibility problems. The classification plan does not conflict with circuit or interconnecting wiring design. It is merely a specific installation procedure. The preparation of drawings that apply a part number to the wiring are not affected by wire classification requirements. Removals or additions of equipment to an existing aircraft present no major problems. Economically, the costs of engineering design are more than offset because of the minimum rework for a given production design. Rework of the final installation design for two military types of aircraft has been negligible. Wire classification eliminates the wide variance in compatibility found on aircraft that contain a random wiring installation.

ACKNOWLEDGMENT

The material presented herein is based upon work conducted by the Aircraft Division of Douglas in the performance of contracts for the Bureau of Naval Weapons.

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2. Wire Harness Identification For Functional Separation

A. Functional/EMC/Sub-Functional Separation Code

The separation code has these properties:

- A separation code is assigned to each wire harness
- When the sub-functional separation is not necessary for 737, 747, 757, and 767 airplane models, the third digit is removed; only 2 digits are necessary
- When the sub-functional separation is not necessary for 777 airplane model, the fourth digit is removed; only 3 digits are necessary
- An N code identifies a wire that does not have any separation conditions and can have the same routing as a wire harness from any other functional separation group.

B. Color Codes of the Separation Groups

NOTE: Refer to the specified model for the color codes that are used for each functional separation code.

A color code system is used so that:

- The separation group of a wire harness can be identified
- The installation and inspection of a wire harness on the airplane is easier.

For the 737, 747, 757, and 767 airplane models, all wire harnesses have color codes except these types:

- A coax cable that is installed as a single cable and does not have any wire harness ties
- Wire harnesses in which all wires are covered with sleeves (white tie material)
- Wire harnesses which that contain only shielded wires (white tie material)
- Shelf harnesses (white tie material)
- Wire harnesses that are identified as neutral (N).

For the 777 airplane model, all wires harnesses have have color codes except these types:

- A coax cable that is installed as a single cable and does not have any wire harness ties
- Shelf harnesses (white tie material)
- Wire harnesses that are identified as neutral (N).

3. Wire Harness Functional Separation

A. Separation by a Distance

Refer to Table I to find the minimum distance for the specified separation code of each model.

NOTE: In the areas where a turbine burst occurs, a larger physical separation is necessary between the specified engine functions.

WIRE SEPARATION

NOTE: More protection or a larger physical separation, or both are given in the areas where damage, that is caused by a mechanical failure, can occur to the primary and the redundant wiring. Some types of mechanical failures are:

- The rupture of a pneumatic duct
- A tire tread that is thrown.

These standby system power wires must be isolated from all other wiring through separation by distance:

- Battery to hot battery bus
- Hot battery bus to battery bus and static inverter
- Static inverter to standby AC bus.

CAUTION: THE STANDBY SYSTEM POWER WIRES MUST NOT HAVE THE SAME ROUTING AS ANY OTHER WIRING. DAMAGE, THAT IS CAUSED BY THE FAILURE OF THE OTHER WIRING, CAN OCCUR TO THE STANDBY SYSTEM POWER WIRES.

TABLE I
FUNCTIONAL SEPARATION BY MINIMUM DISTANCE

Separation Code	Area	Model	Distance (inch)
1	Not Pressurized	747	1/2
	Pressurized	747	1/4
2	Not Pressurized	747	1/2
	Pressurized	747	1/4
3	Not Pressurized	747	1/2
	Pressurized	747	1/4
4	Not Pressurized	747	1/2
	Pressurized	747	1/4
A	Not Pressurized	737	1/4
		757	1/4
		767	1/4
	Pressurized	737	1/4
		757	1/4
		767	1/4
AK	Not Pressurized	777	1/2
	Pressurized	777	1/4
BK	Not Pressurized	777	1/2
	Pressurized	777	1/4

SWPM HARNESS SEPARATION

WIRE SEPARATION

Separation Code	Area	Model	Distance (inch)
C	Not Pressurized	757	1/4
		767	1/4
		777	1/2
	Pressurized	757	1/4
		767	1/4
		777	1/4
CP	Not Pressurized	777	1/2
	Pressurized	777	1/4
H	Not Pressurized	757	1/4
		767	1/4
	Pressurized	757	1/4
		767	1/4
L	Not Pressurized	737	1/4
		747	1/2
		757	1/4
		767	1/4
		777	1/2
	Pressurized	737	1/4
		747	1/4
		757	1/4
		767	1/4
		777	1/4
LM	Not Pressurized	777	1/2
	Pressurized	777	1/4
LP	Not Pressurized	777	1/2
	Pressurized	777	1/4
LR	Not Pressurized	777	1/2
	Pressurized	777	1/4
LS	Not Pressurized	777	1/2
	Pressurized	777	1/4
NN	Not Pressurized	777	1/2
	Pressurized	777	1/4

SWPM HARNESS SEPARATION

WIRE SEPARATION

Separation Code	Area	Model	Distance (inch)
R	Not Pressurized	737	1/4
		747	1/2
		757	1/4
		767	1/4
		777	1/2
	Pressurized	737	1/4
		747	1/4
		757	1/4
		767	1/4
		777	1/4
RM	Not Pressurized	777	1/2
	Pressurized	777	1/4
RP	Not Pressurized	777	1/2
	Pressurized	777	1/4
RR	Not Pressurized	777	1/2
	Pressurized	777	1/4
RS	Not Pressurized	777	1/2
	Pressurized	777	1/4
S	Not Pressurized	737	1/4
		747	1/2
		757	1/4
		767	1/4
		777	1/2
	Pressurized	737	1/4
		747	1/4
		757	1/4
		767	1/4
		777	1/4

SWPM HARNESS SEPARATION

Separation Code	Area	Model	Distance (inch)
SY	Not Pressurized	777	1/2
	Pressurized	777	1/4

B. Separation by an Insulation Material

Insulation sleeves or insulation tubes are used to give the specified separation for the wire harness when these conditions occur:

- The 1/4 inch distance of separation in the pressurized area is not possible
- The 1/4 inch distance of separation in the area that is not pressurized for all airplane models except the 747 and the 777 is not possible
- The 1/2 inch distance of separation in the area that is not pressurized for the 747 and the 777 airplane models is not possible.

To give the specified separation in the areas that are:

- Pressurized, Varglas non-fray, Type HO or Type HP insulation sleeves are used
- Not pressurized, TFE Teflon sleeves or TFE tubes with a wall thickness of 9.0 mils or larger are used.

NOTE: The separation by an insulation material is not necessary where a BACC18AD type of fusible link, single-phase circuit breaker is used to protect the circuit in the wiring that is:

- In the flight deck
- In the E/E compartment
- In between the flight deck and the E/E compartment.

C. Separation by a Fusible Link Circuit Breaker

NOTE: Separation by a fusible link circuit breaker is not sufficient when a wire harness is in a location where it is open to:

- A turbine burst
- The failure of a pneumatic duct
- A tire tread that is thrown
- Other types of physical damage.

If wires with different functional separation codes come directly from a circuit breaker source and are protected with a fusible link circuit breaker:

- The separation by an insulation material is not necessary
- The wires can have the same routing.

A wire, that has the same routing as another wire, must have a insulation sleeve or insulation tube if all of these conditions occur:

- The wires have different functional separation codes
- The wire is not protected with a fusible link circuit breaker
- The other wire is protected with a fusible link circuit breaker.

Ronald J. Hinderberger
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BOEING

12 October, 1999
B-H200-16786 -ASI

Mr. R. Swaim, AS-40
National Transportation Safety B
490 L'Enfant Plaza East, S.W.
Washington DC 20594

← Has Boeing responded with the requested letter? Boeing will probably not stand behind the "unofficial" responses contained in the e-mail. The following letters are their answer.

Subject: Surge Suppresso ... ong Island, N.Y. – 17 ...

Dear Mr. Swaim:

During one of the lab activities ... rmation on surge suppressor development and the status ...

In the FAA's NPRM for Wire Separation/Transient Suppression, the focus was on the airplane wiring. Boeing commented on both wire separation/shielding and transient suppression. The thrust of the Boeing comment on the NPRM with regards to transient suppression was intended to ensure that adequate time was allowed to develop, test and certify a new device of this type. The fuel quantity systems on Boeing airplanes are sensitive and perform an essential aircraft function. Modification of the system must not be unnecessarily rushed. Due to time and resource constraints, and the necessity to comply with the aggressive schedule being set by the FAA, Boeing chose to pursue wire separation due to the seemingly low risk nature of the modification. It was never Boeing's intention in our NRPM response to discourage the use of transient suppression devices.

After the 737 and 747 Classic NPRM's for Wire Separation/Transient Suppression were released, and Boeing had decided to pursue the mandated wire separation, Boeing approached the three affected FQIS suppliers, Honeywell, Smiths Industries and BF Goodrich, about their intentions with regards to a transient suppression device (TSD) for their FQIS's on Boeing aircraft.

Honeywell declined to develop a TSD for their 747 Classic FQIS for technical and business reasons. Smiths Industries stated that they would be developing a TSD for both their 737 and 747 Classic digital FQIS's. BFGoodrich stated that they would be developing a TSD for their 737 Classic digital FQIS's, but not their analog FQIS.

BOEING LETTER OF OCT 12, 1999

BOEING

Since then, Boeing has been in regular contact with both BFGoodrich and Smiths Industries. Boeing has provided technical information to both suppliers regarding the mechanical and electrical interface data requested. Several technical reviews have also been held over the last several months with both companies. In addition, numerous telecons have been conducted to review any issues and status action items. Boeing has also made available to one of the suppliers our mockup of the 747 FQIS in our Fuels lab, which was utilized, for prototype TSD testing. Also, Boeing has had the opportunity to be present during some of the presentations made by the suppliers to the FAA in order to lend support to the supplier and the FAA in evaluating their TSD programs.

Through these regular meetings and contacts with both suppliers, Boeing has assessed the designs of the TSD's being developed and the program commitments and schedules to which each supplier has performed. The design and architecture of these TSD's will accomplish the function of preventing excessive energy from getting into the fuel tank. The modifications necessary to install these devices into the airplane are minimal. These TSD's will provide the airlines a cost effective and timely solution in complying with the associated AD's once the FAA provides approval of the STC's for their installation.

Also, at the request of our customers, Boeing is presently evaluating developing service bulletins which would reference the supplier STC's (once they are FAA approved) for the installation of their TSD's. Boeing is presently in discussions with the FAA on the process and plan for accomplishing this.

If you have any questions, please do not hesitate to call.

Very truly yours,

for Ronald J. Hinderberger
Director, Airplane Safety
Org. B-H200, MC 67-PR
Telex 32-9430, STA DIR AS
Phone (425) 237-8525
Fax (425) 237-8188

cc: Mr. A. Dickinson, IIC

BOEING LETTER OF OCT 12, 1999

Swaim Bob

From: Rodrigues, J D [J.Rodrigues@PSS.Boeing.com]
Sent: Wednesday, November 03, 1999 3:19 PM
To: 'swaimbo@ntsb.gov'
Cc: 'warrens@ntsb.gov'; 'dickina@ntsb.gov'
Subject: EMI/Transient Tests

16809.doc

Bob/Scot
I just faxed this to you.

<<16809.doc>>

J. Dennis Rodrigues
Air Safety Investigation
Phone: (425) 237-8301
Pager: (206) 416-6719
Fax: (425) 237-8188

BOEING LETTER OF NOV 3, 1999

FROM :4252378188 INV TO : 2023146349 1999,11-03 12:47 #239 P.01/01

Ronald J. Hinderberger
Director
Airplane Safety
Commercial Airplanes Group

The Boeing Company
P.O. Box 3707 MC 67-XK
Seattle, WA 98124-2207

BOEING

3 November, 1999
B-H200-16809-ASI

Mr. R. Swaim, AS-40
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington DC 20594

Subject: EMI/Transient Tests, TWA 747-100, N93119
Accident Off Long Island, NY – 17 July 1996

Dear Mr. Swaim:

Boeing has completed the design for the FQIS wire separation and shielding to be used on the 747 classic FQIS to comply with the FAA AD 98-20-40.

We are presently performing EMI/transient tests of this configuration in our EMI laboratory to provide the necessary information to the FAA to substantiate our design. The testing is being done utilizing production equipment and wiring. A set of baseline tests have been run to verify that we could duplicate previous results with the FQIS wiring as it exists in the 747 classic today in both its unshielded and shielded configuration.

The next phase of testing, November 3 and 4, 1999, will involve testing the separated and shielded wiring to be used in the Boeing 747 classic service bulletins for FQIS wire separation and shielding. This testing is to demonstrate that the new separated and shielded wire design ensures that excessive EMI/transient voltages are not transferred to the FQIS system.

Please let us know if you wish to witness any of this testing. As we have been on a very tight and aggressive testing schedule, we are proceeding with our present test plan. If you are not able to attend either of these two days, we will set up a separate demonstration for you at your convenience.

If you have any questions, please do not hesitate to call.

Very truly yours,

for Ronald J. Hinderberger
Director, Airplane Safety
Org. B-H200, MC 67-PR
Telex 32-9430, STA DIR AS
Phone (425) 237-8525
Fax (425) 237-8188

cc: Mr. A. Dickinson, IIC
Mr. S. Warren

BOEING LETTER OF NOV 3, 1999

Swaim Bob

From: Bob Zeliff [bzeliff@aisvt.bfg.com]
Sent: Tuesday, November 23, 1999 1:41 PM
To: swaimbo@ntsb.gov
Subject: FW: BFGoodrich Aerospace 747 Classics Retrofit Fuel Quantity Indicating System

BFG 747 Classic FQIS Attribute...

Bob,

Here is the write up on the 747 system. Hope this meets your needs. The TSD write should be done latter to day as well.

Bob Zeliff
BFGoodrich Aerospace
802-877-4417

BFGoodrich FQIS

BFGoodrich Aerospace 747 Classics Retrofit Fuel Quantity Indicating System Attributes

As an adjunct to an accident investigation, the Federal Aviation Administration published an Airworthiness Directive 98-20-40, applicable to all 747-100, -200, -300, 747SP, and 747SR airplanes, in the 30 September 1998 Federal Register. The airworthiness directive required shielding and separation of all the fuel quantity indicating system (fqis) wiring outside of the fuel tanks and surge tanks, within compliance time of 36 months.

BFGoodrich Aerospace - Aircraft Integrated Systems, supplies capacitive fuel quantity gauging systems to the Boeing Company for the 737, 747-400, 757, and 767 aircraft. BFGoodrich Aerospace-AIS has certified a retrofit capacitive fuel quantity indicating system (FQIS) for the Boeing 747-100, -200, -300, 747SP, and 747SR series airplanes (the 747 "Classics") effected by the Airworthiness Directive AD 98-20-40. The BFG Classics FQIS is certificated under Supplemental Type Certificate ST00020BO and installed on approximately one hundred ten (110) aircraft, of both United States and European registry. Supplemental Type Certificate ST00020BO has been recognized and accepted by the Dutch RLD, the French DGAC, the German LBA, and the UK CAA. The BFG 747 retrofit FQIS had been developed and certificated to improve the reliability of the 747 Classics FQIS by fitting an FQIS similar to the BAC 747-400 Computerized FQIS to the earlier 747 model airplanes. Improvements in the FQIS reliability, maintainability and gauging accuracy provided the basis for a financial analysis substantiating a payback on the investment in a new FQIS. The features of the BFGoodrich retrofit FQIS match the requirements of the AD.

The BFGoodrich Aerospace retrofit capacitive FQIS for the Boeing 747 Classics aircraft satisfies the requirements of Airworthiness Directive 98-20-40. The BFG retrofit FQIS replaces the type certificated (T.C.) Fuel Quantity Indicating System, both in tank and external components and appliances, and installs a FQIS similar to the Boeing type certified 747-400 FQIS.

The BFG 747 Classics FQIS installation involves removing the original T.C. FQIS appliances, probes, and harnesses and installing a new FQIS. The BFG Replacement FQIS is a microprocessor based system composed of a Fuel Quantity Processor Unit (FQPU), mounted beneath the forward cargo bay about fuselage station 980, connected to the capacitive tank units with shielded cables and new in-tank harnesses. The shielded cables are routed separately from other aircraft wiring between the FQPU and the fuel tank wall connections. The FQPU communicates with flight deck and refuel station indicators via dedicated ARINC 429 data busses.

The significant characteristics of the BFG 747 Classics FQIS, satisfying the requirements of Airworthiness Directive 98-20-40, are;

I) Separation of the retrofit FQPU to fuel tank wall penetration ("the dryside") harnesses from the remainder of the aircraft wiring,

II) Use of the FQPU permits the shortening and shielding of the wires effecting penetrations into fuel tanks (i.e., the gauging Hi-Z, Lo-Z, and Comp Lo-Z wires no longer run to the cockpit and refuel station but terminate at the FQPU),

III) Intrinsic shielding provided by the use of shielded wiring to fabricate the dryside harnesses,

IV) Replacement of the T.C. in-tank harnesses with new harnesses fabricated with connectors and processes more suited for the application,

V) Replacement of the T.C. in-tank tank units with new tank units incorporating superior design characteristics, and

VI) Elimination of the in-tank Comp Lo-Z connections to the refuel station indicators.

[BFGoodrich FQIS]

BFGoodrich Aerospace 747 Classics Retrofit Fuel Quantity Indicating System Attributes

The BFGoodrich Aerospace 747 Classics retrofit Fuel Quantity Indicating System applies a modern robust FQIS circuit topology to the 747 Classics aircraft. The BFG 747 Classics FQIS design incorporates improvements in fuel gauging system design permitting improvements in FQIS reliability and safety. Additionally, the BFGoodrich 747 Classics FQIS provides enhanced built in test capabilities and diagnostics.

On 19 July 1999, after an exhaustive review of the BFGoodrich 747 Classics Fuel Quantity Indicating System, certificated under Supplemental Type Certificate ST00020BO, the Federal Aviation Administration found the BFGoodrich 747 Classics FQIS to be an acceptable method of Compliance with Airworthiness Directive 98-20-40. As of November 1999, the BFG 747 Classics FQIS is the only approved method of complying with AD 98-20-40.

BFGoodrich FQIS

BFGoodrich Aerospace 737 Transient Suppression Device (TSD) System Solution (11/23/99)

Overview:

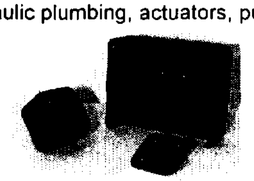
BFGoodrich has developed the Transient Suppression Device (TSD) to provide a total system solution for the 737 Classic Aircraft to obtain compliance with AD 99-03-04. The TSD has been developed to work with the BFG's digital indicator The purpose of the TSD is to limit energy into an aircraft fuel tank to a level that is below the minimum ignition energy of an explosive mixture of jet fuel vapor and air.

Concept:

The TSD is a passive device which operates in-line with the electrical wiring harness that connects the fuel quantity digital indicators to the aircraft fuel tanks, (refer to figure 1). The existing dry side harness interfaces with one connector of the TSD while shielded safe-side harness connects the fuel tank to the safe side connector of the TSD. The TSD is designed to limit any hazardous threats (hot shorts and lightning) present on the existing dry side wire-harness from entering the tank. This safe side harness is installed with appropriate wire separation to mitigate contact with any surrounding threats.

Figure 1.

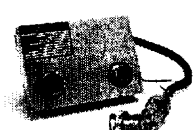
One common part number TSD is required for each fuel tank interface, one for each main tank and one for the center tank. The TSDs are located near the bulkhead connector of the fuel tank and are mounted to aircraft structure using adaptable brackets. These brackets facilitate mounting, given wide variances in aircraft hydraulic plumbing, actuators, pumps, wiring, etc. within the wing and fuselage.



TSD Mounting Bracket

Mechanical Design:

The TSD system was designed to operate without degradation in harsh environments. To insure greatest amount of protection, the TSD is located as close as possible to the bulkhead connector of the tank. The environment in this area is very harsh whereby exposure to extreme temperatures, corrosive fluids, dirt, debris and many other elements can take place. This design is a safety critical design and must be protected from ingestion of fluids, contaminates, galvanic corrosion and structural breakdown. To



BFGoodrich FQIS

protect from these threats, the TSD is hermetically sealed and is housed in a brass enclosure.

TSD Brass Enclosure

Installation:

The TSD system is designed to minimize installation time. Estimated total system install times vary from 18 to 29 labor hours depending on the aircraft configuration. With a typical installation crew of 3 personnel, overnight installations are feasible.

Safety / Maintenance:

One key goal of the TSD system design is to minimize maintenance cost to the operator. A key element of maintenance cost will be the Certification Maintenance Requirement (CMR) mandated by the FAA. This requirement states that the system must be checked at an interval time necessary to insure that the probability of the system having a latent failure that will inhibit fuel tank protection must be less than 1×10^{-9} hrs flight hours. BFG has designed the TSD to maximize this interval time to greater than 5000 hours or a typical 737 C-check interval. The ability to obtain such a large interval time relies on the unique design approach used. The BFG TSD does not rely on a high integrity bond to provide protection which might be used on a simple fuse/shunt protection approach. Instead, it uses isolation transformers to couple the electrical information between the indicators and the fuel probes. When lightning strikes the fuel quantity wiring harness, the energy is applied to all the wires in the harness in a common manner, or common mode. Since transformers only respond to differential signals, not common mode signals, no energy is transferred into the fuel tank by the TSD. This unique design characteristic results in :

a.) Normal operation after a lightning strike
- No TSD Failures
- No Indicator Failures

b.) No Flight Line Maintenance Required

c.) No Bonding Integrity Checks Required

This type of performance is not possible with a simple fuse/shunt protection approach. Additionally, the time required to conduct a CMR has been simplified. Check-out of the TSD requires less than 5 minutes per TSD. This checkout requires leading edge flaps extended and gear down. The TSD does not have to be removed from the aircraft. BFG has developed automated CMR test

Acrobat Document

equipment which performs a quick Go, No-Go verification of the TSD protection components.

Automated CMR Tester

System Features:

The TSD system solution has been designed to minimize any impacts to the existing aircraft FQIS. The present digital indicator BITE of the system is not affected when the TSD is installed, thus not requiring retrofit of the existing digital indicators. When the TSD is installed, the system maintains acceptable accuracy performance. The system is not affected by aircraft ground noise and works with both BFG and Cinch Harnesses.

Certification:

There are a multitude of FQIS variants for the 737 Classics. Provided below are two tables which include the options present on the 737 classics.

737-100/200 ------------------ **737-300/400/500** ----------------------

BFGoodrich FQIS

BFGoodrich Aerospace 737 Transient Suppression Device (TSD) System Solution (11/23/99)

- Analog FQIS
- Analog FQIS (pre-cal)
- Summation Unit
- Vref Indicator
- VTO
- Aux Tanks

- Analog FQIS (pre-cal)
- Digital FQIS
- Summation Unit
- Aux Tanks

To address the options listed above, BFG is certifying the TSD system by amending BFG's existing 737-100/200 Computerized FQIS STC [SA520NE] to extend model applicability to all 737 Classics. The amended STC will address installation of BFG Digital Indicators and TSDs for each tank interface. The STC plan will be conducted in 2 phases listed below.

Phase 1: Extend applicability to 737-300/400/500 A/C's by (Dec 99)
Phase 2: Extend applicability to non-VTO 737-200's (Feb 00)
Note: For 737-100/200 aircraft with VTOs, Boeing service bulletin to replace VTOs with VSO float switch system
must be conducted prior to modification of aircraft.

BFGs STC [SA520NE] includes utilization of the digital summation unit, while BFG's STC [SA531NE] addresses conversion of analog to digital system to use Vref indicators.

Test Status:

BFG has conducted aircraft data surveys at TRAMCO, United Airlines, and SouthWest Airlines. Mechanical and electrical functional checks were conducted on SWA 737 aircraft. These checks have verified gauging performance, system calibration, bracket mounting and wire harness routing. BFG is in the process of completing qualification testing to satisfy the requirements of the FAA TSD Issue Paper (Rev B.)

Industry Support:

BFG anticipates and can meet a production rate of 50 ship-sets a month. Higher delivery rates can be accommodated if required. BFG has turned vendors on for long lead provisioning and is in the process of developing high production rate manufacturing test equipment to support the high production.

BFG will provide on-site support to operators for the first kit installation. Additional support can be provided when requested. Kit deliveries will be provided to match operator maintenance schedules. BFG is planning on first production deliveries to occur in Jan 2000.

BFGoodrich FQIS

Swaim Bob

From: magazzu_russ@si.com
Sent: Friday, December 17, 1999 6:53 PM
To: swaimbo@ntsb.gov
Cc: wyler_john@si.com
Subject: Smiths Transient Suppression Unit

Unknown data type

Hello Mr. Swaim,

Attached you will find six powerpoint slides covering the Smiths Industries Transient Suppression Unit. As you know the TSU was developed as and Alternate Means Of Compliance to the Wire Separation Airworthiness Directive (AD 98-20-40 for B747, AD 99-03-04 for B737). I saved the file as a Powerpoint 95 presentation.

If you should require additional information, please feel free to ask.

Have a very Safe and Happy Holiday Season!!!

Sincerely,

Russ Magazzu

SMITHS FQIS

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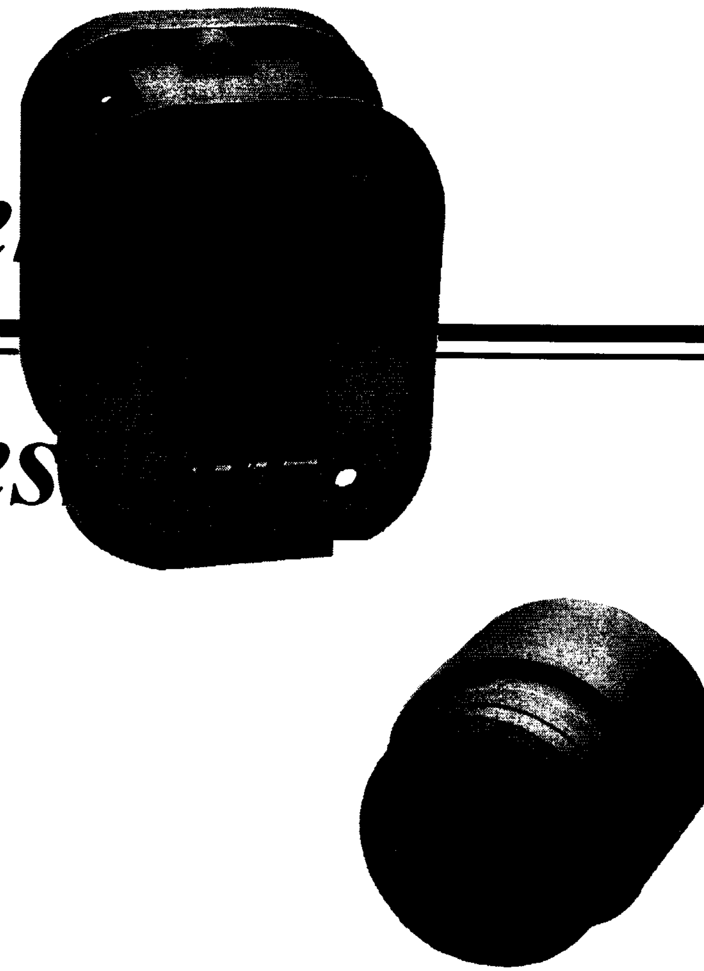
Transie

Suppres



SMITHS FQ15

SMITHS INDUSTRIES

99072

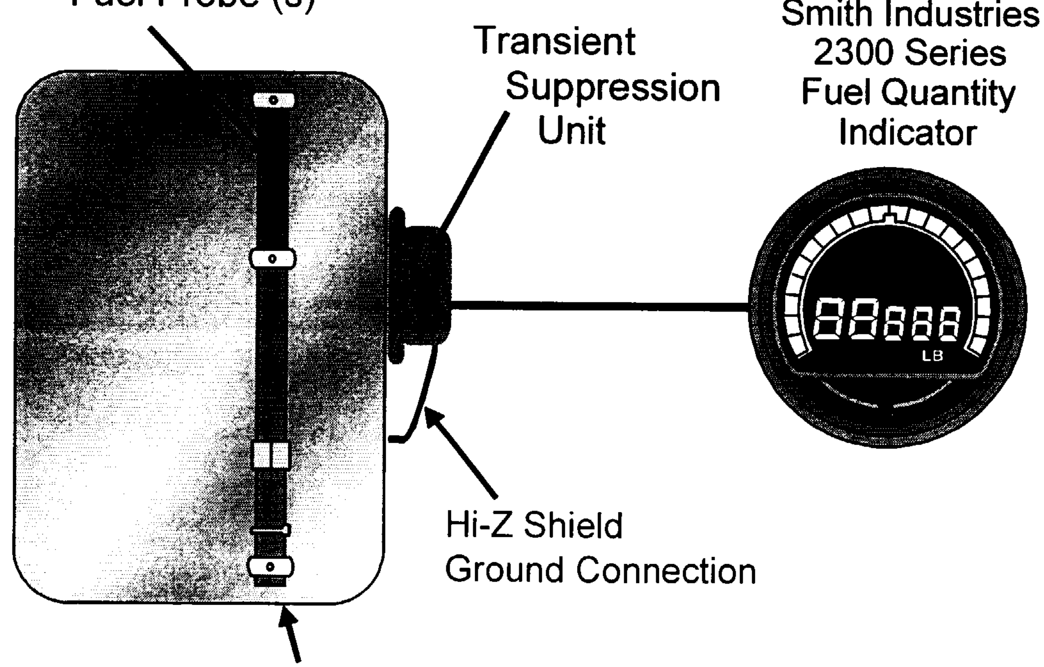
Transient Suppression Unit

- Installation of a TSU at each fuel tank FQIS wire penetration
  - 3 per aircraft
- TSU designed to work in conjunction with Smiths Digital FQIS and to prevent defined electrical threats from entering fuel tank
- Installation of TSU requires no replacement of in-tank hardware

SMITHS FQIS

Transient Suppression Unit

- Insert a suppression circuit in each FQIS wire entering the fuel tank at the tank wall
  - Lo-Z probe
  - Lo-Z compensator
  - Hi-Z
- Provide a ground connection at the tank wall for indicator through Hi-Z shield, and for suppression circuit



SMITHS FQIS

SMITHS FQ15

Design Criteria

- Fault to 28VDC Bus
- Fault to 115VAC 400Hz Bus
- Fault to 350VAC 400Hz Bus
- Indirect effects of lightning
- Coupling to adjacent wiring
- Electro-magnetically induced signals

Protection Requirements

- Limit RMS current into the tank to 10mA steady state
- Limit Energy storage within the tank to 20μJ

SMITHS FQIS

Functional Requirements of TSU

- Provide Transient Suppression to each of the four FQIS wires entering each tank
  - Tank Unit Lo-Z
  - Compensator Lo-Z
  - Hi-Z
  - Hi-Z Shield
- Allow FQIS to continue to gauge fuel accurately
  - Minimal attenuation of signals
  - Minimal phase shift of signals
  - Rapid settling time
- Allow repeaters to continue to function

SMITHS FQIS

Tank Unit & Compensator Lo-Z Circuit

- Voltage Clamp
  - Resistor
  - Fuse
  - Transient Suppressor
- Current Limiting Impedance (Resonant L-C Circuit)
  - Inductor
  - Capacitor
- EMI Protection
  - Ferrite Bead, Capacitors

SMITHS FQ15

Hi-Z Circuit

- Voltage Clamp
  - Resistor
  - Fuse
  - Back to Back Diodes
- Current Limiting Impedance
  - Resistor
- EMI Protection
  - Ferrite Bead, Capacitors

SMITHS FQ15

[4910-13-U]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 39

[Docket No. 97-NM-272-AD]

RIN 2120-AA64

Airworthiness Directives; Boeing Model 747-100, -200, and -300 Series Airplanes

AGENCY: Federal Aviation Administration, DOT.

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This document proposes the adoption of a new airworthiness directive (AD) that is applicable to all Boeing Model 747-100, -200, and -300 series airplanes. This proposal would require the installation of components for the suppression of electrical transients and/or the installation of shielding and separation of the electrical wiring of the fuel quantity indication system (FQIS). This proposal is prompted by testing results, which revealed that excessive energy levels in the electrical wiring and probes of the fuel system could be induced by electrical transients. The actions specified by the proposed AD are intended to prevent electrical transients induced by electromagnetic interference (EMI) or electrical short circuit conditions from causing arcing of the FQIS electrical wiring or probes in the fuel tank, which could result in a source of ignition in the fuel tank.

DATES: Comments must be received by [insert date 90 days after date of publication in the Federal Register].

ADDRESSES: Submit comments in triplicate to the Federal Aviation Administration (FAA), Transport Airplane Directorate, ANM-103, Attention: Rules Docket No. 97-NM-272-AD, 1601 Lind Avenue, SW., Renton, Washington 98055-4056. Comments may be inspected at this location between 9:00 a.m. and 3:00 p.m., Monday through Friday, except Federal holidays.

NPRM 97-NM-272-AD

Information concerning this proposal may be obtained from or examined at the FAA, Transport Airplane Directorate, 1601 Lind Avenue, SW., Renton, Washington.

FOR FURTHER INFORMATION CONTACT: Chris Hartonas, Aerospace Engineer, Systems and Equipment Branch, ANM-130S, FAA, Transport Airplane Directorate, Seattle Aircraft Certification Office, 1601 Lind Avenue, SW., Renton, Washington 98055-4056; telephone (425) 227-2864; fax (425) 227-1181.

SUPPLEMENTARY INFORMATION:

Comments Invited

Interested persons are invited to participate in the making of the proposed rule by submitting such written data, views, or arguments as they may desire. Communications shall identify the Rules Docket number and be submitted in triplicate to the address specified above. All communications received on or before the closing date for comments, specified above, will be considered before taking action on the proposed rule. The proposals contained in this notice may be changed in light of the comments received.

Comments are specifically invited on the overall regulatory, economic, environmental, and energy aspects of the proposed rule. All comments submitted will be available, both before and after the closing date for comments, in the Rules Docket for examination by interested persons. A report summarizing each FAA-public contact concerned with the substance of this proposal will be filed in the Rules Docket.

Commenters wishing the FAA to acknowledge receipt of their comments submitted in response to this notice must submit a self-addressed, stamped postcard on which the following statement is made: "Comments to Docket Number 97-NM-272-AD." The postcard will be date stamped and returned to the commenter.

Availability of NPRMs

Any person may obtain a copy of this NPRM by submitting a request to the FAA,

NPRM 97-NM-272-AD

Transport Airplane Directorate, ANM-103, Attention: Rules Docket No. 97-NM-272-AD, 1601 Lind Avenue, SW., Renton, Washington 98055-4056.

Discussion

On July 17, 1996, a Boeing Model 747 series airplane was involved in an accident shortly after takeoff from John F. Kennedy International Airport in Jamaica, New York. In support of the subsequent accident investigation, the FAA participated in testing of the fuel quantity indication system (FQIS). Results of that testing revealed that excessive energy could be induced by high transient voltage levels in the electrical wiring and probes of the fuel system. These excessive levels occurred when the wiring of the FQIS was subjected to electrical transient testing. These electrical transients may be caused in the airplane when switching electrical loads in the wiring adjacent to the FQIS wiring.

The FQIS was tested to determine its performance in accordance with airplane electromagnetic interference (EMI) requirements. In this test, conductive debris, such as steel wool and lockwire, was used to bridge the FQIS probes to simulate debris that has been found during inspections of transport category airplanes. Results of this test indicated that transient voltage levels induced in the FQIS wiring and probes could be in excess of 800 volts, and the resulting energy levels in the FQIS wiring and probes could be greater than the energy required to ignite fuel vapor inside a fuel tank.

In addition, recent inspections of the fuel probe wiring in Model 747 fuel tanks revealed damaged wiring insulation, which exposed the conductors inside the fuel tank. This condition, together with the introduction of induced transients or short circuit conditions, increases the likelihood for potential ignition sources in the fuel tank.

The conditions described above, if not corrected, could result in excessive levels of energy in the FQIS wiring and a consequent potential source of ignition in the fuel tank.

FAA's Conclusions

While none of the above conditions have been identified at this time as the cause of

NPRM 97-NM-272-AD

the accident discussed previously, the FAA concludes that results of the tests and inspections that have been performed indicate that modifications are required to limit the energy level induced in the FQIS wiring and probes. Further, the FAA has determined that shielding and separation of the FQIS electrical wiring from adjacent wiring is necessary to provide protection from wire-to-wire electrical short circuit conditions, which are a potential source of ignition in the fuel tank.

Explanation of Requirements of Proposed Rule

Since an unsafe condition has been identified that is likely to exist or develop on other products of this same type design, the proposed AD would require the installation of components for the suppression of electrical transients and/or the installation of shielding and separation of the electrical wiring of the FQIS. The actions would be required to be accomplished in accordance with a method approved by the FAA.

Cost Impact

There are approximately 650 Model 747-100, -200, and -300 series airplanes of the affected design in the worldwide fleet. The FAA estimates that 167 airplanes of U.S. registry would be affected by this proposed AD.

Since the manufacturer has not yet developed a modification commensurate with the requirements of this proposal, the FAA is unable at this time to provide specific information as to the number of work hours or the cost of parts that would be required to accomplish the proposed modification. A further problem in developing a specific cost estimate is the fact that modification costs are expected to vary from operator to operator and from airplane to airplane depending upon airplane configuration. The proposed compliance time of 12 months should provide ample time for the development, approval, and installation of an appropriate modification.

However, based on similar modifications accomplished previously on other airplane models, the FAA can reasonably estimate that the proposed modification would require 40 work hours to accomplish, at an average labor rate of $60 per work hour. The cost of required parts is estimated to be $10,000 per airplane. Based on these figures, the cost impact of the proposed AD on U.S. operators is estimated to be $2,070,800, or $12,400 per airplane.

As indicated earlier in this preamble, the FAA specifically invites the submission of comments and other data regarding this economic aspect of proposal.

The cost impact figure discussed above is based on assumptions that no operator has yet accomplished any of the proposed requirements of this AD action, and that no operator would accomplish those actions in the future if this AD were not adopted.

Regulatory Impact

The regulations proposed herein would not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is determined that this proposal would not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

For the reasons discussed above, I certify that this proposed regulation (1) is not a "significant regulatory action" under Executive Order 12866; (2) is not a "significant rule" under the DOT Regulatory Policies and Procedures (44 FR 11034, February 26, 1979); and (3) if promulgated, will not have a significant economic impact, positive or negative, on a substantial number of small entities under the criteria of the Regulatory Flexibility Act. A copy of the draft regulatory evaluation prepared for this action is contained in the Rules Docket. A copy of it may be obtained by contacting the Rules Docket at the location provided under the caption "ADDRESSES."

List of Subjects in 14 CFR Part 39

Air transportation, Aircraft, Aviation safety, Safety.

NPRM 97-NM-272-AD

The Proposed Amendment

Accordingly, pursuant to the authority delegated to me by the Administrator, the Federal Aviation Administration proposes to amend part 39 of the Federal Aviation Regulations (14 CFR part 39) as follows:

PART 39 - AIRWORTHINESS DIRECTIVES

1. The authority citation for part 39 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701.

§ 39.13 [Amended]

2. Section 39.13 is amended by adding the following new airworthiness directive:

BOEING: Docket 97-NM-272-AD.

Applicability: All Model 747-100, -200, and -300 series airplanes, certificated in any category.

NOTE 1: This AD applies to each airplane identified in the preceding applicability provision, regardless of whether it has been otherwise modified, altered, or repaired in the area subject to the requirements of this AD. For airplanes that have been modified, altered, or repaired so that the performance of the requirements of this AD is affected, the owner/operator must request approval for an alternative method of compliance in accordance with paragraph (b) of this AD. The request should include an assessment of the effect of the modification, alteration, or repair on the unsafe condition addressed by this AD; and, if the unsafe condition has not been eliminated, the request should include specific proposed actions to address it.

Compliance: Required as indicated, unless accomplished previously.

To prevent electrical transients induced by electromagnetic interference (EMI) or electrical short circuit conditions from causing arcing of the fuel quantity indication system (FQIS) electrical wiring or probes in the fuel tank, which could result in a source of ignition in the fuel tank, accomplish the following:

(a) Within 12 months after the effective date of this AD, install components for the suppression of electrical transients and/or install shielding and separation of the wiring of the FQIS, in accordance with a method approved by the Manager, Seattle Aircraft Certification Office (ACO), FAA, Transport Airplane Directorate.

(b) An alternative method of compliance or adjustment of the compliance time that provides an acceptable level of safety may be used if approved by the Manager, Seattle ACO, FAA. Operators shall submit their requests through an appropriate FAA Principal Maintenance Inspector, who may add comments and then send it to the Manager, Seattle ACO.

NOTE 2: Information concerning the existence of approved alternative methods of compliance with this AD, if any, may be obtained from the Seattle ACO.

(c) Special flight permits may be issued in accordance with sections 21.197 and 21.199 of the Federal Aviation Regulations (14 CFR 21.197 and 21.199) to operate the airplane to a location where the requirements of this AD can be accomplished.

Issued in Renton, Washington, on November 26, 1997.

Stewart R. Miller, Acting Manager,
Transport Airplane Directorate,
Aircraft Certification Service.

NPRM 97-NM-272-AD

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Boeing Commercial Airplane Group
P.O. Box 3707
Seattle, WA 98124-2207

BOEING

MAY 26 1998

B-T113-98-3552

Transport Airplane Directorate, ANM-103
Airworthiness Rules Docket No. 97-NM-272-AD
Federal Aviation Administration
Northwest Mountain Region
1601 Lind Avenue Southwest
Renton, Washington 98055-4056

Dear Ms. Upton:

Subject: BCAG's Response to FAA NPRM 97-NM-272-AD, Boeing Model 747-100, -200, and -300 Series Airplanes, dated December 3rd, 1997

NPRM SUMMARY:

"This document proposes the adoption of a new airworthiness directive (AD) that is applicable to all Boeing Model 747-100, -200, and -300 series airplanes. This proposal would require the installation of components for the suppression of electrical transients and/or the installation of shielding and separation of the electrical wiring of the fuel quantity indication system (FQIS). This proposal is prompted by testing results, which revealed that excessive energy levels in the electrical wiring and probes of the fuel system could be induced by electrical transients. The actions specified by the proposed AD are intended to prevent electrical transients induced by electromagnetic interference (EMI) or electrical short circuit conditions from causing arcing of the FQIS electrical wiring or probes in the fuel tank, which could result in a source of ignition in the fuel tank."

Boeing Response Summary

In responding to this NPRM it is Boeing's position that the 747 Classic[1] Fuel Quantity Indicating System (FQIS)[2] is safe as delivered and when maintained per Boeing approved maintenance documents. Changes such as those proposed by the FAA, although intended to add an additional layer of safety to an already safe system, must be weighed against the effects of implementing significant modifications to the airplane or affecting the functionality and performance of the Fuel Quantity Indicating System: when measured in those terms, they are not recommended. As has been iterated previously by both government and industry groups, the safety record of the 747 airplane has been, and continues to be, excellent. This does not minimize the tragedy of the Flight 800 accident. This

[1] For the purposes of this response, when referring to the 747 Classic model, this encompasses the 747-100/200/300/SR/SP airplanes, i.e. those affected by this NPRM

[2] When referring to the Fuel Quantity Indicating System (FQIS) for the 747 Classic, this includes the Flight Deck Indicators, the Refuel Panel Indicators, the Volumetric Shutoff Unit, the interconnecting wiring internal and external to the fuel tank and any other miscellaneous components directly associated with the system (e.g. - clamps, circuit breakers, etc.).

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tragedy has energized both government and industry groups[3] to review existing fuel system designs and philosophies to assess additional means that may be implemented to enhance the safety, of not only 747 fuel systems, but the fuel systems of the entire commercial airline fleet.

BOEING

The following actions by Boeing have been taken to respond to the NPRM:

1) A preliminary design for wire separation that includes spatial separation of the FQIS wiring from all other aircraft wiring and protective sleeving or special purpose wire in those areas where spatial separation is not practical or possible. An EMI shield is added over all of the FQIS wiring. Boeing has also included the wiring associated with the 747 Classic Volumetric Shutoff (VSO) System, since it too has components in the fuel tank to which wiring is routed.

   Our estimates show that the kit of parts to accomplish this change will cost approximately $9,000.00. The estimated labor-hours required to incorporate the Service Bulletin is 450 hours (these hours do not include hours for preparation, functionally testing, or calibrating the FQIS and the airplane). Boeing is estimating that this work be done with a crew of 5 and should take 11 days with 1 shift or 6 days with 2 shifts. It is Boeing's recommendation that if the FAA does mandate the separation and shielding of the wiring noted above, that the incorporation should occur during heavy maintenance of the airplane. It is only during these heavy maintenance activities that the airplane is available and prepared for significant changes such as defined by this modification. The service bulletin and kits will be available 18 to 24 months after go-ahead.

2) Boeing has been working with the 747 Classic FQIS suppliers to assist and assess their progress in providing a response to the NPRM covering a transient suppression device. Two FQIS suppliers are planning to provide a device by supplemental type certificate(STC). Internally, independent Boeing analysis and tests have shown that such a device may possibly be designed, manufactured and implemented, but there are some areas of concern that need to be addressed prior to introduction into service. The following are some of the areas of concern: degradation of FQIS functionality; additional FQIS maintenance requirements; reduced reliability of FQIS; and new FQIS failure modes.

   Therefore, adequate time must be provided to allow the careful and disciplined design, test, analysis, manufacture and implementation of a new product of this nature. The Fuel Quantity Indicating System plays a significant role in the safe operation of the airplane. Premature introduction of a transient suppression device into the FQIS could result in a degradation to the safety of the airplane.

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[3] The FAA/JAA ARAC Fuel Tank Harmonization Working Group tasked with reviewing the fleet history, enhancement techniques and proposed regulatory action. The SFAR commitment by the FAA to validate original certification compliance and to enhance airline fuel system maintenance program; The joint AIA/ATA/AECMA industry Inspection Program to conduct detailed inspection on a large number of airplanes to provide data to develop enhanced maintenance programs.

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The suppliers that provide FQISs for the 747 Classic and choose to enter into the development of this new component by STC will be providing a separate response to the NPRM outlining the design, analysis, test, certification and manufacturing schedule for the component, the cost associated with manufacturing and implementing the part and the associated risks.

BOEING

Boeing has estimated that the cost of the suppression device will be approximately $25,000 per ship set and be available in 18 to 24 months. The time required for incorporating of the suppression device has not yet been determined, but we anticipate from 16 to 24 hours for installation.

NPRM Response

In responding to this NPRM it is Boeing's position that the 747 Classic[4] Fuel Quantity Indicating System (FQIS)[5] is safe as delivered and when maintained per Boeing approved maintenance documents. Changes such as those proposed by the FAA, although intended to add an additional layer of safety to an already safe system, must be weighed against the effects of implementing significant modifications to the airplane or affecting the functionality and performance of the Fuel Quantity Indicating System: when measured in those terms, they are not recommended. As has been iterated previously by both government and industry groups, the safety record of the 747 airplane has been, and continues to be, excellent. This does not minimize the tragedy of the Flight 800 accident. This tragedy has energized both government and industry groups[6] to review existing fuel system designs and philosophies to assess any additional means that may be implemented to enhance the safety, of not only 747 fuel systems, but the fuel systems of the entire commercial airline fleet.

There are no known examples of an internal ignition source inside the center wing tank of a 747. Boeing considers an ignition source to be any source of released energy that would be sufficient to ignite a flammable fuel/air vapor mixture. It is, and has long been well known that commercial transport aircraft operate with flammable vapors in the fuel tank ullage space (the air space above the liquid fuel layer inside a fuel tank). The flammability of that vapor is dependent on temperature and pressure (altitude) conditions. However, to be conservative, Boeing assumes that the fuel tank vapor is flammable at all times. Therefore it is imperative to preclude the presence of an ignition source within the fuel tank.

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[4] For the purposes of this response, when referring to the 747 Classic model, this encompasses the 747-100/200/300/SR/SP airplanes, i.e. those affected by this NPRM.

[5] When referring to the Fuel Quantity Indicating System (FQIS) for the 747 Classic, this includes the Flight Deck Indicators, the Refuel Panel Indicators, the Volumetric Shutoff Unit, the interconnecting wiring internal and external to the fuel tank and any other miscellaneous components directly associated with the system (e.g. - clamps, circuit breakers, etc.).

[6] The FAA/JAA ARAC Fuel Tank Harmonization Working Group tasked with reviewing the fleet history, enhancement techniques and proposed regulatory action. The SFAR commitment by the FAA to validate original certification compliance and to enhance airline fuel system maintenance program; The joint AIA/ATA/AECMA Industry Inspection Program to conduct detailed inspection on a large number of airplanes to provide data to develop enhanced maintenance programs.

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The 747 Classic FQIS (and all commercial transport FQISs) is designed to preclude the presence of an internal ignition source during both normal operation or with any failure that might be expected to occur during the life of the fleet.

The following paragraphs are examples of some of the FQIS design features which safeguard against internal ignition sources:

BOEING

1) FQIS Indicator

The FQIS indicators on the 747 Classic airplane house the electronics that determine the amount of fuel in the tank. The FQIS indicator supplies very low power to the fuel probes and compensators inside the tank. This energy is restricted to 10 times lower than the industry standard minimum ignition energy required to ignite a fuel/air mixture. This is accomplished through the careful layout of electronic components and wiring in the indicator as well as implementation of redundant electrical current limiting devices on the indicator outputs to the fuel tanks. If a wire short was to occur inside the tank, an arc of sufficient energy to ignite fuel vapors would not occur because the energy to the wire and components in the tank is limited at the source; i.e. the FQIS indicator. The effect of a shorting condition would be indicated by erroneous system performance and, once identified, would be corrected.

The following are some of the design characteristics of the Indicators that ensure the integrity of the unit for the life of the airplane. The Insulation Resistance between all mutually insulated parts must be > 20 Mohms @ 500VDC and 100 Mohms @ 500 VDC between the lighting circuit and case. The Dielectric Withstanding Voltage of the unit is 500VAC RMS @ 60/400 Hz with less than 0.5mA of leakage current. The Indicators are hermetically sealed to prevent moisture and contaminants from damaging the electronics.

2) FQIS External Fuel Tank Wiring

The FQIS wire from the connector on the rear of the FQIS indicator in the Flight Engineer's(FE) Panel to the FE Panel disconnect is general purpose wire. This segment is approximately four feet in length. The portion from the Indicator disconnect to the first bundle clamp is sleeved with Raychem RT876, BMS 13-52 Type 1B, or Type V, a Polyester (tight weave) sleeve to protect against chafing. This portion of wiring is in a stable low vibration area.

The FQIS wire bundle that runs from the Flight Engineer's Panel disconnect to the wing tank spar disconnects is specified as MIL-W-16878C. MIL-W-16878C is rated as a high temperature wire that can operate continuously at 200°C and 1000 VAC, rms. The inner conductor is silver plated copper wire. This wire bundle is protected against wire-to-wire abrasion with a varnish impregnated nylon sleeve. The insulation resistance is specified at > 2000 Mohm @ 500VDC with a Dielectric Withstanding Voltage specified at less than 2.0 milliamps of leakage per connector plus 2.0 milliamps of leakage per 100 inches of cable at

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1500VRMS @60/400 Hz. The wiring from the Flight Engineer's Panel to the wing-to-body disconnect panels and the rear spar is covered with a varnish impregnated nylon jacket for additional abrasion protection. The FQIS wiring from LN 244 and on incorporate an Electromagnetic Interference(EMI) shield on the bundle from the Flight Engineer's disconnect to the spar disconnects and from LN 455 and on incorporate an EMI shield on the bundle in the Flight Engineer's panel. The shielding was added due to fluctuating indication caused by EMI.

Wiring from Flight Engineer's disconnect down to Volumetric Shutoff (VSO) Unit in the Electrical/Electronics(EE) Bay, and from the VSO Unit to the spar mounted connectors, is general purpose wire.

All FQIS wiring along the wing leading edge incorporates an overall lightning shield to provide lightning protection.

3) FQIS Wiring - In Tank

Wiring within the tank is the same MIL-W-16878C wire that is utilized on the external fuel tank wiring. FQIS wiring in the tanks is affixed to structure by clamps that prevent the wiring from contacting structure, thus reducing the likelihood of abrasion of the wire insulation. Penetration points through structure are lined with plastic grommets to prevent abrasion during installation or by incidental contact with the hole edges. A drip loop in the wire is provided at each probe and compensator to shed moisture.

4) FQIS Probes and Compensator

The mounting of the fuel probes within the tank ensures positive spacing from structure. The ends of the probes employ plastic endcaps to preclude metal contact with structure. This is done to prevent inadvertent contact with structure which could result in an electrical short and cause erroneous system performance. These measures further reduce the likelihood that an electrical short can occur in the tank.

The Dielectric Withstanding Voltage of the probes is 1500VAC RMS @ 60/400 Hz with less than 0.5mA of leakage current and the Insulation Resistance is specified to be greater than 200Mohms @ 500VDC. These two tests are conducted on every new probe assembly to verify the integrity of the part after assembly. The Insulation Resistance Test is conducted on probes that have undergone repair or refurb. These tests provide a high level of confidence that the mutually insulated parts within the probe do not breakdown over the life of the part.

The probe inner electrode is coated with polyurethane varnish to prevent moisture adhesion and the outer electrode is anodized to prevent corrosion. The anodizing provides an additional layer of protection against short circuits between the inner and outer electrode and the outer electrode and structure, as the anodizing is non-conductive.

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Design of mutually-insulated parts protects against sulfide contamination on the probe assembly. There are limited copper or silver parts on the Probes and Compensators. There is a copper braze (weld) between two joints on the terminal block. There is inconsequential exposure of brazing material to fuel and therefore little, if any resulting sulfide contamination. There is a small solder joint in the compensators but there has never been a reported degradation of compensator insulating capability or performance due to this solder joint as a result of sulfide contamination.

Summary

The 747 Classic FQIS is designed to preclude the ignition of fuel vapor in the tanks. The FQIS incorporates design features which provide tolerance to environmental factors associated with residence in fuel tanks, e.g. vibration, corrosion, contamination. These in turn provide extended life expectancy and tolerance to conditions which may cause shorting or grounding conditions.

NPRM Concern:

1) Voltage Transients

Boeing has evaluated the concerns noted in the NPRM. The first concern as discussed in the NPRM is:

> **"On July 17, 1996, a Boeing Model 747 series airplane was involved in an accident shortly after takeoff from John F. Kennedy International Airport in Jamaica, New York. In support of the subsequent accident investigation, the FAA participated in testing of the fuel quantity indication system (FQIS). Results of that testing revealed that excessive energy could be induced by high transient voltage levels in the electrical wiring and probes of the fuel system. These excessive levels occurred when the wiring of the FQIS was subjected to electrical transient testing. These electrical transients may be caused in the airplane when switching electrical loads in the wiring adjacent to the FQIS wiring.**
>
> **The FQIS was tested to determine its performance in accordance with airplane electromagnetic interference (EMI) requirements. In this test, conductive debris, such as steel wool and lockwire, was used to bridge the FQIS probes to simulate debris that has been found during inspections of transport category airplanes. Results of this test indicated that transient voltage levels induced in the FQIS wiring and probes could be in excess of 800 volts, and the resulting energy levels in the FQIS wiring and probes could be greater than the energy required to ignite fuel vapor inside a fuel tank."**

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The testing referred to in the above paragraphs was laboratory testing conducted at Boeing. The purpose of the testing was to evaluate what would be required to cause excessive energy to be induced into the tank through the FQIS wiring and then what subsequent in-tank failures would be required to result in an ignition path. The purpose of testing was not to determine the performance of the FQIS in accordance with established airplane(EMI) requirements nor is the insertion of conductive debris a normal part of this type of test. The test configuration and procedure were derived from a generic equipment test which was intended to demonstrate the resistance of a piece of electronic equipment to EMI. The test configuration was never intended to be used as a dielectric breakdown evaluation.

The concern is that an electrical voltage transient (voltage spike) of sufficient strength, induced onto FQIS wiring, might result in an arc in a fuel probe if the probe were contaminated with conductive debris. Voltage transients in wiring are generated when power to equipment is switched from one state to another state, like turning a light from Off (0 VAC) to On (115VAC). These trantients can greatly exceed the normal voltage in the wire for very short periods of time. When other wires are close or adjacent to the wire that is undergoing switching, these transients may be coupled onto the adjacent wiring by what is referred to as, Electromagnetic Interference(EMI). When voltage and current are present on a wire, electromagnetic fields are established around the wire. When the voltage or current in the wire changes, the fields around the wire change. If there is other wiring adjacent to the wire that is switching from off to on, these fields cause a similar, but reduced, change in the adjacent wiring, i.e. the voltage transient was "induced" onto the adjacent wiring. The FAA's concern arose from the results of Boeing laboratory tests which demonstrated that, given high enough levels of voltage transients (over 800 volts in laboratory conditions) induced onto the FQIS wiring that is outside the fuel tank, an arc could be generated on a fuel probe that had been purposely contaminated with debris. These tests were designed to "stress test" the system and did not reflect the actual airplane environment.

Testing conducted by Boeing, and coordinated with both the NTSB and FAA, on an operational 747 configured similar to the Flight 800 airplane, has demonstrated that voltage spikes induced onto the FQIS wiring and into the tank (61V peak) were far below that required to present any hazard. This testing demonstrated that the available energy levels would not result in an arc in the fuel tank even with debris present in the probe. The earlier laboratory testing referred to above, which did create an arc, required extremely high voltage spikes and carefully placed debris, in order to obtain this result. Boeing is in the process of conducting a second test on an operational 747 Classic in order to gather the data necessary to substantiate the previous airplane results. Boeing has also completed laboratory testing that assessed the effects of other EMI sources, internal and external to the airplane, that might induce voltage on

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the FQIS wiring and might have resulted in excessive energies being conducted into the fuel tank. This testing indicated that HIRF (High Intensity Radiated Frequency) EMI radiated directly onto the FQIS wiring did not result in any voltage of sufficient magnitude to result in an ignition source in the tank during normal and failure conditions.

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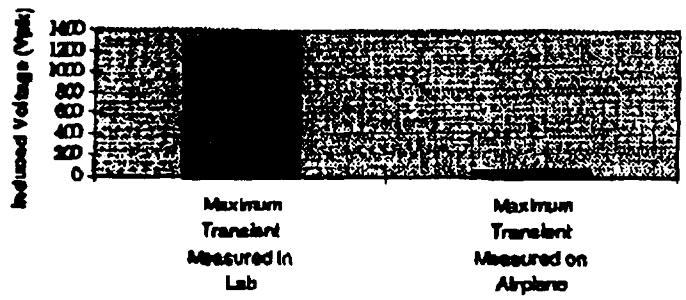
Comparison of Lab to Airplane Center Wing Tank Test Results



2) Damage to Wiring in the Fuel Tank

The second concern as discussed in the NPRM is:

> **"In addition, recent inspections of the fuel probe wiring in Model 747 fuel tanks revealed damaged wiring insulation, which exposed the conductors inside the fuel tank. This condition, together with the introduction of induced transients or short circuit conditions, increases the likelihood for potential ignition sources in the fuel tank."**

This scenario postulates the occurrence of multiple, independent failures which, when combined, could result in an arc being created in the center wing tank.

Portions of FQIS wiring in the airplane's fuselage are routed with or are bundled with other wiring that contains up to 350 V rms. In order for a higher than normal voltage to get onto the external fuel tank wiring of the FQIS and into the tank, a failure would have to occur that would breech the insulation of both wires. The mechanism for doing this would be either through abrasion of the two wires to each other or some arcing condition resulting in damage that exposed the conductors of both wires and shorted them together. This failure alone would cause the fuel quantity indicators to read erroneously and would not result in the ignition of fuel vapors in the tank due to the design and construction of the probes and in-tank wiring. In addition, other systems affected by the shorting condition would malfunction also, providing a second means of identifying and repairing the fault. Our service history does not record that such an occurrence involving FQIS wiring has ever been experienced on any 747.

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An additional independent failure would have to exist inside the fuel tank simultaneously with the external fuel tank wiring failure described above, to present a potential ignition source hazard. A high-resistance path would have to exist somewhere inside the center wing fuel tank FQIS probes or wiring which could create an arc path when subjected to 350 V rms or less (associated with the first failure described above). It has been postulated that the source of such a high resistance path may be in the form of:

a) two bare wires with their exposed conductors laying very close together but not shorting, or

b) conductive debris bridging the inner and outer tubes of a fuel probe without causing a hard short circuit, or

c) a path caused by high resistance debris/contamination across two exposed wires.

These high-resistance paths may not result in erroneous FQIS performance and could go undetected.

Note: If any of these failures actually resulted in a direct short circuit condition, the FQIS would not function correctly and the malfunction would be noticed by the ground/flight crews in most instances. The only instance where a direct short circuit of the FQIS wiring would not be noticed is where the resultant fuel indication drove to zero (0) and the affected tank was empty[7,8].

With respect to item (a), Boeing has conducted testing to determine the voltage required to create an arc across two exposed conductors laying very close together. In this testing, one wire had all of its insulation removed and the other wire had its insulation removed in a small area exposing the conductor. The "damaged" area of the second wire was placed facing the exposed conductor, separated only by the width of the wire insulation jacket of the second wire. Under this condition the voltage required to bridge the air gap (approximately 10 mils - 10/1000 of an inch) and create an arc was over 1100V AC rms, 60 HZ. This gap must be reduced to approximately 1 mil distance (1/1000 of an inch, or about the thickness of a piece of paper) before the breakdown voltage approached 350V AC rms, 60 HZ,. These tests were conducted at sea level. Therefore, similar tests were conducted at 13,000 feet altitude with the following test results: the break down voltage required to bridge the gap and create an arc at 10 mil gap was over 800V AC rms, 60HZ, and

[7] With regards to Flight 800, the center tank fuel quantity indication was functioning normally on the previous flight when the center tank was fueled and was properly indicating residual fuel in the center tank at the time of the accident.

[8] This is true only for the analog FQIS indicators such as was on Flight 800. The 747 Classic also employs digital indicators which, when detecting a failure that results in an unknown tank quantity, will blank the displayed quantity for the affected tank, even if empty at the time of the failure. A "blank" display is readily apparent to flight and maintenance crews. In addition to the blank display, the digital systems on the 747 Classic also have BITE capability and would display the appropriate fault code for this failure.

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this gap must be reduced to approximately 4 mills distance before the break down voltage approached 350V AC rms, 60 HZ. The conclusion that is drawn by this test is that the scenario necessary to develop an ignition path as a result of damaged wiring in the tank is highly unlikely since the spacing of the two exposed surfaces must be held extremely close together over an extended period of time without actually being in a short, or intermittent short condition.

With respect to item (b), Boeing has also conducted testing to determine the voltage required to create an arc when conductive debris is bridging the inner and outer tubes of a fuel probe. Even with the protective varnish layer removed from the inner electrode of the probe, a voltage level greater than 350 VAC was required to result in a breakdown between the electrodes with conductive debris (steel wool) between them. This is due to the anodize coating on the outer electrode which broke down at a minimum of 516 VAC rms, 60 HZ, in tests conducted at Boeing. Anodize coatings are very stable and do not generally degrade over time unless subjected to abrasion, therefore it is our opinion that this does not represent a plausible undetected ignition path in the tank.

With respect to item (c), it has been proposed that silver and copper sulfides acted as a possible means of creating such a path. Silver and copper sulfides are the result of the sulfur component in jet fuel reacting with the exposed silver and copper metals on FQIS wiring in the fuel tank. It has been postulated that a sufficient buildup of these contaminants across two damaged wires on the terminal block could lead to an electrical bridge of the exposed wiring. Unless the buildup of these sulfide contaminants is so severe that fuel quantity indication is affected, the buildup could go undetected by the flight or maintenance crews. The damaged wiring observed on a fuel probe with a "Series 3" terminal block is cited as an example of the potential for damaged wiring.[9]

[9] Wiring to fuel probes inside fuel tanks are attached to what is referred to as a terminal block. The NTSB has examined terminal block wiring removed from a retired 747 and identified degraded wiring conditions associated with an early version of the terminal block. The first sixty-four 747 Classic airplanes had terminal blocks which used a non-slip, knurled surface against which the probe wiring was clamped. It was discovered that the knurled surface could damage the wire insulation locally. These same terminal blocks, identified by part identification number as "Series 3" (and lower), were also available as spares for all 747 Classic airplanes (the 747-400 has a newer FQIS that has a different probe design). Series 4 (and higher) terminal blocks eliminated the design features that may cause damage to the FQIS wiring, and are the current standard for the 747 Classics.
Boeing has worked with the FAA and NTSB on this issue and Service Bulletin 747-28A2208 has been released to remove probes with Series 3 (and lower) terminal blocks and replace them with Series 4 (or higher) terminal blocks. Also, the wiring to all Series 3 (and lower) terminal blocks will be replaced to eliminate any possibly damaged wiring from the fuel tank. In assessing the threat of an ignition source in the tank, the following factors were considered; the area on the terminal block that could potentially damage wiring is small, approximately one-half inch square. The wiring is held in place by a clamp on the terminal block and is not subject to rotation. Any damage caused by the terminal block surfaces and clamp will tend to remain stationary. If two nicked surfaces happened to face each other, the remaining insulation will hold the two exposed surfaces apart. Even if two exposed wires did come in contact they would not create an ignition source. Although not a direct hazard to system integrity, the service bulletin will remove the Series 3 (and lower) terminal blocks from service.
In addition, this same service bulletin addresses wire routing issues on all fuel probe terminal blocks in the center tank to ensure that there is no damage to the wiring due to misrouting, and to provide detailed drawings on how to properly route wires on the terminal blocks of 747 Classic probes and compensators.

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Boeing has studied this scenario closely with the following conclusions. The mechanism of silver and copper sulfide buildup is understood and recognized by Boeing. This is not new information as a result of the Flight 800 investigation. The extent of contamination and the coupling of that contamination to ignition sources in the fuel tanks is a new theory. This theory is based on Air Force experience regarding a military aircraft that encountered problems associated with copper and silver sulfide deposits. The design of the probes utilized on the military aircraft caused it to be susceptible to these deposits due to the large amount of exposed metal shielding present in the design and the spacing of mutually insulated conductors (conductors which must remain insulated from one another).

Boeing is also in the process of examining probes removed from two in-service 747 airplanes. A detailed visual and electrical examination of one shipset of these probes has been conducted. To date, four probes, with their in tank wiring attached have exhibited dielectric breakdown below the levels specified for brand new equipment but still above any voltage levels that can be expected on the airplane. The lowest breakdown voltage on any probes was 713V AC rms, 60 HZ, at sea level. Boeing is continuing this examination on a second shipset of probes and wiring.

Boeing has also released Service Bulletin 747-28A2208 on the 747 Classic Fuel Quantity Probes and Wiring in the center wing tank. This bulletin inspects for and removes any probes with "series 3" terminal block. It also provides instructions to inspect for damage to the FQIS wiring and remove any damaged wire from the tank. This action further addresses the stated concern that damaged FQIS wiring, in combination with sulfide contamination, could create a potential ignition path.

Details of separation and shielding of all external fuel tank wiring for the affected 747 airplanes

In response to the NPRM mandate for "... **the installation of shielding and separation of the electrical wiring of the FQIS**", Boeing has prepared a preliminary design for wire separation that includes spatial separation of the FQIS wiring from all other aircraft wiring and protective sleeving or special purpose wire in those areas where spatial separation is not practical or possible. An EMI shield is added over all of the FQIS wiring. It was not possible to replace all of the FQIS wiring with this special purpose wire type due to the sensitivity of capacitive fuel quantity systems to changes in the capacitance of the wire used, so the Hi-Z wire type was not changed. Boeing has also included the wiring associated with the 747 Classic Volumetric Shutoff (VSO) System, since it too has components in the fuel tank to which wiring is routed. The same special purpose wire is utilized for the VSO wiring in addition to providing shielding for EMI voltage transient protection. Estimated cost and labor-hours associated with implementing these changes in a 747 Classic are also provided.

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The change involves capping and stowing all replaced FQIS wires. The old wiring will not be removed from the airplane but will be properly terminated and retained in the airplane. This alleviates the necessity of having to remove existing bundle ties and clamps which would result in disturbing a significant amount of existing wiring and systems in order to remove the old FQIS/VSO wiring. The new wiring will be included in the kit supplied with the Service Bulletin(SB). The SB will instruct the operators on how and where to route new wire bundles for the FQIS/VSO system to meet the separation and shielding requirements of the NPRM. The new wire bundles will generally follow the existing routing of the wiring being replaced and will use existing attach points or install new ones, as required. There are approximately 10 to 13 wire bundles affected by this change, dependent upon the configuration of the airplane, which adds up to approximately 2100 feet of new wiring.

Access to the wiring must be accomplished. This will involve the partial disassembly of the airplane in some areas.

Our estimates show that the kit of parts to accomplish this change will cost approximately $9,000.00. The estimated labor-hours required to incorporate the Service Bulletin will be 450 hours (these hours do not include hours for preparation, functionally testing, or calibrating the FQIS and the airplane). Boeing is estimating that this work be done with a crew of 5 and should take 11 days with 1 shift or 6 days with 2 shifts.

It is our estimate that the following numbers of airplanes will be affected by this NPRM:

747 Airplanes - Active - US and Foreign

TOTAL:	650 AIRPLANES	
Breakdown:	747-100	132 airplanes
	747-200	372 airplanes
	747-300	79 airplanes
	747SP/SR/Other	67 airplanes

747 Airplanes - Active - Registered in US

TOTAL:	202 AIRPLANES	
Breakdown:	747-100	81 airplanes
	747-200	108 airplanes
	747SP/SR/Other	13 airplanes

The Service Bulletin and kit of parts to support retrofit of the 747 Classic fleet will be available 18 to 24 months after the go-ahead.

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As noted previously, it is Boeing's position that the 747 Classic FQIS is a safe system and that these actions represent the addition of another layer of safety, therefore immediate or accelerated incorporation is not required. This is also taking into consideration the service bulletins that Boeing has and will provide to the airlines to address any known issues. It is Boeing's recommendation that if the FAA does mandate the separation and shielding of the wiring noted above, that the incorporation should occur during heavy maintenance of the airplane. It is only during these heavy maintenance activities that the airplane is available and prepared for significant changes such as defined by this modification.

Transient Suppression Device

In response to the NPRM, which called for "... **the installation of components for the suppression of electrical transients ...**" Boeing has been working with the 747 Classic FQIS suppliers to assist and assess their progress in providing a response to the NPRM. Internally, independent Boeing analysis and tests have shown that such a device may possibly be designed, manufactured and implemented, but there are some areas of concern that need to be addressed prior to introduction into service. These are:

1) Degradation of FQIS accuracy and functionality resulting from wiring stray capacitance and EMI reacting with the suppression circuitry. An in-service evaluation of a prototype unit(s) should be considered to ensure there are no unknown negative effects/functions prior to full scale implementation in addition to rigorous laboratory, ground and flight testing.

2) Collateral damage to the FQIS Indicator due to lightning transients. It must be ascertained that there are no modes of operation of the device that would cause damage to the FQIS indicator(s) in the Flight Deck. If so, it may be necessary to develop a secondary modification to the indicators to prevent this damage.

3) Reliability of the suppression circuitry may negatively impact airplane operation, dispatch or maintenance. Rigorous electrical and environmental testing must be accomplished prior to introducing this device into revenue service.

4) Latent failures of critical components. The devices under consideration are passive in nature, i.e. there are no active electronics that would enable you to determine if the device is functioning. Further analysis is required to limit exposure to this type of failure to acceptable levels.

5) Additional maintenance will be required because there are no active electronics that would enable you to determine if the device is functioning.

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Adequate time must be provided to allow the careful and disciplined design, test, analysis, manufacture and implementation of a new product of this nature. The Fuel Quantity Indicating System plays a significant role in the safe operation of the airplane. Premature introduction of a transient suppression device into the FQIS could result in a degradation to the safety of the airplane.

BOEING

The suppliers that provide FQISs for the 747 Classic and choose to enter into the development of this new component by supplemental type certificate(STC) will be providing a separate response to the NPRM outlining the design, analysis, test, certification and manufacturing schedule for the component, the cost associated with manufacturing and implementing the part and the associated risks.

Boeing has estimated that the transient suppression device will cost approximately $25,000 per ship set and be available in 18 to 24 months after receipt of orders. The time required for incorporating of the suppression device has not yet been determined, but we anticipate from 16 to 24 hours for installation.

Boeing remains open to providing all 747 Classic FQIS suppliers the airplane design information necessary to install the device in the airplane and consultation on the design, test and certification requirements. Boeing is committed to ensuring that the interest of the airlines and flying public are maintained throughout this process.

It is understood that both of our organization's key people are involved in numerous fuel system related activities over the next few months and that allowance must be made in schedules to ensure that the appropriate individuals are able support this activity.

Please contact this office or Leo Rydzewski at (425) 234-5403 if you have any questions or need additional information.

Very truly yours,

D. W. Berg
Manager, Certification
Delivery & Fleet Support, B-T113
M/S 9U-RL, (425) 237-0300

LJR

cc C. Hartonas (FAA) ANM-130S 6Y-01

BOEING LETTER OF MAY 26, 1998

UNITED AIRLINES

Maintenance Operations

May 26, 1998

Federal Aviation Administration
Transport Airplane Directorate
1601 Lind Avenue, SW.,
Renton, WA 98055-4056

Attention: Rules Docket No. 97-NM-272-AD

Subject: 747 Fuel Quantity Indication System (FQIS) Wiring Voltage Suppression Device and/or Wire Separation and Shielding

To Whom it May Concern:

This letter is to submit United Airlines' comments on the subject NPRM, which was issued on March 23, 1998. The NPRM states that within 12 months of the effective date of the proposed AD, operators must install components for the suppression of electrical transients and/or accomplish the shielding and separation of all FQIS wiring. United feels that additional time (36 months) is necessary to design, develop, and test a voltage transient device so that an alternative to wire-separation is available to us.

The NPRM gives an option to either implement wire separation of all FQIS wiring and/or install a voltage transient suppression device (VTSD). United does not feel that we currently have a VTSD option, as a device for this purpose does not yet exist. However, we also do not believe wire separation to be an effective solution. This is based on the risks involved by potentially introducing other failures while accomplishing an extensive wire-separation modification of this magnitude. In reviewing Boeing's preliminary wire separation details, there are 10 to 13 FQIS related wire bundles that will be affected between the cockpit, the forward E&E compartment and the wing of the 747 aircraft. All the wire bundles that will be accessed are under floorboards or behind hard-to-reach panels. In accessing these difficult areas, other defects may result which could impact other systems. United is also concerned about the considerable downtime per airplane which would be required to accomplish wire separation, as opposed to the relatively short installation time a VTSD would require. United is very opposed to wire-separation being the only available terminating action for the proposed AD due to the lack of a VTSD.

San Francisco International Airport, San Francisco, California 94128

UNITED LETTER, MAY 26, 1998

United feels that the prior testing which was performed by Boeing to show electromagnetic interference (EMI) was not a realistic aircraft simulation. United feels that further Boeing testing should be performed to evaluate realistic EMI effects on aircraft FQIS.

United shares Boeing's conviction that the 747 FQIS is safe when operated and maintained per approved methods. However, if action is mandated, it is our opinion that transient suppression is the only viable approach. In addition, we strongly encourage Boeing to lead the development of a VTSD rather than allow individual vendors to develop their own device with Supplemental Type Certification (STC). The vendor STC option could have financial and reliability ramifications which we wish to avoid. United feels that more time should be given to Boeing to allow VTSD development.

If you should have any further questions, you could reach me at (650) 634-7175 or Bill Bowen at (650) 634-4783.

Sincerely,

J. M. Gay

J.M. Gay
Chief Engineer

cc: Bill Bowen, United Airlines - SFOEG
D.K. Loo, United Airlines - OAKEG
Jim Takeuchi, United Airlines - SFOEG

UNITED LETTER, MAY 26, 1998

[Federal Register: September 30, 1998 (Volume 63, Number 189)]
[Rules and Regulations]
[Page 52147-52152]
From the Federal Register Online via GPO Access [wais.access.gpo.gov]
[DOCID:fr30se98-6]

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DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 39

[Docket No. 97-NM-272-AD; Amendment 39-10808; AD 98-20-40]
RIN 2120-AA64

Airworthiness Directives; Boeing Model 747-100, -200, -300, SP, and SR Series Airplanes

AGENCY: Federal Aviation Administration, DOT.

ACTION: Final rule.

SUMMARY: This amendment adopts a new airworthiness directive (AD), applicable to all Boeing Model 747-100, -200, -300, SP, and SR series airplanes, that requires the installation of shielding and separation of the electrical wiring of the fuel quantity indication system (FQIS). This amendment is prompted by a failure analysis of the FQIS, and by testing results, which revealed that excessive energy levels in the electrical wiring and probes of the fuel system could be induced by electrical transients. The actions specified by this AD are intended to prevent electrical transients, induced by electromagnetic interference (EMI), or electrical short circuit conditions from causing arcing of the FQIS electrical wiring or probes in the fuel tank(s). Such arcing

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could result in ignition of the fuel tank(s).

EFFECTIVE DATE: November 4, 1998.

ADDRESSES: Information pertaining to this amendment may be examined at the Federal Aviation Administration (FAA), Transport Airplane Directorate, Rules

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Docket, 1601 Lind Avenue, SW., Renton, Washington; or at the Office of the Federal Register, 800 North Capitol Street, NW., suite 700, Washington, DC.

FOR FURTHER INFORMATION CONTACT: Chris Hartonas, Aerospace Engineer, Systems and Equipment Branch, ANM-130S, FAA, Transport Airplane Directorate, Seattle Aircraft Certification Office, 1601 Lind Avenue, SW., Renton, Washington 98055-4056; telephone (425) 227-2864; fax (425) 227-1181.

SUPPLEMENTARY INFORMATION: A proposal to amend part 39 of the Federal Aviation Regulations (14 CFR part 39) to include an airworthiness directive (AD) that is applicable to all Boeing 747-100, -200, and -300 series airplanes was published in the Federal Register on December 1, 1997 (62 FR 63624). [An action to reopen the comment period for the proposal was issued on March 23,1998 (63 FR 14850, March 27, 1998).] That action proposed to require the installation of components for the suppression of electrical transients and/or the installation of shielding and separation of the electrical wiring of the fuel quantity indication system (FQIS).

Interested persons have been afforded an opportunity to participate in the making of this amendment. Due consideration has been given to the comments received.

Support for the Proposal

Two commenters support the proposed rule.

Request To Withdraw Proposed AD: Lack of Evidence

Three commenters, including the manufacturer, state that the proposed AD should be withdrawn or significantly delayed, based on the lack of conclusive evidence that the Trans World Airlines Flight 800 accident on July 17, 1996 (hereinafter referred to as TWA Flight 800), which involved a Model 747-100 series airplane, was caused by failure

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of the FQIS components and wiring that is routed to the tanks. In addition, the manufacturer comments extensively on the features of the existing system that are intended to prevent an ignition source from existing in the fuel tanks due to FQIS wiring or component failures. The manufacturer further comments that it believes that the current design of the FQIS is safe in the originally delivered configuration, when it is maintained in accordance with the manufacturer's approved maintenance documents. The manufacturer states that multiple failures within the FQIS would be required to create an ignition source within a fuel tank.

The FAA does not concur that the proposed AD should be withdrawn or delayed. The FAA agrees that no conclusive evidence exists that failure of the FQIS components or wiring that is routed to the tanks caused the TWA Flight 800 airplane accident. However, during such accidents, evidence that could lead to a conclusive identification of the cause of the accident is often destroyed. Even without the destruction caused by the accident, there often is no specific physical evidence of low-energy electrical arcing. In addition, in consideration of the amount of wiring installed on a Boeing Model 747 series airplane, and in consideration of the amount of damage to the wiring that occurred during the airplane fire, breakup, and subsequent recovery, conclusive identification of a specific wire that was damaged before the fire and breakup is extremely unlikely.

Following the determination that a fire in the center wing fuel tank of the TWA Flight 800 airplane was the initial event in the airplane breakup, and the determination that the fire was not caused by an external source such as a bomb or missile, the National Transportation Safety Board (NTSB) has necessarily used systems analysis methods to determine what systems on the airplane are most likely to have been the source of ignition energy. That analysis included an examination of system failure modes and effects, an examination of service history, and examinations of similar airplanes. It was that analysis that led the FAA to propose the requirements specified in the notice of proposed rulemaking (NPRM).

In commenting on the specific design features of the FQIS on Model 747 series airplanes, the manufacturer points out that multiple independent failures would be required to create an FQIS-related ignition source in the fuel tank, implying that such an event is therefore impossible. The FAA agrees that more than one failure would be required to create an ignition source inside the fuel tank. The fact that fuel tank explosions on Model 747 series airplanes have been rare would seem to support a claim that single failures have not been the cause of fuel tank explosions. However, during the accident investigation, the FQIS safety analysis and the examinations of Model 747 series airplanes performed by the NTSB revealed several scenarios

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where a combination of a latent failure or aging condition within the fuel tank and a subsequent single failure or electrical interference condition outside the tank can cause an ignition source to occur inside a fuel tank.

Examples of these in-tank and out-of-tank conditions that can contribute to a multiple-failure ignition scenario were found in airplane service records and on airplanes that were inspected by the FAA and the NTSB. Various center wing fuel tanks were found with conductive debris in the tanks, damaged FQIS wire insulation at the fuel probes, and contamination of probes and in-tank wiring by conductive copper/sulfur or silver/sulfur films. Each of these conditions can create latent potential ignition locations inside the fuel tank.

In addition, several conditions have been identified that can lead to sufficient energy in the FQIS wiring to create an ignition source if combined with one of the latent conditions described above. For example, electromagnetic coupling between systems routed together in bundles can occur. In addition, direct short circuit conditions can occur in wire bundles containing FQIS wiring. Airplanes were found with aluminum drill shavings on and inside various wire bundles in several locations between the flight deck and the fuel tank. Such shavings can, with vibration or other motion, cut through wire insulation and provide a conductive path between wires in a bundle. Service history contains records of wire bundle fires, which may have been due to such conditions. An examination of one wire bundle involved in such a fire revealed the presence of aluminum globules, presumably from molten shavings.

The manufacturer also stated that, if a failure in a wire bundle involving the FQIS were to occur, the FQIS indications would be affected and the failure would be noted and repaired. No arc would be created inside the fuel tank due to the inherently safe design of the in-tank components and wiring. The FAA does not agree. If one of the latent in-tank conditions discussed above existed on the accident airplane, the first indication of a wire bundle failure or electromagnetic interference (EMI) event outside the tank may have been ignition of the fuel vapor in the tank. In the minutes immediately preceding the in-flight breakup of the TWA Flight 800 airplane, the cockpit voice recorder indicates that the crew noticed a fuel flow indicator that was providing erratic indications. Such indications could have been due to a failure occurring in a wire bundle. The NTSB investigation determined that the fuel flow indicator wiring was routed in the same wire bundle as FQIS wiring on the TWA Flight 800 airplane.

An examination of the service history for transport category airplanes on which shielding and separation of the

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FQIS wiring from other systems have been incorporated has shown that fewer fuel tank fire/explosion events have occurred (a tabulation of transport airplane fuel tank fires was included in the FAA Notice of Request for Comments on NTSB Safety Recommendations published in the Federal Register on April 3, 1997 (62 FR 16014)). The two most recent fuel tank explosion accidents--a Boeing Model 737-300 series airplane operated by Philippine Airlines in 1990, and a Boeing Model 747-100 series airplane operated as TWA Flight 800 in 1996--remain unsolved, and both airplane types follow the wiring practices addressed by this rule.

Therefore, the FAA has determined that, to address the potential for fuel tank ignition due to a latent failure plus one subsequent failure, the type design of the Model 747 series airplane must be brought up to the same wiring standards as other transport category airplanes certificated during the same time period that the Model 747 series airplane was certificated. (Similar rulemaking has been proposed for Model 737 series airplanes. Reference Rules Docket No. 98-NM-50-AD (63 FR 38524, April 22, 1998).) No change to this final rule is necessary.

Request To Withdraw Proposed AD: Inaccurate Test Results

Four commenters state that the proposed AD should be withdrawn and the problem studied further. The commenters claim that the results of laboratory EMI testing performed by the manufacturer are not representative of actual conditions on an airplane.

These commenters further state that results of additional testing performed by the manufacturer on an airplane did not agree with the findings obtained in the laboratory, and showed much lower levels of electromagnetic coupling between the FQIS and other systems on the airplane. The FAA does not concur that the proposed AD should be withdrawn. The laboratory testing performed by the manufacturer was based on an industry-accepted procedure (FAA Advisory Circular 21-16C, ``Radio Technical Commission for Aeronautics'' Document DO-160C). The test set-up and procedure re-create a well-known electrical transient event resulting from switching of airplane electrical systems.

The industry-accepted test set-up and procedure were developed by industry with key support from the manufacturer, and were based, in part, on data provided by the manufacturer for typical switching transients on the manufacturer's airplanes.

Also, the FAA has determined that the test procedures used during the manufacturer's airplane test were not representative of all the possible conditions on an airplane in operation. The test was performed

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on an out-of-service airplane with only some of the relevant systems powered and switched. No attempt was made to represent any system failure conditions or compromised shielding/grounding provisions on the systems that were powered and switched. Also, because of the way airplane wire bundles are manufactured and installed, significant variation in levels of coupling among systems has been seen in the past and would be expected on Model 747 series airplanes.

Moreover, the FAA's determination of the existence of an unsafe condition is not wholly dependent on the results of the tests discussed above. In the FQIS system safety analysis and airplane inspections performed by the NTSB, several tank ignition scenarios were identified involving a combination of a latent failure or aging condition inside the fuel tank and a subsequent failure or electromagnetic coupling outside the tank. Various FAA and NTSB activities identified actual examples of, or the specific potential for, each of those types of contributing conditions. The FAA has proposed a separate AD action to address contributing in-tank failure or aging conditions that have been identified. [Reference Rules Docket No. 98-NM-163-AD (63 FR 39765, dated July 24, 1998).] This final rule is intended to address the out-of-tank contributing conditions that could lead to tank ignition.

By requiring ``best practices'' to be used both inside the tank (to eliminate the possibility for the creation of latent ``spark-gap'' locations in the event of high voltage on the FQIS wires) and outside the tank (to avoid introduction of ignition energy onto the FQIS wires), the FAA believes that the FQIS design of the Model 747 series airplane will meet appropriate fail-safe standards. The modified design will then provide the level of safety (i.e., tank ignition events should never occur) intended by the regulations in place at the time of original certification of the design, and the unsafe condition will be eliminated from this threat. No change to the final rule is necessary.

Request To Withdraw Proposed AD: Potential for Other Safety Problems

Seven commenters state that the proposed rule should be withdrawn and the need for the rule should be studied further. The commenters are concerned that the proposed changes may introduce other unforeseen problems onto an airplane that has an excellent safety record. The commenters are specifically concerned about transient suppression devices reducing the accuracy of the FQIS and the replacement of wiring causing damage to remaining wiring on older airplanes. These commenters also express concern that transient suppression devices could have latent failure conditions under which electrical transients would not be suppressed, and therefore would require added repetitive inspections or tests.

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The FAA does not concur that the proposed AD should be withdrawn. However, the FAA agrees with comments from the manufacturer and one of the operators that the use of transient suppression devices to perform a critical function of preventing tank ignition is new, and that the industry should be cautious in exploring that option. Therefore, the FAA is not including a requirement for the incorporation of such devices in the final rule. The FAA instead is requiring that the FQIS wiring be shielded and separated from other wiring, as explained previously. This requirement is merely a subset of those requirements specified in the proposed AD. The modified wiring configuration proposed by the manufacturer caps and stows the existing wiring and requires the new wiring to be installed as a separate bundle in most parts of the airplane. This method minimizes the disturbance of existing wiring, which reduces the likelihood that additional problems will be caused by the modification of the FQIS wiring. The FAA has revised the final rule to eliminate the proposed requirement for installation of transient suppression devices.

Request To Delay Issuance of the AD: Make Service Information Available

Two commenters, including the manufacturer of FQIS components, state that the proposed AD should not be issued until service information to accomplish the required actions is available from the manufacturer. These commenters state that the cost of the proposed rule could not be assessed accurately in the absence of service information, and that a significant portion of the proposed compliance time would be used up in the preparation of service information.

The FAA does not concur. The FAA does not consider that delaying this action until after the release of the service bulletin planned by the manufacturer is warranted because sufficient technology currently exists to devise and install the required features within the compliance time. However,

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paragraph (a) of the final rule has been revised to allow 36 months for the modification of airplanes. The extension of the compliance time afforded by this change is intended to allow sufficient time for the preparation of a manufacturer's service bulletin and for the subsequent modification of the affected airplanes during scheduled maintenance. The FAA has determined that this extension of the compliance time will not have a significant adverse effect on the safety of the fleet of Model 747 series airplanes.

At the time the NPRM was issued, the manufacturer had not prepared

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service information with specific cost information; the FAA estimated the costs based on similar modifications accomplished previously on other airplane models. The cost estimate has been revised based on information provided by the manufacturer, as discussed below.

Request To Delay Issuance of the AD Until a Meeting Is Held

One commenter states that the rule should be withdrawn or delayed until a meeting can be held among representatives of operators, manufacturers, and the FAA. The FAA does not concur. The commenter provided no technical justification for the proposed delay. As indicated previously, the compliance time has been extended from 12 months, as proposed, to 36 months in this final rule. To delay this action further would be inappropriate, since the FAA has determined that an unsafe condition exists and that affected airplanes must be modified to ensure continued safety. No change to the AD is necessary.

Request To Extend Compliance Time

Seven commenters, including the manufacturer, a vendor of transient suppression systems, and several operators, state that a longer compliance time should be allowed to allow modification of airplanes during heavy maintenance activities scheduled previously and to allow time for service information to be prepared. The manufacturer states that 18 to 24 months would be required to prepare service information.

The FAA concurs partially. Although, as explained previously, the FAA does not agree that 18 to 24 months would be required solely to prepare service information, the FAA does agree that schedule interruptions should be minimized in performing the modifications to the Model 747 series airplane fleet. The FAA has attempted to determine a compliance time that provides for the most timely modification possible without causing unnecessary schedule interruptions. As stated previously, the FAA has revised paragraph (a) of the final rule to extend the compliance time to 36 months for accomplishment of the modification. This compliance time is expected to allow sufficient time for preparation of service information, and for the affected airplanes to be modified during scheduled ``C'' or ``D'' checks.

Preference for a Specific Design Solution

Three commenters, including the manufacturer, propose no specific change to the rule, but state a preference for a particular design change to address the unsafe condition. The manufacturer states that it believes that wire separation and shielding is currently the preferable solution because of concerns about transient suppression devices

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reducing the accuracy of the fuel quantity indication and concerns about those devices having latent failure conditions under which electrical transients would not be suppressed. Another commenter, an operator, prefers that transient suppression alone be used because it would be less costly and disruptive to install. A specific technical and marketing proposal for transient suppression devices was submitted by a vendor of such devices for other types of installations.

The FAA infers that the commenters request that a particular design be required rather than offering optional methods of compliance. The FAA concurs partially. As discussed previously, the FAA agrees that wire separation and shielding provide the preferred design solution. Based on comments from the manufacturer and on its own further analysis, the FAA has determined that transient suppression devices alone may not meet the intent of the rule. The FAA has concerns that transient suppression devices may have latent failure modes that render the transient suppression function inoperative, or may have failure modes that may allow introduction of high voltage signals into the fuel tank that otherwise would not have occurred.

Based on the comments and the FAA's concerns, paragraph (a) of the final rule has been revised to eliminate the general requirement for transient suppression. Operators that have specific design changes other than those required by the AD that may provide an acceptable level of safety may request approval of an alternative method of compliance in accordance with paragraph (b) of the AD.

Request for Inclusion of Optional Method of Compliance

Three commenters suggest that the installation of a BFGoodrich Aerospace FQIS be allowed as an optional method of compliance in the proposed AD. The commenters state that the BFGoodrich system, already approved by a Supplemental Type Certificate and installed on approximately 75 airplanes, incorporates shielding and separation of the FQIS wiring from the wiring for other airplane systems.

The FAA does not concur. Until specific design data are reviewed, the FAA cannot determine whether the BFGoodrich design should be approved as an alternative method of compliance. To delay this action while the FAA reviews the BFGoodrich design would be inappropriate, since the FAA has determined that an unsafe condition exists and that affected airplanes must be modified to ensure continued safety. Interested operators may request approval of an alternative method of compliance in accordance with the provisions of paragraph (b) of the AD. No change to the final rule is necessary.

Request To Revise Cost Estimate of the Proposed AD

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Three commenters propose no specific change to the rule, but disagree with the cost estimate in the proposed rule, and offer differing specific cost estimates. One commenter, an operator, states that at least 200 work hours per airplane would be required to perform the proposed modification, and even more hours would be required if the FQIS wire routing is changed significantly. A vendor of FQIS's states that, based on its own experience retrofitting such systems in Model 747 series airplanes, 600 to 1,200 work hours per airplane would be required to perform the proposed modifications. The manufacturer states that 450 work hours and $9,000 for parts would be required to separate and shield the FQIS wiring, and that 16 to 24 work hours and $25,000 for parts would be required to install transient suppression devices.

The FAA infers that the commenters are requesting revision of the cost impact information of the AD. The FAA concurs. At the time the NPRM was issued, the manufacturer had not prepared service information with specific cost information. The FAA made an estimate of the costs based on similar modifications accomplished previously on other airplane models. The cost estimate in this final rule has been revised based on information provided by the manufacturer, and now reflects that modification of affected

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Model 747 series airplanes to install shielded FQIS wiring and to separate the FQIS wiring from other wiring is expected to require 450 work hours and $9,000 for parts.

Request for Clarification of Affected Fuel Tanks

One commenter states that the proposed AD refers only to fuel tanks and is not clear as to whether it is intended to apply to all fuel tanks or just the center wing fuel tank. The FAA concurs that clarification is necessary, and has changed the final rule to clearly indicate that it is applicable to all fuel tanks.

Clarification of Systems Affected

Since the issuance of the NPRM, the FAA recognized that the proposed AD may be unclear with respect to which electrical circuits were intended to be affected by the proposed AD. The FAA considers the FQIS wiring to include all electrical circuits associated with the control or indication of the fuel quantity on the airplane. This would include, but is not limited to, the FQIS tank probe circuits, the volumetric shutoff compensator circuits, densitometer circuits, and float switch circuits. The term ``circuits'' is considered by the FAA

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to include airplane wiring as well as wiring within components. No change to the final rule is necessary.

Clarification of Airplane Models Affected

The NPRM indicated that the airplanes affected by the proposed AD were Boeing Model 747-100, -200, and -300 series airplanes. The proposed AD was intended to apply to all Boeing Model 747 series airplanes that do not have shielded and separated FQIS wiring, including the 747SR and 747SP series airplanes. The estimate of the affected fleet size that was provided in the NPRM included those airplanes, which many, including the manufacturer, consider to be part of the Model 747-100 series. Those models are listed separately on the Model 747 Type Certificate Data Sheet. Therefore, in order to clarify that this AD does apply to those models, the final rule has been revised to list the affected airplanes as Boeing Model 747-100, -200, -300, SP, and SR series.

Conclusion

After careful review of the available data, including the comments noted above, the FAA has determined that air safety and the public interest require the adoption of the rule with the changes previously described. The FAA has determined that these changes will neither significantly increase the economic burden on any operator nor increase the scope of the AD.

Cost Impact

There are approximately 650 Model 747-100, -200, -300, SP, and SR series airplanes of the affected design in the worldwide fleet. The FAA estimates that 202 airplanes of U.S. registry will be affected by this AD, that it will take approximately 450 work hours per airplane to accomplish the required actions, and that the average labor rate is $60 per work hour. Required parts will cost approximately $9,000 per airplane. Based on these figures, the cost impact of the AD on U.S. operators is estimated to be $7,272,000, or $36,000 per airplane.

The cost impact figure discussed above is based on assumptions that no operator has yet accomplished any of the requirements of this AD action, and that no operator would accomplish those actions in the future if this AD were not adopted.

Regulatory Impact

The regulations adopted herein will not have substantial direct

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effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is determined that this final rule does not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

For the reasons discussed above, I certify that this action (1) is not a ``significant regulatory action" under Executive Order 12866; (2) is not a ``significant rule" under DOT Regulatory Policies and Procedures (44 FR 11034, February 26, 1979); and (3) will not have a significant economic impact, positive or negative, on a substantial number of small entities under the criteria of the Regulatory Flexibility Act. A final evaluation has been prepared for this action and it is contained in the Rules Docket. A copy of it may be obtained from the Rules Docket at the location provided under the caption ADDRESSES.

List of Subjects in 14 CFR Part 39

Air transportation, Aircraft, Aviation safety, Safety.

Adoption of the Amendment

Accordingly, pursuant to the authority delegated to me by the Administrator, the Federal Aviation Administration amends part 39 of the Federal Aviation Regulations (14 CFR part 39) as follows:

PART 39--AIRWORTHINESS DIRECTIVES

1. The authority citation for part 39 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701.

Sec. 39.13 [Amended]

2. Section 39.13 is amended by adding the following new airworthiness directive:

98-20-40 Boeing: Amendment 39-10808. Docket 97-NM-272-AD.

Applicability: All Model 747-100, -200, -300, -SP, and -SR series airplanes, certificated in any category.

Note 1: This AD applies to each airplane identified in the

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preceding applicability provision, regardless of whether it has been modified, altered, or repaired in the area subject to the requirements of this AD. For airplanes that have been modified, altered, or repaired so that the performance of the requirements of this AD is affected, the owner/operator must request approval for an alternative method of compliance in accordance with paragraph (b) of this AD. The request should include an assessment of the effect of the modification, alteration, or repair on the unsafe condition addressed by this AD; and, if the unsafe condition has not been eliminated, the request should include specific proposed actions to address it.

Compliance: Required as indicated, unless accomplished previously.

To prevent electrical transients induced by electromagnetic interference (EMI) or electrical short circuit conditions from causing arcing of the fuel quantity indication system (FQIS) electrical wiring or probes in the fuel tank(s), which could result in ignition of the fuel tank(s), accomplish the following:

(a) Within 36 months after the effective date of this AD, replace all of the FQIS wiring outside of the fuel tanks and surge tank with shielded wiring, and install that wiring so as to provide separation of that wiring from other airplane systems wiring, in accordance with a method approved by the Manager, Seattle Aircraft Certification Office (ACO), FAA, Transport Airplane Directorate.

(b) An alternative method of compliance or adjustment of the compliance time that provides an acceptable level of safety may be used if approved by the Manager, Seattle ACO. Operators shall submit their requests through an appropriate FAA Principal Maintenance Inspector, who may add comments and then send it to the Manager, Seattle ACO.

Note 2: Information concerning the existence of approved alternative methods of compliance with this AD, if any, may be obtained from the Seattle ACO.

(c) Special flight permits may be issued in accordance with sections 21.197 and 21.199 of the Federal Aviation Regulations (14 CFR 21.197 and 21.199) to operate the airplane to a location where the requirements of this AD can be accomplished.

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(d) This amendment becomes effective on November 4, 1998.

AD 98-20-40

Issued in Renton, Washington, on September 23, 1998.
Darrell M. Pederson,
Acting Manager, Transport Airplane Directorate, Aircraft Certification Service.
[FR Doc. 98-25972 Filed 9-29-98; 8:45 am]
BILLING CODE 4910-13-U

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U.S. Department of Transportation
Federal Aviation Administration

Transport Airplane Directorate
Aircraft Certification Service

1601 Lind Avenue S.W.
Renton, Washington 98055-4056

In Reply
Refer To: 99-130S-0292

Boeing Commercial Airplane Group
Attention: R.C. Shields, Manager, Certification
Delivery & Fleet Support
P.O. Box 3707
Seattle, WA 98124-2207

Subject: Systems Affected by Airworthiness Directive 98-20-40.

Reference: (1) Meeting on January 6, 1999, between Boeing – J. Hulm, E. Groat, K. Longwell. F. Jaques, R. Erickson, M. Conrad and FAA SACO -- J. Regimbal, D. Stanley, A. Habbestad, C. Hartonas, FAA National Resource Specialists (NRS) I. Thomas and D. Walen.
(2) 14 Code of Federal Regulations 21.99, "Required Design Changes"

Gentlemen:

The purpose of this letter is to express our concern that Boeing has not yet developed all the design data to support operators with complying with AD 98-20-40 regarding the 747 – 100/200/300/SP/SR Fuel System Wiring Separation and Shielding.

Section 21.99 of the Federal Aviation Regulations requires Boeing as the holder of the type certificate, to develop design data to address the unsafe condition identified by AD 98-20-40.

On January 6, 1999, Boeing presented preliminary design material, describing changes to be made to out-of-tank FQIS wiring installed on the airplanes. However, the design changes presented by Boeing did not address the separation and shielding of all circuits and components associated with the control or indication of the fuel quantity on the airplanes. In AD 98-20-40 the term "circuits" is considered to include airplane wiring as well as wiring within components. Boeing proposed to present design changes to indicator circuits, volumetric shutoff circuits (VSO), float switch circuits, and temperature sense circuits at a later date.

In selecting the 36 months compliance time the FAA alloted approximately 12 months after the effective date of AD 98-20-40 for design data preparation and approval (this period of 12 months is in addition to the ten months provided during the notice period, which included an extension to the comment period requested by Boeing to allow preparation of design data).

FAA LETTER, APRIL 7, 1999

Five months of the allotted 12 months remain for service data preparation and approval. We are concerned that operators will have difficulty modifying airplanes within the AD compliance time if Boeing takes longer than five more months to prepare service data to address all of the affected fuel quantity control and indication circuits.

Please submit a schedule for the completion of all design changes and coordinate a meeting with the Seattle Aircraft Certification Office to discuss the schedule before April 30, 1999.

Your prompt response will be appreciated.

Sincerely,

Alvin R. Habbestad

for Donald Riggin
Manager, Seattle Aircraft
Certification Office, ANM-100S

FAA LETTER, APRIL 7, 1999

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TELEPHONE 05 61 93 33 33
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TELEX AIRBU 530526 F

AIRBUS INDUSTRIE

DATE Blagnac, November 2nd, 1998
YOUR REFERENCE
OUR REFERENCE AI/E-fs 420.0277/98
DIRECT LINE 33.(0)5.61.93.30.52
TELECOPY 33.(0)5.61.93.44.29

Mr. Robert SWAIM

National Transportation Safety Board
490 L'Enfant Plaza East SW
Washington DC 20594-2000
U.S.A.

SUBJECT : TEMPERATURES OF CENTER WING FUEL TANK AND AIR CONDITIONING SPACES

Dear Mr. Swaim,

Further to your fax requesting information on temperatures of Center Wing Tank and Air Conditioning spaces on Airbus aircraft, the following are the answers to your questions :

1) *Temperatures of the space beneath the CWT or within the CWT*

We have no direct measurements of the temperature of the fuel and ullage space in the CWT and we have therefore used an existing thermal model of the air conditioning pack areas to predict temperatures. After the TWA 800 accident the model was further developed to provide CWT temperatures. The model has been validated with flight and ground test data and was used in the recent ARAC Fuel Tank Harmonisation activity. The results of this work are shown in attachment (a colour version will be mailed to you).

This thermal model is based on the A310 CWT/pack area configuration. We are working on results for our other aircraft but we believe the A310 results are representative of all our other aircraft types having a similar arrangement.

2) *Pack Area Ventilation and CWT Cooling*

The basic principle is to use force venting and cooling air in the pack area to minimise the ambient temperature.

.../...

AIRBUS LETTER, NOV 2, 1998

A300/A310/A319/A320/A321 use differential pressure to generate the cooling airflow.

A330 and A340 use a turbofan to boost the cooling air flow rate when the packs are operating.

All aircraft are fitted with either heat shields or vapour seals to protect the CWT from heat transfer by radiation from the hot parts of the machine and against impingement of hot air leakage. There are also monitoring systems to detect hot bleed air leaks and to isolate the defective bleed system. The A330 and A340 are fitted with monitors to detect failures of the turbofan airflow and to switch off one of the packs.

3) ***Reduce CWT Flammability through Active or Operational Means***

The direct ventilation system is operational in flight and on the ground when ever the air conditioning pack is active. Cooling the lower skin of the CWT helps to reduce the fuel flammability exposure time of the AIRBUS fleet, currently our analysis on the A310 indicates an average of about 4 %. This is significantly better than the ARAC FTHWG recommendation of 7 %.

4) ***Protection of Fuel Tank Wiring from Short Circuits or Induced Energy***

The design aim for AIRBUS aircraft has been for all in-tank wiring to be segregated from power sources. As such electrical segregation exists on all aircraft together with physical segregation from 115 volt power wiring. We have found an exception with some fuel level sense wiring in A300 and A310 where wiring runs locally in the same routes as 115 volt wiring. This point is under review with the JAA. It is worth noting that one would need to have failures of the insulation of both level sense and power cables and for the wires to touch before starting to generate heat in the sensor.

It is important to note that AIRBUS aircraft do not have high-energy fuel pump wiring routed inside fuel tanks. On all our aircraft types the fuel pump wiring is routed outside of the wing box. The pumps are also protected from over heating by thermal fuses, which limit the surface temperatures to 200°C, which is below the fuel auto-ignition temperature.
The only wiring routed inside fuel tanks is for specific fuel gauging and level sensing components and all such circuits are energy limited to below the fuel ignition conditions as defined for the aircraft certification. Equipment such as valves and pressure switches are a two-part design with the electrical part outside the tank and separated from fuel by a barrier seal.

…/…

AIRBUS LETTER, NOV 2, 1998

5) ***Wire Insulation and Shielding***

The majority of the wiring in AIRBUS aircraft uses a double layer of Polyimide or a combination of Polyimide and PTFE as insulation. The Polyimide insulated wire is used in benign environmental areas and the Polyimide/PTFE insulation in areas subject to more severe environments.
Wiring within wings is shielded by metal conduits or metal troughs.

I hope this information is helpful.

Yours sincerely,

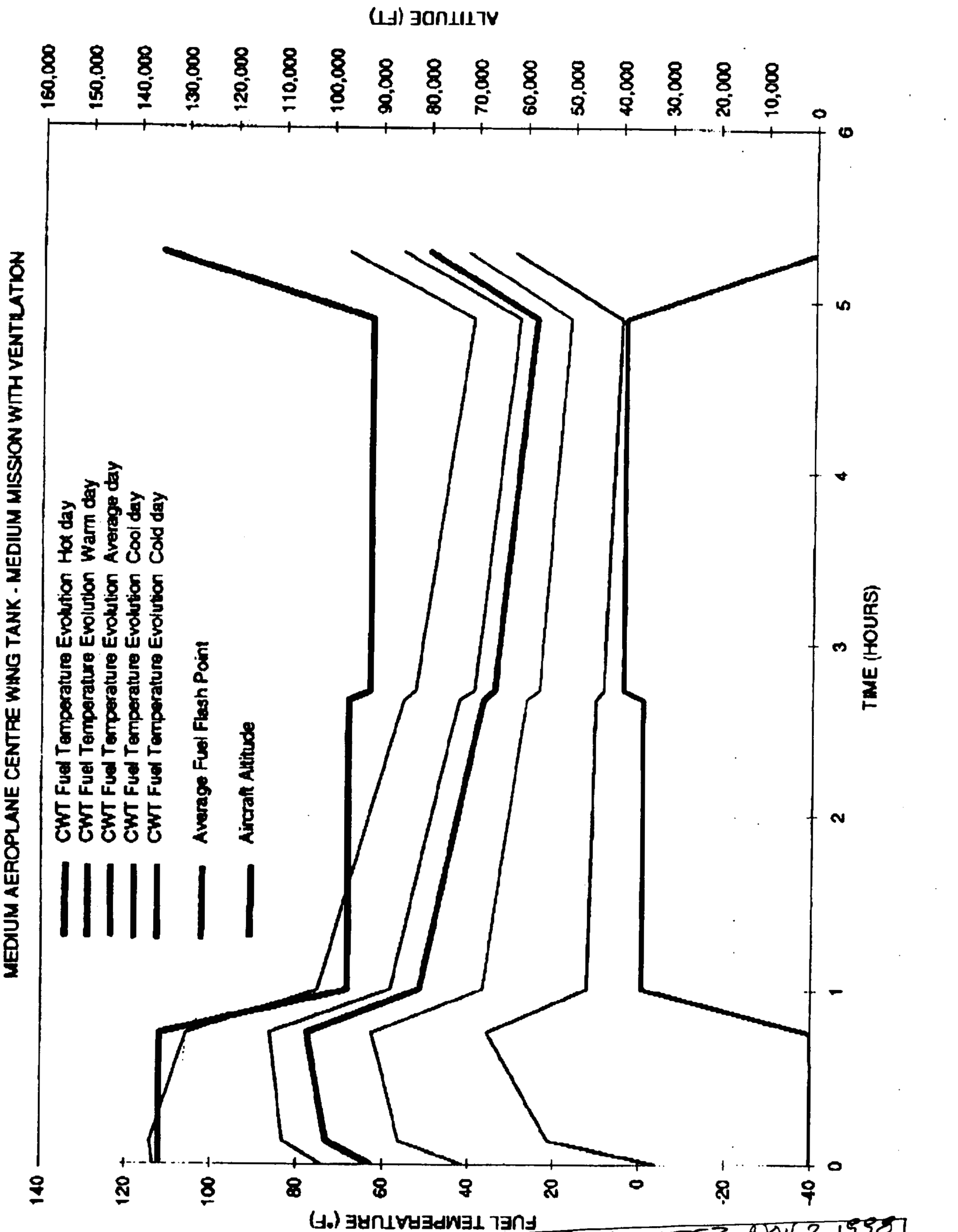
pp.

Yves BENOIST
Director Flight Safety

Copy

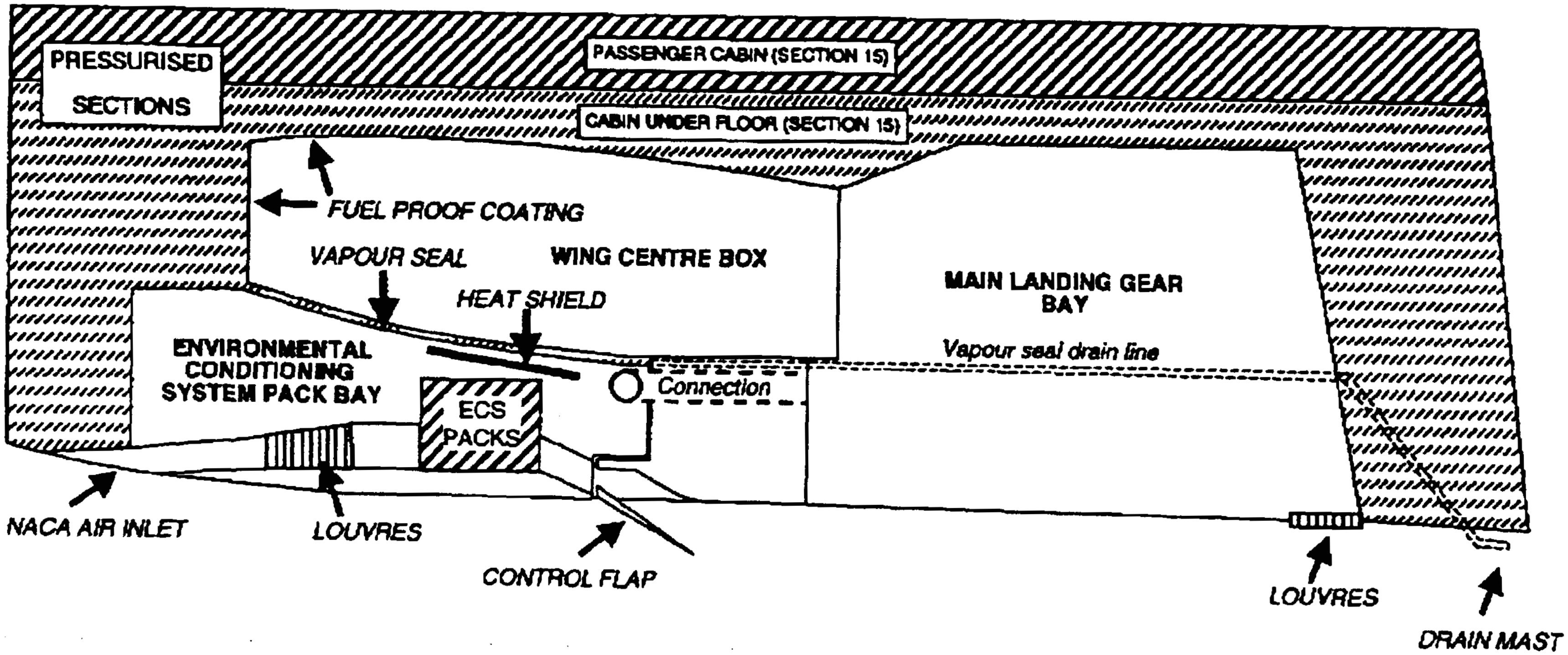
Bureau Enquêtes Accidents   Mr. P.L. ARSLANIAN

AIRBUS LETTER, NOV 2, 1998



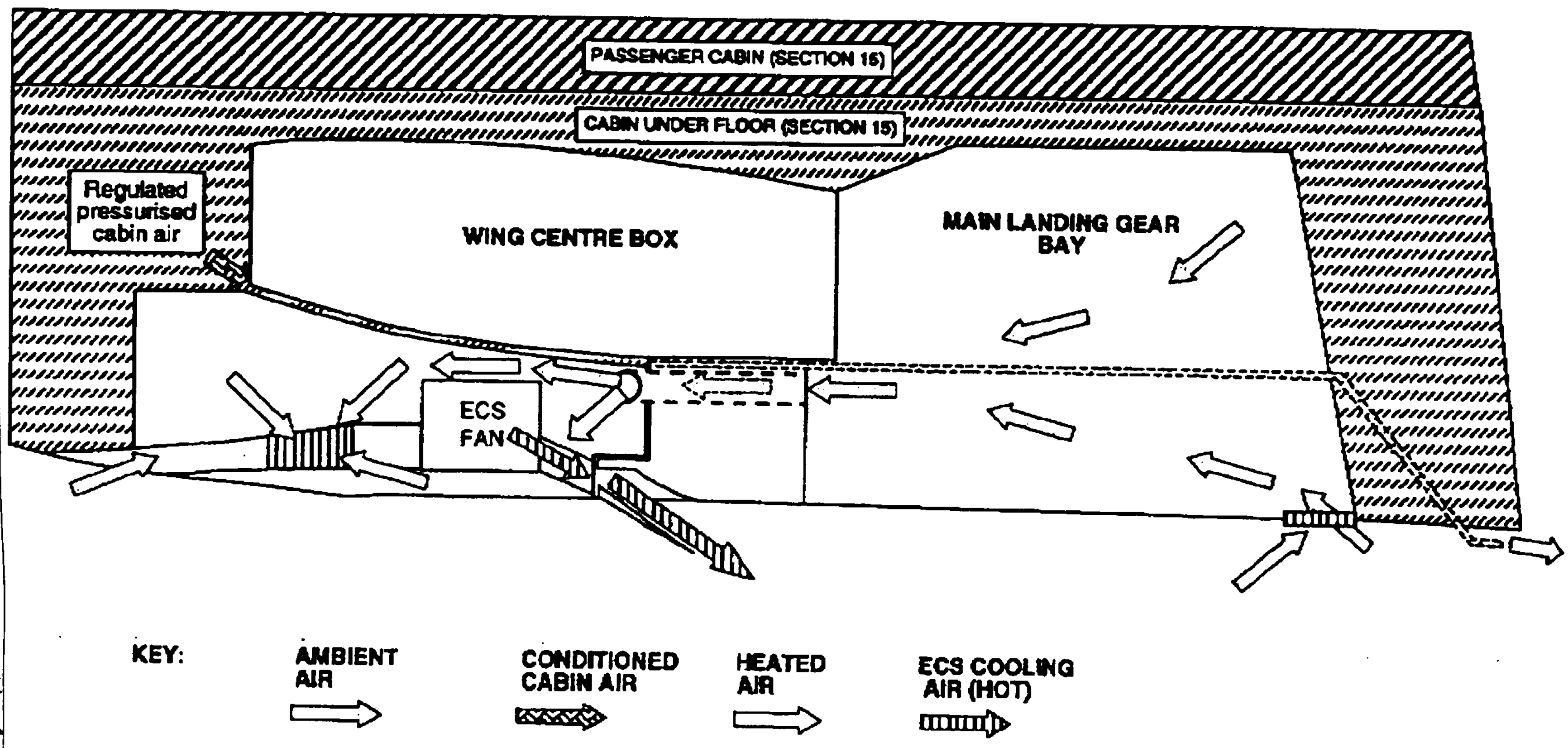
AIRBUS LETTER, NOV 2, 1998

Typical AIB ECS Pack Bay and Centre Wing Tank **INSTALLATION**



AIRBUS LETTER, NOV 2, 1998

Typical AIB ECS Pack Bay and Centre Wing Tank **GROUND VENTILLATION**



AIRBUS LETTER, NOV 2, 1988

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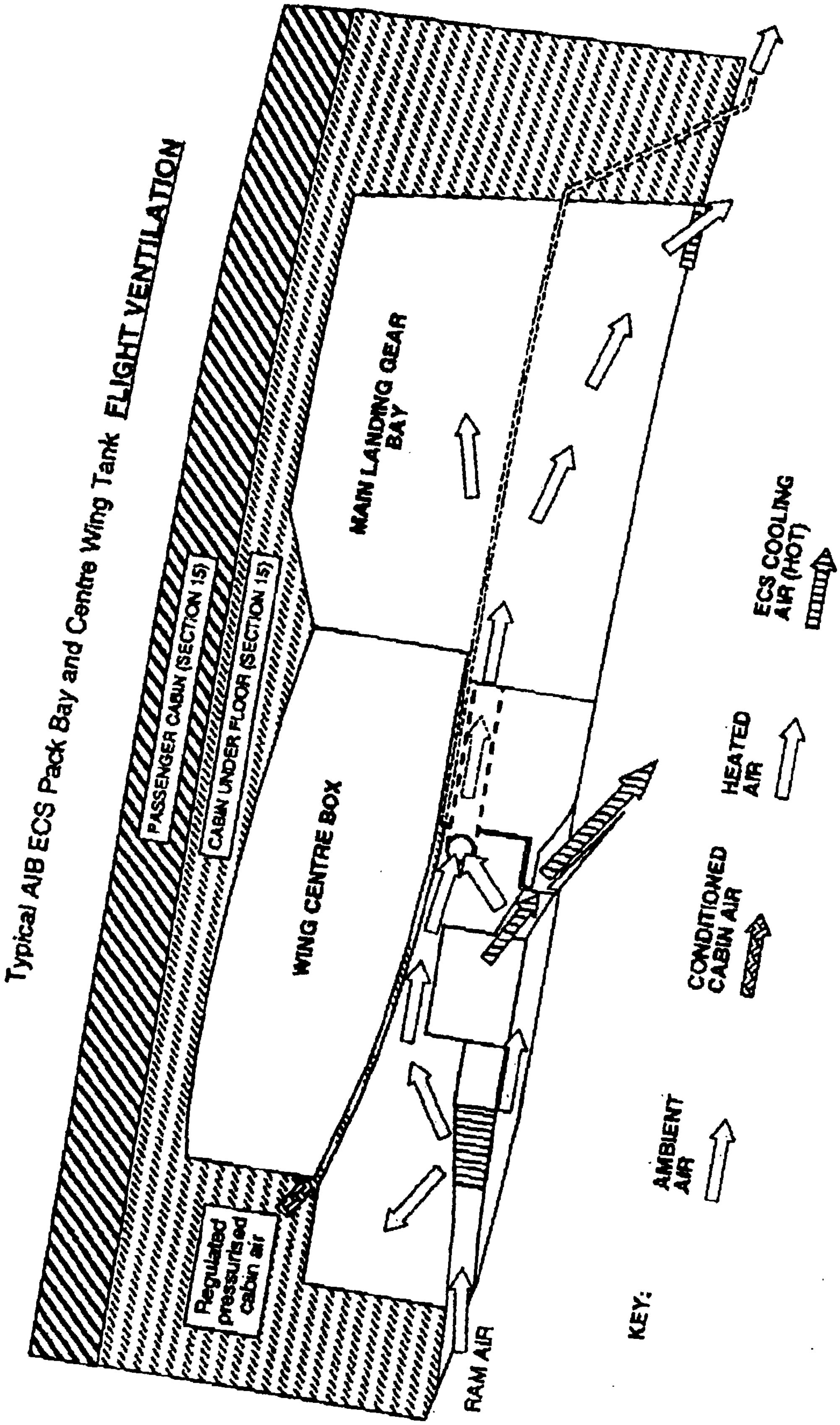
03/11/98 17:17 Pg: 7/7



AIRBUS LETTER, NOV 2, 1998

Ronald J. Hinderberger
Director
Airplane Safety
Commercial Airplanes Group

The Boeing Company
P O Box 3707 MC 67-XK
Seattle, WA 98124-2207

25 May 1999
B-H200-16698 -ASI

BOEING

Mr. R. Swaim, AS-40
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington DC 20594

Subject: Wire Separation Guidelines, TWA 747-100, N93119 Accident off Long Island, NY - 17 July 1996

Dear Mr. Swaim:

Following is in response to your question regarding how Boeing established the ¼-inch wire separation guidelines.

The operation of the airplane in all its phases on the ground and in the air depends on various airplane systems. These in turn depend on the airplane interconnecting wiring. The airplane wiring design and installation must incorporate appropriate measures to minimize the effect of the electrical wiring faults, and to isolate fault damage and prevent propagation of failures between redundant systems.

To achieve these requirements, in 1969, 1970, and during the 747 airplane design and certification program, Boeing conducted a series of tests. These tests included laboratory evaluations to determine the minimum wire bundle free air space necessary to achieve wire fault propagation protection.

These tests were performed on various types of wire and cable used on Boeing airplanes. The results of these tests showed that wire bundles which are separated by minimum ¼-inch air space from the failed wire bundle will not sustain damage that compromises the electrical integrity of the wire bundle. The wire under test passed the 1500 volts dry dielectric withstand voltage test.

In the late 1980, the ¼-inch air space separation was further validated with a series of testing on different types of wire insulation which are currently used on Boeing aircraft. These tests included both the overload protection and short circuit protection. At the completion of these tests, the wires were subjected to

BOEING LETTER OF MAY 25, 1999

a 1500 volts dry dielectric withstand voltage test. In all cases the electrical integrity of the wire under test was maintained.

If you have any questions, please do not hesitate to call.

Very truly yours,

BOEING

Ronald J. Hinderberger
Director, Airplane Safety
Org. B-H200, M/S 67-PR
Telex 32-9430, STA DIR AS
Phone (425) 237-8525
Fax (425) 237-8188

cc: Mr. A. Dickinson, IIC

BOEING LETTER OF MAY 25, 1999

Ronald J. Hinderberger
Director
Airplane Safety
Commercial Airplanes Group

The Boeing Company
P.O. Box 3707 MC 67-XK
Seattle, WA 98124-2207

BOEING

12 October, 1999
B-H200-16786 -ASI

Mr. R. Swaim, AS-40
National Transportation Safety Board
490 L'Enfant Plaza East, S.W.
Washington DC 20594

Subject: Surge Suppressor, TWA 747-100, N93119 Accident off Long Island, N.Y. – 17 July 1996

Dear Mr. Swaim:

During one of the lab activities at Wright Patterson you requested information on surge suppressor development and the status of that activity.

In the FAA's NPRM for Wire Separation/Transient Suppression, the focus was on the airplane wiring. Boeing commented on both wire separation/shielding and transient suppression. The thrust of the Boeing comment on the NPRM with regards to transient suppression was intended to ensure that adequate time was allowed to develop, test and certify a new device of this type. The fuel quantity systems on Boeing airplanes are sensitive and perform an essential aircraft function. Modification of the system must not be unnecessarily rushed. Due to time and resource constraints, and the necessity to comply with the aggressive schedule being set by the FAA, Boeing chose to pursue wire separation due to the seemingly low risk nature of the modification. It was never Boeing's intention in our NRPM response to discourage the use of transient suppression devices.

After the 737 and 747 Classic NPRM's for Wire Separation/Transient Suppression were released, and Boeing had decided to pursue the mandated wire separation, Boeing approached the three affected FQIS suppliers, Honeywell, Smiths Industries and BF Goodrich, about their intentions with regards to a transient suppression device (TSD) for their FQIS's on Boeing aircraft.

Honeywell declined to develop a TSD for their 747 Classic FQIS for technical and business reasons. Smiths Industries stated that they would be developing a TSD for both their 737 and 747 Classic digital FQIS's. BFGoodrich stated that they would be developing a TSD for their 737 Classic digital FQIS's, but not their analog FQIS.

BOEING LETTER OF OCTOBER 12, 1999

BOEING

Since then, Boeing has been in regular contact with both BFGoodrich and Smiths Industries. Boeing has provided technical information to both suppliers regarding the mechanical and electrical interface data requested. Several technical reviews have also been held over the last several months with both companies. In addition, numerous telecons have been conducted to review any issues and status action items. Boeing has also made available to one of the suppliers our mockup of the 747 FQIS in our Fuels lab, which was utilized, for prototype TSD testing. Also, Boeing has had the opportunity to be present during some of the presentations made by the suppliers to the FAA in order to lend support to the supplier and the FAA in evaluating their TSD programs.

Through these regular meetings and contacts with both suppliers, Boeing has assessed the designs of the TSD's being developed and the program commitments and schedules to which each supplier has performed. The design and architecture of these TSD's will accomplish the function of preventing excessive energy from getting into the fuel tank. The modifications necessary to install these devices into the airplane are minimal. These TSD's will provide the airlines a cost effective and timely solution in complying with the associated AD's once the FAA provides approval of the STC's for their installation.

Also, at the request of our customers, Boeing is presently evaluating developing service bulletins which would reference the supplier STC's (once they are FAA approved) for the installation of their TSD's. Boeing is presently in discussions with the FAA on the process and plan for accomplishing this.

If you have any questions, please do not hesitate to call.

Very truly yours,

for Ronald J. Hinderberger
Director, Airplane Safety
Org. B-H200, MC 67-PR
Telex 32-9430, STA DIR AS
Phone (425) 237-8525
Fax (425) 237-8188

cc: Mr. A. Dickinson, IIC

BOEING LETTER OF OCTOBER 12, 1999

Ronald J. Hinderberger
Director
Airplane Safety
Commercial Airplanes Group

The Boeing Company
P.O. Box 3707 MC 67-XK
Seattle, WA 98124-2207

BOEING

10 January, 2000
B-H200-16802-ASI

Dr. Bernard S. Loeb, AS-1
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington DC 20594

Subject: Recommendation A-98-34, TWA 747-100 N93119, Accident off Long Island, NY -- 17 July 1996

Reference: (a) B-H200-16798-ASI, Dated 22 Oct 1999
(b) Meeting NTSB/Boeing Sep 23, 1999

Dear Dr. Loeb:

In the reference (a) letter, item 2, the NTSB requested that we provide a letter outlining Boeing's position on each of the recommendations coming out of the subject accident investigation.

At the reference (b) meeting Boeing presented comments to the NTSB Open Recommendation A-98-34. The purpose of this letter is to provide a fuller response than what was shown in summary during the meeting presentation.

The NTSB Recommendation A-98-34 recommends action be taken to inspect, replace and repair FQIS in-tank wiring and probes on 747 Classic airplanes. The exact wording of the recommendation is as follows:

"Issue, as soon as possible, an airworthiness directive to require a detailed inspection of fuel quantity indication system wiring in Boeing 747-100, -200, and -300 series airplane fuel tanks for damage, and the replacement or the repair of any wires found to be damaged. Wires on Honeywell Series 1-3 probes and compensators should be removed for examination. (A-98-34)."

In response to this recommendation, Boeing has taken the following actions that we believe directly and adequately address the issues noted in the NTSB Recommendation:

A. Boeing issued Service Bulletin (SB) 747-28-2205 (currently at Revision 2 issued March 11, 1999). This SB does contain instructions to the operators for the inspection of in-tank FQIS wiring. Subsequently, the FAA has released Airworthiness Directive 99-08-02 that requires the complete inspection instructions of SB 747-28-2205 to be accomplished. This AD was issued May 11, 1999 with a two year compliance period.

BOEING LETTER OF JANUARY 10, 2000

From the voluntary information provided to Boeing by the airlines, our records show that approximately 437 747 airplanes have had the Service Bulletin inspection accomplished. This represents approximately 39% of the world wide 747 fleet and 42% of the U.S. registered 747 fleet.

BOEING

B. Boeing also issued Service Bulletin 747-28A2208 on May 14, 1998 (presently at Revision 1, dated August 26, 1999). This Service Bulletin provides instructions to remove and replace those fuel quantity probes and compensators that have the knurled surface terminal block. The SB further specifies that any wiring that was attached to such a probe or compensator is to be replaced. This can be accomplished either through the re-termination of the existing wiring or replacing the affected wire bundle.

The SB also requires that all wiring attached to any terminal block on probes or compensators are to be rerouted as shown in the SB. The routing shown in the SB ensures that there is no inadvertent contact of the wiring to the edges of the terminal block, eliminates any excessive routing of wiring through the clamp on the terminal block to prevent compression damage and provides improved separation between the mutually insulated Hi-Z, Lo-Z and Hi-Z shield wires.

The SB also specifies that all the wiring and components in the center fuel tank are to be inspected. Although the SB does not require the removal of all clamps retaining the wiring to inspect for damage under the clamps, it is Boeing's belief that the SB addresses the area of concern most noted by the NTSB, that is, the wiring at the terminal blocks.

Lastly, SB 747-28A2208 provides instructions to perform a low level insulation resistance (IR) test of the FQIS center tank wiring from the Flight Deck to the center fuel tank. The purpose of this test is to determine if there is any significant compromise in the insulation of the FQIS wiring. The test checks the IR between the Lo-Z, Hi-Z and Hi-Z Shield wire and each wire to ground.

The FAA has issued AD 99-08-02, that, amongst other things, requires the accomplishment of SB 747-28A2208. The AD was issued May 11, 1999 with a 24 month compliance period.

To date Boeing has received voluntary reports on 72 airplanes owned by 7 operators that have accomplished SB 747-28A2208. The data provided by these operators indicates that the intent of the SB is being met, i.e. that the knurled surface terminal blocks are being removed and replaced with terminal blocks that do not have the knurled surface, that the FQIS wiring is being inspected and replaced/re-terminated as required, that the wiring at

BOEING LETTER OF JANUARY 10, 2000

the terminal block is being repositioned and that the insulation resistance tests are being conducted.

C. Boeing removed, inspected and tested two full shipsets of 747 Classic FQIS wiring and components. The NTSB has received the reports that describe all analyses, tests and inspections that were performed on the removed wiring and components. In summary, the results showed that damage to wiring was insignificant and was mainly related to removal of the wiring from the airplane for this study. Sulfide contamination was evident on the Hi-Z wiring near the terminal blocks, but test results showed the dielectric strength of the wiring had not been compromised to a point to be considered hazardous. There was some evidence of degradation of the Hi-Z ground shield under the terminal block, but again, the dielectric strength of the probe had not been compromised to a point to be considered hazardous.

BOEING

Please advise whether the NTSB believes the actions taken and described above do not satisfy the intent of the recommendation.

If you have any questions, please do not hesitate to call.

Very truly yours,

for

Ronald J. Hinderberger
Director, Airplane Safety
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CC: Mr. B. Berman, AS-10
Mr. A. Dickinson, IIC
Mr. T. Haueter
Mr. J. Drake
Dr. M. Birky
Dr. J. Kolly
Mr. R. Swaim
Mr. D. Campbell

BOEING LETTER OF JANUARY 10, 2000

Swaim Bob

From: Slenski George A Civ AFRL/MLSA [George.Slenski@ml.afrl.af.mil]
Sent: Thursday, May 06, 1999 2:01 PM
To: 'Swaim Bob'; 'Emmerling, Bill'; Gonsiska Allen ASC/ENFS; Hart Dale L Contractor AFRL/MLSA; Johnson David H Civ AFRL/MLSA; Rodriguez Beatriz C ASC/ENFA; Zentner John C ASC/ENAI; Slenski George A Civ AFRL/MLSA; 'Stewart Miller'; Welch John S ASC/ENAE
Subject: Issues related to fuel probe wiring and electrical distribution p anels

I thought some of you would be interested in what I presented at the SAE AE-8A committee meeting on Electrical Wiring and Optic Interconnect Systems Installation last week (29 April 99):

Analysis of fuel tank wiring and other components suggests silver-plated wiring should not be used in areas where fuel is present. A corrosion reaction has been noted that can electrically degrade connections and create conductive residues. The residues can lower the resistance between normally isolated areas. Another related issue is mixing power wiring with fuel quality measurement or fuel probe wiring. There is a scenario where wires carrying both power and fuel probe wiring can short together and inject sufficient energy through the fuel probe wiring to ignite vapors in a fuel tank.

Several recent aircraft mishaps involving smoke in the cockpit have been attributed to printed wiring board electrical fires. A presentation that discusses the problem was given.

After a brief discussion, the committee decided to immediately add a paragraph concerning fuel probe wiring and separation of electrical distribution systems. The following paragraphs were voted on and approved for incorporation into the referenced specifications. The issue of silver plated wiring in fuel tanks will be discussed at the next meeting in Oct 99.

For AS50881, Aerospace Vehicle Wiring (procurement document used to specify aerospace wiring, replaces MIL-W-5088):

3.10.12.3 Fuel probe wiring shall be physically separated throughout its entire length including connectors, terminations and junction boxes.

For ARP4404,Aircraft Electrical Systems (Guidance document for design of aerospace vehicle electrical systems):

4.1.3.3--Add fuel probe systems to critical circuits' list and reference AS 50881 paragraph 3.10.12.3

6.3--Wiring should be installed and interconnected so that operation of any one unit, or system of units, will not adversely affect simultaneous operation of any other electrical unit or system essential to safe operation

George A. Slenski
AFRL/MLSA, 2179 Twelfth St., Rm122
WPAFB, OH 45433-7718
Tel: (937) 656-9147 Fax: (937) 656-4600
email: george.slenski@afrl.af.mil

SAE WIRING SEPARATION

Swaim Bob

From: Swaim Bob
Sent: Wednesday, July 28, 1999 8:35 AM
To: 'Slenski George A Civ AFRL/MLSA'
Subject: RE: Wire separation

From: Slenski George A Civ AFRL/MLSA
[mailto:George.Slenski@ml.afrl.af.mil]
Sent: Tuesday, July 27, 1999 2:29 PM
To: 'Swaim Bob'
Subject: Wire separation

Bob, I can show you examples of wire chafing, the documents we reference are MIL-W-5088 and the new SAE industry consensus documents (which Boeing supports). Most documents just require physical separation with an attempt to move the wire bundle to ensure it can't touch another critical circuit or structural component. I can't find my 5088 document but here are quotes from SAE documents:

SAE ARD50055 (draft) only reference to distance is par.. 143.c and d. c. is separation from movable controls 0.5 inch
d. Flammable fluids and gasses, minimum 0.5 inch separation, Other par.. mentions shielding and clamping

SAE version of MIL-W-5088, AS50881A par.. 3.10.12 requires separation par. 3.11.4 anti chafing separation of at least 0.375 inches, if not maintained then additional protection is required.

George A. Slenski
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email: george.slenski@afrl.af.mil

AFRL EMAIL JULY 28, 1999

AGING AIRCRAFT SYSTEMS

MIL-HDBK-1530

RAND TESTIMONY

USAF/RAND PROJECT

DOT WHCSS SUMMARY

COMMISSION

FAA AGING SYSTEMS PLAN

FAA PROGRESS

USAF LETTER OF SEPT 10, 1999

NOT MEASUREMENT SENSITIVE

MIL-HDBK-1530
31 OCTOBER 1996
SUPERSEDING
MIL-STD-1530A(11)
11 DECEMBER 1975

DEPARTMENT OF DEFENSE HANDBOOK

AIRCRAFT STRUCTURAL INTEGRITY PROGRAM GENERAL GUIDELINES FOR

THIS HANDBOOK IS FOR GUIDANCE ONLY. DO NOT CITE THIS DOCUMENT AS A REQUIREMENT

AMSC: N/A

FSC 15GP

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

(Copies of TRs are available from National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield VA 22161.)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the latest issue of the DoDISS, and supplement thereto.

MCIC-HDBK-01	Damage Tolerance Design Handbook

(Copies are available from Metals and Ceramics Information Center, Battelle Memorial Institute, 505 King Avenue, Columbus OH 43201-2681.)

RP #7	Society of Allied Weight Engineers

(Copies are available from Society of Allied Weight Engineers, P O Box 60024, Terminal Annex, Los Angeles CA 90060-0024.)

2.4 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Damage tolerance. Damage tolerance is the attribute of a structure that permits it to retain its required residual strength for a period of unrepaired usage after the structure has sustained described levels of fatigue, corrosion, and accidental or discrete source damage such as (a) unstable propagation of fatigue cracks, (b) unstable propagation of initial or service induced damage, and/or (c) impact damage from a discrete source.

3.2 Design service goal. The design service goal is the period of time (in flight cycles/hours) established at design during which the structure will be reasonable free from significant structural degradation.

3.3 Durability. The ability of the airframe to resist cracking (including stress corrosion and hydrogen induced cracking), corrosion, thermal degradation, delamination, wear, and the effects of foreign object damage for a described period of time.

3.4 Economic life. The operational service period during which there is no significant departure from the cost burden associated with the Force Structural Maintenance Plan for a newly manufactured aircraft, based on an evaluation of data developed during full scale development. The economic life is indicated by the results of the durability test program, i.e., test performance interpretation and evaluation in accordance JSGS-87221. The economic life should be evaluated with the incorporation of Air Force approved and committed production or retrofit changes and the supporting application of the force structural inspection and maintenance documentation in accordance with this handbook. In general, production or retrofit changes will be incorporated to correct local design and manufacturing deficiencies disclosed by test. It will be assumed that the economic life of the test article has been attained with the occurrence of fatigue cracking which could be uneconomical to repair and, if not repaired, could cause functional problems affecting operational readiness. This may sometimes be characterized by a rapid increase in the number of damage locations or repair costs as a function of cyclic test time.

b. Minimize the probability of loss of the aircraft due to propagation of undetected cracks, flaws, or other damage.

c. Minimize cracking (including stress corrosion and hydrogen induced cracking), corrosion, delamination, wear, and the effects of foreign object damage.

Damage tolerance design approaches should be used to ensure structural safety since undetected flaws or damage can exist in critical structural components despite the design, fabrication, and inspection efforts expended to eliminate their occurrence. Durability structural design approaches should be used to achieve Air Force weapon and support systems with low in-service maintenance costs and meet operational readiness throughout the design service goal.

5.1.2.1.1 Damage tolerance. The damage tolerance design guidance is provided in JSGS-87221 and should be applied to the principal structural elements and mission essential structure. Damage tolerance designs are categorized into two general concepts:

a. Fail-safe concepts where unstable crack propagation is locally contained through the use of multiple load paths or crack arrest structures in multiple load path structures.

b. Slow crack growth concepts where flaws or defects are not allowed to attain the size required for unstable rapid propagation in single load path structures.

Either design concept should assume the presence of undetected flaws or damage, and should have a described residual strength level both during and at the end of a described period of unrepaired service usage. The initial damage size assumptions, damage growth limits, residual strength requirements, and the minimum periods of unrepaired service usage depend on the type of structure and the appropriate inspectability level.

5.1.2.1.2 Durability. The durability design guidelines are provided in JSGS-87221. The airframe should be designed such that the economic life is greater by the desired margin than the design service goal when subjected to the design service loads/environment spectrum. The design service goal and typical design usage requirements will be described by the Air Force in the contract specifications for each new aircraft. The design objective is to minimize cracking or other structural or material degradation which could result in excessive maintenance problems or functional problems such as fuel leakage, loss of control effectiveness, or loss of cabin pressure.

5.1.2.1.3 Corrosion control and prevention. Corrosion control and prevention guidelines are provided in JSGS-87221, AF Policy Directive 21-1, and AF Instruction 21-105. The goals are to control the maintenance cost burden associated with corrosion and ensure that it does not cause a safety of flight problem. These goals are attainable if corrosion control and prevention are addressed early in design. Materials and processes, finishes, coatings, and films that have been proven in service or by comparative testing in the laboratory should be the basis for choices to meet the goals. Corrosion prevention should also be a primary consideration in the development and implementation of the durability and damage tolerance control process and the fleet management process.

5.1.2.2 Battle damage criteria. Where applicable, specific battle damage criteria will be provided by the Air Force. These criteria will include the threat, flight conditions, and load carrying capability and duration after damage is imposed, etc. The structure should be designed to these criteria and to other criteria as described in JSGS-87221.

5.1.2.3 Repairability. Repairability must be designed into the aircraft from the beginning and must be a design influence throughout the design process. Repairability is required to support production, maintain the fleet, and maximize operational readiness by repairing battle damage. High or moderate to assess the economic impact of bringing the aircraft into the Air Force inventory. If the certification basis is considered adequate, then the compliance with the Air Force structural performance requirements for the candidate aircraft is evaluated. This effort should examine the differences between the structural design criteria of the candidate aircraft and the Air Force structural design criteria. Each aspect of the criteria that affects the vibration, acoustic, flutter, load, strength, fatigue, and damage tolerance capability of the aircraft should be examined. For example, the candidate aircraft may have been designed to a limit load factor of 3.5 and the Air Force operations dictate the need for a limit load factor of 4.5. This indicates a deficiency in strength and possibly in durability and damage tolerance capability. An incompatibility in the velocity/altitude boundary requirements may indicate a deficiency in the flutter margins. If the structural performance requirements for the aircraft are not compatible with the design of the candidate aircraft, then the aircraft is subjected to a technical assessment. If it is compatible, then the candidate aircraft is assessed against the service life goals, missions, and usage that are desired. If the candidate aircraft is not compatible with the desired service goals, missions, and usage, then it goes to the technical assessment. If it is compatible, then the candidate aircraft service history is examined. For this task the maintenance program for the candidate aircraft and its operational history would be assessed. Also, it should be determined if it has adequate past and continuing operational experience to ensure that any potential economic issue with the aircraft has been revealed and that any potential safety issue will be revealed before it occurs on a USAF aircraft. If there is adequate service history, then the aircraft should be expected to meet the structural requirements, and the evaluation would be complete. If it is judged that there is not an adequate service history, then it should be subjected to a technical assessment.

A.1.4 Additional analyses. If the aircraft can not meet the requirements from A.1.2., then suitable additional analyses should be performed in an in-house technical assessment to ensure that any potential economic or safety problem is revealed. In many cases, FAR Part 25 aircraft have been subjected to a damage tolerance assessment as part of the FAA requirements for a Supplementary Structural Inspection Document (SSID). In these cases, this damage tolerance assessment can be modified by the contractor to evaluate the impact of usage changes. The in-house assessment should be based on information from the contractor. Typically, this information is more easily obtained during on-site visits to the contractor facility. This information should include information on design configuration and design usage, loads, stresses, tests, corrosion protection systems, and service experience.

A.1.5 Risk assessment. In the event that the in-house assessment reveals that the candidate aircraft has significant deficiencies or an inadequate data base exists then the results are referred back to the program manager with an assessment of the associated risks so that a decision can be made to either reject the candidate aircraft or define further efforts. If the in-house assessment of the candidate aircraft shows that it can meet the desired objectives, then that information is given to the program manager.

A.1.6 New or modified structure. For new or extensively modified structure, the engineering and manufacturing structural development and qualification guidance in this document are appropriate for this structure. This describes the level of effort, design analyses, and testing required regardless of who certifies the new or modified structure. An in-house structural assessment of the magnitude of the structural modification can be conducted to further clarify the required level of design effort, analyses, and testing.

A.1.7 Airframe condition. Particularly difficult structural integrity problems often accompany the procurement of aging, off-the-shelf aircraft. In the marketplace there are many used aircraft that may be purchased far below the price of a new off-the-shelf aircraft. The reasons for the low price on these aircraft may be that they have flown beyond their design service goal, they have corrosion problems, they have widespread fatigue problems, they have numerous repairs (many of which are not damage tolerant), or any combination of these reasons. That is, they generally possess all of the ingredients to be classified as aging aircraft. Unfortunately, many of these problems can be hidden from view and the aircraft may appear to be airworthy. Experience has shown that significant problems do exist and the cost of refurbishing these aircraft is considerably above original expectations.

ADDITIONAL GUIDANCE FOR AGING AIRCRAFT

B.1 Aging Aircraft. For a new aircraft the development of the Force Structural Maintenance Plan (FSMP) in Task IV provides the basis for the maintenance costs that are expected to be incurred for the aircraft during its design service goal. When the FSMP needs to be changed because the aircraft 1. has overflown its design service goal, 2. is corroded, 3. has reached the time of onset of widespread fatigue damage (WFD), or 4. has been repaired, then the aircraft is said to be aging.

B.1.1 Operations beyond the design service goal of the aircraft. If the aircraft has flown or is expected to be flown beyond its design service lifetime, the service inspection program should be updated to include necessary additional structural locations and/or inspection intervals to assure structural integrity. This is accomplished through a damage tolerance assessment to search for new structural areas that may need to be inspected or modified. This would include a review of inspection results from operational aircraft and a review of findings from previous durability testing. If an aircraft can be removed from operational service, then a teardown inspection should be performed to determine if there are any fatigue cracking or corrosion problems that were not predicted earlier through design and test.

B.1.2 Corrosion. Inspections of individual aircraft should be accomplished to ascertain condition of the airframes with respect to corrosion. Emphasis should be placed on corrosion detection through nondestructive inspections and prevention. For those areas found to be corroded, the preferred approach is to eliminate the corrosion by removing it or replacing the structural elements in question. In some rare cases this may not be feasible because of near term operational requirements. In these cases an assessment should be accomplished to determine the change in the inspection program that will account for the influence of corrosion on structural integrity.

B.1.3 Widespread fatigue damage. An initial prediction of the time of onset of WFD should be made based on the results from the durability test, aircraft inspections, and usage tracking. Before the predicted time of the onset of WFD, a teardown inspection of a high time aircraft needs to be accomplished to validate the crack distribution function. This refined distribution should be used to recalculate the time of onset of WFD. Before operational aircraft reach this time, a detailed nondestructive inspection program is needed to validate the prediction. When the aircraft has reached the time of onset of WFD, then it should be modified to remove the problem since routine inspections are inadequate to protect flight safety

B.1.4 Repairs. Both metallic and composite repairs should be designed to be damage tolerant in addition to satisfying the strength and aeroelastic requirements. Further, they should be added to the FSMP so that they can be properly tracked to determine the inspection times. Further, the data base for the aircraft needs to be established such that there is configuration control of the repairs. Any interaction of repairs should be taken into consideration in the damage tolerance assessment of them.

T E S T I M O N Y

RAND

Aging Aircraft: Implications for Programmed Depot Maintenance and Engine-Support Costs

Raymond Pyles

CT-149

February 1999

Project AIR FORCE

The RAND testimony series contains the statements of RAND staff members as prepared for delivery.

RAND TESTIMONY

STATEMENT OF DR. RAYMOND A. PYLES
BEFORE THE PROCUREMENT SUBCOMMITTEE OF THE
HOUSE ARMED SERVICES COMMITTEE

24 February 1999

I would like to thank the members of the Procurement Subcommittee for the opportunity to discuss the increasing age of the Air Force's aircraft fleet and the implications for future readiness and cost. I am fortunate to be joined today by my colleagues, Dr. Laura Baldwin, Dr. Jean Gebman, and Mr. Hyman Shulman, each of whom made important contributions to this study.

RAND Project AIR FORCE's long-term interest in the topic of aging aircraft was rekindled in 1994, when we participated in the Air Force Scientific Advisory Board Summer Study [1] that raised technical concerns about the viability of retaining certain aircraft past their original design lives. In 1997, the National Research Council's report [2] on aging USAF aircraft reinforced those concerns. At that time, we initiated a modest Air Force-sponsored research effort focused on emerging technical challenges for aircraft maintenance activities. Last summer we built on that technical background to examine the potential effects that aging aircraft would have on the costs of programmed depot maintenance (PDM) and engine support. The results of that work are documented in the annotated briefing [3] that has been made available to the subcommittee. This year, we have broadened our review to cover other support and modernization activities where aircraft age may affect costs and readiness.

SUPPORT COSTS WILL GROW IF CURRENT TRENDS CONTINUE

As one of several efforts to control costs in the face of both higher unit prices for aircraft and constrained military budgets, the Air Force has slowed the pace of modernizing its aircraft fleet. It has reduced the rate of new aircraft procurement and simultaneously extended the service-life objectives of several existing Mission Design Series.

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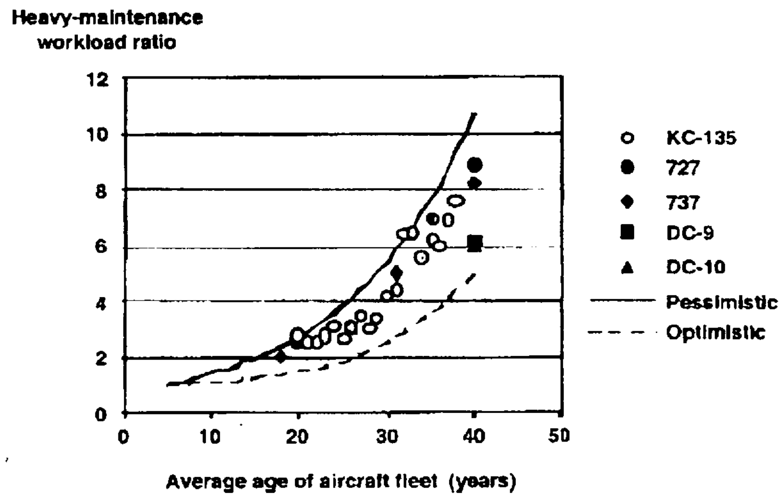
Although that policy aims to cut costs in procurement accounts, we found that, if previous cost-growth trends were to continue, annual PDM and engine-support costs would increase $5-6 billion by 2020.



Our results were based on reviews of historical PDM cost growth and on a previous analysis of engine life-cycle costs [4]. In particular, we reviewed historical and planned heavy-maintenance workloads for the KC-135, 727, 737, DC-9, and DC-10.[1] In each case, heavy-maintenance workload increased from five- to nine-fold over a 40-year span. Figure 1 depicts this growth rate for a range of average fleet ages. The growth rate is expressed as a ratio of heavy-maintenance workload over time to the workload at the first heavy-maintenance inspection. (Future research will address whether growth rates for smaller fighter aircraft differ.) From those data, we created cost-growth relationships that bound the upper and lower costs, also depicted in Figure 1.

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[1] We are indebted to Mr. D. Pearce of the Oklahoma City Air Logistics Center for the KC-135 histories and to Mr. M. Donato of the Boeing Company for the historical and planned workload growth factors for the commercial aircraft.

The heavy maintenance workloads for commercial aircraft in their 40th year are Boeing's current projections for those aircraft, based on currently planned workload requirements. Those aircraft are only now approaching age 40.

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Figure 1. Heavy-Maintenance Workload for Large Aircraft Grows Over Time

Previous Project AIR FORCE research [4] had addressed the effects of age and other factors on engine-support costs. Although that work did not include modular engines for fighters, results indicated annual age-driven growth rates of 4.5 percent and 5.3 percent for depot and base-level engine repair, respectively. Thus, over a 35-year period, engine-support costs would increase five- to six-fold, depending on the balance between depot and base-level workloads.

The Air Force intends to replace many fighter aircraft over the next 20 years. However, current plans call for retaining the existing fleets of bomber, tanker, command and control, and cargo aircraft for much longer periods, sometimes for more than 70 years. To understand how continued PDM and engine-support cost growth might affect future budgets, we extrapolated our upper and lower estimates of PDM workloads to cover a 70-year period. We combined those projections, the engine-support workload, 1994 PDM expenditures [5], and the Air Force's time-phased aircraft fleet composition plans (including the reserve component) to estimate annual PDM and engine-support costs from 1998 to 2022. Our results indicate that, if recent trends continued, annual costs for those two activities would initially rise at a modest rate. Then, in the second decade of the next century, they would accelerate, mainly because of the increasing age of the cargo and tanker fleets. Figure 2 depicts our high and low estimates of those annual costs.

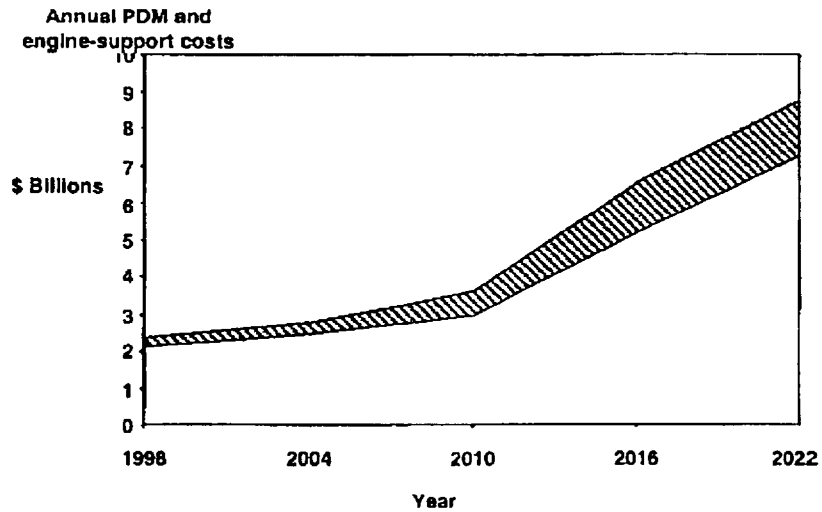

Figure 2. Projected Cost Growth of PDM and Engine-Support Workload

CURRENT WORKLOAD GROWTH TRENDS MAY CHANGE

Of course, neither the Air Force nor U.S. commercial airlines have ever before operated aircraft for such a long time. Therefore, no one knows whether these trends will continue. However, faced with the possibility of escalating maintenance and support costs, the Air Force has already begun to implement management initiatives intended to moderate workload growth rates.

New Support Challenges May Emerge

Cautious observers argue that the Air Force will encounter new flight-safety, cost, and readiness challenges as it seeks to extend the service lives of its existing fleets. In particular, major problems may result from corrosion, insulation cracking, composite delamination, and other material degradation processes for which there are no scientific aging models or relevant historical experience. For examples, one need look no further than the C-141 weephole, the VC-137 corrosion workload, and the more recent C-5 horizontal stabilator tie box fitting. If this were to occur, workload growth rates could exceed our high PDM and engine cost-growth estimates.

In any case, high costs will be incurred for modernization. Over the next decade, the Air Force will need to retrofit existing aircraft to

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meet new international standards for navigation, noise, and pollution. Further, the increasing peacetime exposure of tankers and cargo aircraft to potentially hostile actions increases the likelihood that continuing threat-related modifications to those aircraft will be required, to say nothing of the modifications needed for bombers, fighters, and attack aircraft.

Production obsolescence for uniquely military components may drive up costs even further. In general, the declining market for military aircraft and related materials has combined with the rapid technological advances of the past few decades to make production of many older military components unprofitable, thereby causing vendors to leave the marketplace entirely. Some older components simply cannot be manufactured any longer. Functionally equivalent replacement components must be designed, tested, and produced at considerably higher costs than the originals.

Most important, many of the problems associated with aging material have emerged with little or no warning. This raises the concern that an unexpected phenomenon may suddenly jeopardize an entire fleet's flight safety, mission readiness, or support costs, and that an extended time period may be required to design, test, and field a replacement aircraft.

Management Initiatives May Control or Eliminate Some Cost Growth

Optimistic observers hold out the promise that maintenance and modification initiatives (e.g., new corrosion-prevention compounds and procedures, improved failure tracking) now underway will successfully control age-related and many other support costs. Several one-time, semipermanent fixes currently taking place (e.g., selective rewiring, selective component replacement, and redesign of obsolete components) aim to substantially reduce the likelihood of future technical surprises while offsetting some effects of age. In addition, improved information systems that compile historical data on maintenance workload should provide additional insights about how the phenomena of aging are affecting specific fleets of aircraft.

These management initiatives are intended to ensure that most surprises are detected early and that focused, one-time maintenance

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"rework" actions are applied. If effective, those actions should reduce current workload growth rates.

AIR FORCE OPTIONS TO MANAGE READINESS AND COST UNCERTAINTIES

Both sides are right. New, unforeseen failure mechanisms will emerge and old failure mechanisms will accelerate, sometimes with little or no warning. At the same time, proactive implementation of targeted maintenance and modification initiatives will reduce the potential negative effects on flight safety, readiness and cost, at least in cases where the scientific and technical community has sufficient understanding of those effects.

The larger issues, then, are (1) the extent to which the management initiatives will succeed and (2) what additional strategies the Air Force can employ to help control age-related failures and their effects on readiness and cost.

To help the Air Force address these issues, we have identified three broad strategies: selective risk management, development of contingency plans for aging aircraft fleets, and mission-area portfolio management. These strategies complement one another. The first would reduce uncertainties; the other two would mitigate the effects of surprises.

- ***Selective risk management*** embodies and extends the approach implicit in the current management initiatives. This strategy seeks to identify and catalog specific age-related hazards that may affect future costs, characterize the relationships between those hazards and the risks to readiness and cost, and then develop specific technical solutions to reduce exposure to the hazards or to control their effects on cost and readiness. Current Air Force science and technology research and development initiatives in the areas of fatigue, high-cycle fatigue, corrosion, and other material science areas typify that solution direction, as do investments to gather additional technical data from maintenance activities. Accurate and detailed records of failures are also a key component of this strategy.

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- ***Contingency plans for aging aircraft fleets*** reflect the Air Force's recognition that uncertainty can never be eradicated. Such plans would seek to reduce aircraft design and production lead times (e.g., by modifying a commercial aircraft design or developing early conceptual designs) for older aircraft fleets that may be subject to unforeseen events. These plans would be implemented if a surprise occurred, such as sharply escalating PDM costs, an expensive modification, or a readiness shortfall. Contingency plans for different fleets might require different approaches, depending on the size of the fleet and the risk to the mission.

- ***Mission-area portfolio management*** would seek to implement acquisition and retirement plans that balance fleet ages within a particular mission area. Achieving this balance would reduce the risk of degraded mission capability by making the Air Force less dependent on a particular fleet of aircraft. For example, if today's C-5A fleet were unexpectedly grounded, the C-5B fleet, which is 15 years younger, could perform the outsize cargo mission, although at a diminished capacity. And because new materials will continue to introduce unknown hazards into each new aircraft design, this strategy may be an effective long-term hedge against such hazards.

PROJECT AIR FORCE WILL REFINE READINESS AND COST-GROWTH FORECASTS

In concert with the Air Force's Aging Aircraft Integrated Process Team (AAIPT), RAND Project AIR FORCE is helping to formulate, refine and evaluate all three strategies. The AAIPT aims to develop Air Force processes to manage aging fleets and, as a first step, it will assess the current system's readiness and cost performance. We will extend and refine our initial analysis of PDM and engine-support costs to help carry out that assessment. We will then use those analytic methods to evaluate alternate maintenance solutions to particular age-related hazards (selective risk management), to assess alternate fleet replacement plans (fleet contingency planning), and to determine the cost effectiveness of alternate mission-area procurement strategies (mission-area portfolio management).

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We continue to work in partnership with the Air Force to address the aging-aircraft issues identified in the AFSAB and the NRC reports. It may appear that these issues will not reach crisis proportions for many years. However, the problem is extensive, complex and susceptible to surprises. Long-term solutions will require considerable time to develop and implement. We are confident that the Air Force will continue to exert steady and sustained effort to find ways of meeting these challenges.

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REFERENCES

1. Ad Hoc Committee of the Scientific Advisory Board, *Life Extension and Mission Enhancement For Air Force Aircraft, Vol. II: Panel Reports*, United States Air Force, Washington D.C., 1994.

2. Committee on Aging of U.S. Air Force Aircraft, *Aging of U.S. Air Force Aircraft*, National Materials Advisory Board, Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington D.C., NMAB-488-2, 1997.

3. Pyles, Raymond, Laura Baldwin, Jean Gebman, Timothy Ramey, and Hyman Shulman, *Aging Aircraft: Implications for Programmed Depot Maintenance and Engine-Support Costs*, RAND, Santa Monica, California, AB-237-1-AF, 1998.

4. Nelson, J. R., *Life-Cycle Analysis of Aircraft Turbine Engines*, RAND, Santa Monica, California, R-2103-AF, 1977.

5. McPeak, M. A., *Weapon System Cost Reduction*, United States Air Force, Washington D.C.

RAND TESTIMONY

Swaim Bob

From: Laura Baldwin [lbaldwin@rand.org]
Sent: Monday, July 20, 1998 2:13 PM
To: Swaim Bob
Cc: Laura_Baldwin; Jean_Gebman; Raymood_Pyles; Bob_Roll
Subject: RAND's work on aging aircraft

Bob,

I enjoyed talking with you last week. I am attaching a copy of the project description for RAND's aging aircraft logistics research sponsored by the Air Force.

Jean Gebman and I anticipate that we will be traveling to Washington sometime within the next few weeks. We'd like to hear more about your work and tell you more about our research. Once we pin down our travel schedule, we'll be in touch to see if we can schedule a meeting.

Thanks,
Laura Baldwin

------ Forwarded Message

AGING AIRCRAFT RESEARCH PROPOSAL

Background

The persistence of limited budgets has led the Air Force to extend the service lives of many of its aircraft weapon systems in order to conserve funds for other important needs such as force modernization. At the same time that budgets have been falling, the Air Force has had to prepare to meet new operational challenges.

Air Force logisticians face three classes of challenges associated with aging aircraft weapon systems: loss of military relevance, growth in maintenance costs, and loss of weapon system integrity. The potential for loss of military relevance lies in rapidly-changing needs and technologies and in insufficient planning and funding for weapon system modifications. The potential for growth in maintenance costs lies in uncertainty about aging mechanisms, which limits the Air Force's ability to make informed tradeoffs among competing resource demands. Finally, the Air Force already may be seeing signs of a potential decline in structural integrity in aging fleets where aircraft have arrived at the depot requiring so much programmed depot maintenance (PDM) work that it was deemed too costly.

Approach

RAND's initial exploratory research has produced a framework for an integrated strategy that the Air Force can develop to more cost-effectively plan and manage the remaining lives of its aging weapon systems. This framework has three components: planning, maintenance, and R&D. Research during the current and future years will help the Air Force develop this framework.

Planning: More effective planning for the remaining lives of aging aircraft weapon systems requires an ongoing process that (1) facilitates incorporation of operational (and retirement) plans and policy into the maintenance and R&D activities for the weapon system; (2) promotes interaction among the planning, maintenance, and R&D communities (e.g., for modifications, maintenance problems); and (3) provides information about the needs of weapon systems to Air Force leadership.

The first step toward improving the planning function is to identify the current state of the Air Force's aging aircraft. Using PDMSS, a new system that records maintenance findings and actions taken during depot-level maintenance (e.g., PDMs), and other data sources, the Air Force needs to baseline the current effects of aging mechanisms on aircraft airframes and

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subsystems. The Air Force then needs to estimate how maintenance costs may change over time given the current maintenance structure, policies, and practices. This would identify those aging mechanisms most likely to lead to unacceptable increases in future maintenance costs. The Air Force would then be in a better position to construct plans to enable its aging aircraft to meet operational goals.

Next, the Air Force needs to promote interaction among the weapon system planning organizations, maintenance community, R&D community, and senior Air Force leadership to improve planning for extended weapon system lives.

RAND can help the Air Force use tools like PDMSS to baseline the current conditions of its aging fleets and assess trends in maintenance costs for the remaining service lives of these weapon systems.

Maintenance: This component of the strategy is concerned with understanding the current maintenance structure, policies, and practices and seeking changes to these that would help minimize the remaining life cycle costs associated with aging weapon systems. Cost containment is especially important for the larger fleets such as the F-16, KC-135, F-15, and C-130.

As aging aircraft are, in effect, being asked to fulfill a second service life, the Air Force needs to re-address the questions of what maintenance should occur, where it should occur, who should perform it, and how frequently. The Air Force can begin by assessing its current maintenance practices such as the scope, frequency, and providers of inspections and preventative actions, documentation and tracking of problems, and policies and practices that facilitate revisions of inspection programs in response to the emergence of new problems. It can then work with commercial airlines and original equipment manufacturers to determine maintenance alternatives that have been proven effective for controlling aging mechanisms.

RAND can assist the Air Force with this component of the strategy by identifying how to use existing data sources to accomplish these tasks with a minimum expenditure of resources.

R&D: The Air Force would benefit from improving its R&D support for the remaining life needs of aging aircraft. There are at least two important components of managing R&D support: (1) choosing the most effective portfolio of R&D projects and (2) coordinating efforts and funds across weapon system and organizational boundaries.

There are many open scientific questions surrounding maintenance of aging aircraft, and the Air Force has limited funds to apply toward researching these issues. AFMC has created an Aging Aircraft System Management Office to coordinate the Air Force's R&D on aging aircraft issues. The Air Force needs to examine the activities of this office and seek ways to strengthen its analysis of potential R&D projects and coordination processes to help ensure that the Air Force maximizes the return from its investment in R&D.

RAND could assist the Air Force by helping develop an R&D portfolio that reflects aging aircraft needs and priorities in ways that secure necessary support during the budget preparation process.

------ End of Forwarded Message

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WHITE HOUSE COMMSSION ON AVIATION SAFETY AND SECURITY
THE DOT STATUS REPORT

EXECUTIVE SUMMARY

One year ago, the White House Commission on Aviation Safety issued its final report. The Department of Transportation (DOT), the Departments of Defense, Justice, State, and Treasury, the National Transportation Safety Board, the National Aeronautics and Space Administration and numerous other Federal agencies have made significant progress implementing the Commission's recommendations. Together, with our partners in the aviation community, the federal government has worked to change the way we do business.

The federal government has established the Commission's proposed safety goal as our primary safety goal. We are committed to **reduce the aviation fatal accident rate by a factor of five within 10 years** (Recommendation 1.1). Both the DOT and the National Aeronautics and Space Administration (NASA) have adopted the goal in their new strategic plans, and incorporated means of measuring the progression of this goal in their performance agreements. The Federal Aviation Administration (FAA) has set out a strategic goal of reducing the aviation fatal accident rate 80 percent by 2007. NASA has also set a longer-range goal of reducing the fatal accident rate by a factor of 10 within 20 years. FAA and NASA are tailoring their research and program plans to achieve these goals.

Aviation security has been established as a national security priority (Recommendation 3.1). The President has publicly recognized aviation as a major element of our strategy against terrorism, and the White House publication *A National Security Strategy for a New Century* includes aviation security as a critical element. The DOT Strategic Plan specifically recognizes aviation security as a key component in advancing the nation's vital security interests. The National Security Council has established a subgroup, headed by the DOT and including all agencies involved in aviation security, to address the White House Commission security recommendations specifically.

Over the past year, the following White House Commission recommendations have been completed.

- The Department has instituted into its rulemaking practices a policy to **ensure that costs alone are not dispositive in the rulemaking process** (Recommendation 1.5). The new policy recognizes the importance of both tangible and intangible benefits of rules, the need for risk analysis and examination of potential mitigation measures, and the need to identify and act on high-risk potential accident causes before accidents occur.

- The FAA is continuing to explore innovative means to **accelerate the installation of advanced avionics in general aviation aircraft** (Recommendation 2.3) as part of its Advanced General Aviation Transport Experiments (AGATE). The goal is to improve general aviation safety and improve access to the airspace system. FAA is revising two Advisory Circulars (AC) on certification, and a new RTCA task force is reviewing avionics certification processes. Flight 2000, FAA's program to demonstrate and validate new National Airspace System (NAS) capabilities, also will validate avionics, including low-cost weather data link systems for general aviation aircraft.

- In September 1997, the National Civil Aviation Review Commission (NCARC) released its Recommendations on ways for the **users of the National Airspace System (NAS) to fund its development and operation** (Recommendation 2.5). A new FAA reauthorization proposal will address those recommendations.

- **The FAA identified and justified the frequency spectrum necessary for the transition to a modernized air traffic control system** (Recommendation 2.6) and released its study in July 1997. The results will be incorporated into the next Federal Radionavigation Plan. FAA is continuing to address the sufficiency of the radio frequency spectrum to support the communication needs of the NAS.
- The Department of Transportation issued on February 12, 1997, a final rule to **improve passenger manifests** (Recommendation 3.26) by requiring more information on passenger manifests for flights to or from the United States.
- In June 1997 **FAA submitted a proposed resolution, through the U.S. Representative, that the International Civil Aviation Organization (ICAO) begin a program to verify and improve compliance with international security standards** (Recommendation 3.8). ICAO has not yet adopted the resolution, which the United States continues to support.
- DOT strengthened its working relationship with the Departments of Defense, Energy, and other Federal agencies and local authorities to **assess the possible use of chemical and biological weapons as tools of terrorism** (Recommendation 3.9). Interagency activities are ongoing.

STATUS

DOT WHCSS SUMMARY

- The Department of Defense (DOD) has **established an interagency task force to assess the potential use of surface-to-air missiles against commercial aircraft** (Recommendation 3.17.) DOD convened the task force and held its first meeting on May 12, 1997.
- FAA has **given properly cleared airline and airport security personnel access to needed classified information** (Recommendation 3.23). Industry officials, with appropriate security clearances, are now routinely provided classified information regarding threats.
- The FBI **significantly increased the number of agents assigned to counter-terrorism investigations to improve intelligence and crisis response** (Recommendation 3.27). Congress provided funding and FBI deployed 644 Special Agents, 620 support positions, and additional funding for investigations, intelligence gathering, forensic analysis, and crisis management.
- The FAA has been a full partner with the Department of State in **providing anti-terrorism assistance through airport security training to countries where there are airports served by airlines flying to the United States** (Recommendation 3.28). The Department of State and FAA provide airport security training through the Anti-Terrorism Assistance Training Program (ATAP.)
- **The National Transportation Safety Board (NTSB) finalized a coordinated federal response plan to aviation disasters** (Recommendation 4.1). The plan has been implemented in four aviation disasters, including the Korean Air 801 disaster in August 1997 at Guam.
- **The Department of Transportation and the NTSB have implemented key provisions of the Aviation Disaster Family Assistance Act of 1996** (Recommendation 4.3.) The Secretary's Task Force on the Assistance to Families of Aviation Disasters was appointed in March 1997. It issued its report, containing 61 recommendations, to Congress and the Vice President in October 1997. The government and industry are implementing many of the Task Force's recommendations.

Beyond the fully completed recommendations, DOT, FAA, and other agencies have made substantial progress toward implementing virtually all the remaining recommendations. Highlights include:

- The new passenger screening system, Computer Assisted Passenger Screening (CAPS), was prototyped, tested with Northwest Airlines in 1997, and is being phased in by U.S. airlines in 1998. FAA tested passenger bag matching in 1997 and, on January 1, 1998, augmented the bag-matching program in conjunction with both manual screening and CAPS. After a thorough review, the Department of Justice concluded that the screening system did not violate the civil rights of any individuals.
- FAA hired 375 new safety inspectors and created a group to provide analytical support to field offices and target inspector oversight where it is most needed.
- Some 79 certified explosives detection systems and advanced technologies for screening of checked bags were purchased in 1997. Deployment will be completed in 1998. In addition, over 50 trace explosives detection devices were deployed in 1997, bringing the total in place from 78 to 128. About 365 more trace detection devices will be purchased and installed by the end of 1998.
- NASA has reprogrammed $500 million to invest in safety research over the next five years. They have identified a lead research center for safety research and established a program management staff throughout NASA Centers.
- The FAA and NASA are working as partners to develop a research plan to achieve the national aviation safety goal of an 80 percent reduction in aviation fatal accidents in 10 years. Both agencies will work with industry to create and install new safety technology as quickly as possible. This work will assist FAA in implementing many of the safety recommendations.
- Notices of Proposed Rulemakings (NPRM) have been drafted or issued on *Enhanced Ground Proximity Warning Systems* in aircraft; improved standards for certification of foreign aircraft repair stations worldwide; amended criteria for certification of explosives detection systems to include detonators; computer assisted passenger screening; and expanded applicability of rules concerning criminal background checks and FBI fingerprint checks to all screeners and their supervisors. An Advanced NPRM was published on the certification of security screening companies.
- The FAA and NASA have developed a human factors plan to address the implementation of items included in three key reports: *The National Human Factors Plan* ; the *1997 Aviation Safety Plan* ; and a report on flight deck human factors. In addition, FAA coordinated an FAA/NASA/DOD Aviation Safety Program, strengthened collaborative safety research efforts, identified new safety research requirements, and are executing a research plan for a flight deck automation study.
- The FAA and the National Academy of Sciences signed an agreement to create a panel for the Assessment of Technologies for Aviation Security.
- Cooperative research agreements and partnerships have been established to develop new security technology.
- The DOT is continuing its efforts to ensure the accuracy, availability, and reliability of the Global Positioning System (GPS) as part of a worldwide Global Navigation Satellite System (GNSS). This includes measures to provide secure uninterrupted civilian access to the GPS carrier; work with the Department of Defense on a plan for a second GPS frequency; and work with international organizations on how to detect and protect GNSS from

potential interference. The DOT and the Departments of State and Commerce are encouraging worldwide use of GPS in international forums. FAA has agreements with 14 nations that ensure the use of U.S. GPS standards around the world.

- The Administration is supporting legislation introduced in Congress to ensure equitable treatment for families of passengers involved in international aviation disasters. It is also is supporting legislation to amend the Death on the High Seas Act which would enable the family members of those killed in international aviation disasters to obtain fair compensation.

This report summarizes accomplishments toward achieving the 57 recommendations in the White House Commission report and discusses some of the issues that will affect implementation in the future. The federal government and its partners in the aviation community are fully committed to continuing implementation in the years ahead.

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partnership to eliminate controlled flight into terrain - a major cause of air accidents worldwide. ATA member airlines will voluntarily equip 4,300 of their aircraft with advanced terrain awareness warning systems, such as EGPWS by 2003. The General Aviation Integrated Product Leadership Team has incorporated EGPWS into the plan considering options for low-cost general aviation avionics. This equipment is incorporated into the Advanced General Aviation Transport Experiments, which is a new generation of airplane being built specifically for general aviation. The FAA's Flight 2000 operational evaluation program, which uses advanced technology for more efficient routes, will provide valuable data on EGPWS on general aviation aircraft in actual operations.

1.8—The FAA should work with the aviation community to develop and protect the integrity of standard safety databases that can be shared in accident prevention programs.

- The FAA is drafting a Notice of Proposed Rulemaking regarding information submitted to the FAA on a voluntary basis. This proposal would implement a new statutory provision. It is intended to encourage people to provide information that will assist the FAA in carrying out its safety and security duties by assuring that the information will be treated confidentially.

- The FAA is participating with the aviation community to improve the integrity and standardization of aviation safety databases in its worldwide Global Analysis and Information Network (GAIN) program. The FAA continues to promote GAIN, which proposes a privately owned, and operated worldwide infrastructure to collect, analyze, and disseminate aviation information.

- The FAA's Office of Commercial Space Transportation has initiated efforts to improve and standardize safety data for commercial space transportation.

- An internal FAA task force on aviation safety data standardization was established on April 24, 1997. This task force completed an inventory and documentation of aviation safety data standardization efforts within the FAA, in other agencies, and in the aviation community on December 31, 1997.

1.9—In cooperation with airlines and manufacturers, the FAA's Aging Aircraft program should be expanded to cover non-structural systems.

- The FAA is developing the data to determine the need for full and complete teardowns of aging aircraft. Such teardowns would provide more information to the FAA to target properly the areas of concern for aging aircraft research and rulemaking.

- FAA, NASA and DoD are coordinating aging aircraft research activities and are planing for the inclusion of aging aircraft systems.

1.10—The FAA should develop better quantitative models and analytic techniques to inform management decision-making.

- A FAA cross-organizational team developed, and FAA accepted, a formal plan that provides an integrated framework for identifying and developing analytical models to facilitate FAA decisionmaking across all lines of business. For example, it would include FAA's mission need analysis process, which apply quantitative models and analytical techniques for use in executive management decisionmaking. The integrated model plan contains both short and long-term goals. Implementation of the short-term goals has begun.

- FAA initiated a program to develop a credible cost accounting system as mandated in the Federal Aviation Reauthorization Act of 1996.

- FAA has developed general functional requirements, finalized the detailed system design, and evaluated, acquired, and installed Commercial Off-the-Shelf (COTS) cost accounting software, and began to identify detailed functional requirements for all lines of business. This effort will be completed in February 1998.

- FAA implemented a baseline cost accounting system that provided prototype cost accounting data to selected organizations as an initial capability.

- The FAA's Office of Commercial Space has developed quantitative models and analytic techniques to forecast

United States General Accounting Office

GAO

Testimony

Before the Subcommittee on Aviation, Committee on Commerce, Science and Transportation, U.S. Senate

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AVIATION SAFETY AND SECURITY

Challenges to Implementing the Recommendations of the White House Commission on Aviation Safety and Security

Statement by Gerald L. Dillingham,
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Resources, Community, and Economic Development Division

GAO/T-RCED-97-90

Commission

Mr. Chairman and Members of the Subcommittee:

We appreciate the opportunity to share our views on the recommendations contained in the recently released report of the White House Commission on Aviation Safety and Security. The Commission's 57 recommendations broadly cover safety, security, air traffic control, and disaster response. As you know, 1996 was a bad year for aviation safety. Last year, 380 people died in air accidents involving large U.S. air carriers, the highest number in 11 years. The crashes of TWA Flight 800 off New York and ValuJet Flight 592 in Florida accounted for most of those deaths. Although the nation's air transportation system remains the safest in the world and the Federal Aviation Administration (FAA) the model for other nations, these tragic events have served to raise the Congress's, the administration's, the aviation industry's, and the flying public's consciousness of the need to continuously increase the existing margin of safety.

During the past several years, we have reported to the Congress on the status of a wide range of programs and initiatives intended to expand that margin of safety. Our testimony this morning, based on this prior work and on an analysis of the Commission's recommendations, will focus on the implementation issues relating to three areas addressed by the Commission: aviation safety, air traffic control modernization, and aviation security.

We believe that the Commission's recommendations are a good start toward an evolutionary process of making real the Commission's vision of ensuring greater safety and security for passengers, restructuring the relationships between the government and the industry, and maintaining America's position of global leadership in aviation. However, key questions remain about how and when the recommendations will be implemented, how much it will cost to implement them, and who will pay the cost. Our message this morning focuses on the challenges that lie ahead in taking the next steps to convert the Commission's recommendations from concepts to realities.

Aviation Safety

The Commission made 14 recommendations in the general area of aviation safety. Foremost among these is establishing a national goal to reduce the fatal accident rate by 80 percent within 10 years. This is a very challenging goal, particularly in the light of the projected increases in the amount of air traffic in the coming decade.

COMMISSION

We applaud the Commission's adopting such a goal for accident reduction and endorse many of its recommendations for improving safety. These recommendations include, for example, expanding FAA's inspection program to cover not only aging aircraft's structural integrity but also such areas as electrical wiring, fuel lines, and pumps. A number of these recommendations resonate with safety and efficiency improvements that we and others, including FAA, have suggested over the years.[1] However, we believe that, as FAA tries to fundamentally reinvent itself as the Commission contemplates through some of its recommendations, FAA and the aviation industry will be challenged in three areas: (1) FAA's organizational culture and resource management, (2) FAA's partnerships with the airline industry, and (3) the costs of and sources of funding to implement the recommendations.

A number of recent studies and the FAA itself have pointed to the importance of culture in the agency's operations. Last year, our review of FAA's organizational culture found that it had been an underlying cause of the agency's persistent acquisition problems, including substantial cost overruns, lengthy schedule delays, and shortfalls in the performance of its air traffic control modernization program.[2] Furthermore, the lack of continuity in FAA's top management, including the Administrator and some senior executive positions, has fostered an organizational culture that has tended to avoid accountability, focus on the short term, and resist fundamental improvements in the acquisitions process.

Similarly, a 1996 report issued by the Aviation Foundation and the Institute of Public Policy stated that the recent actions taken to reorganize FAA have done nothing to change the long-term structural problems that plague the organization.[3] The study concluded that FAA does not have the characteristics to learn and that its culture does not recognize or serve any client other than itself.

As FAA's own 1996 report entitled Challenge 2000 points out, it will take several years to overcome the many cultural barriers at FAA, determine the

[1]For example, see Aviation Safety: New Airlines Illustrate Long-Standing Problems in FAA's Inspection Program (GAO/RCED-97-2, Oct. 17, 1996); Aviation Safety: Targeting and Training of FAA's Safety Inspector Workforce (GAO/T-RCED-96-26, Apr. 30, 1996); and Aircraft Maintenance: FAA Needs to Follow Through on Plans to Ensure the Safety of Aging Aircraft (GAO/RCED-93-91, Feb. 26, 1993).

[2]Aviation Acquisition: A Comprehensive Strategy Is Needed for Cultural Change at FAA (GAO/RCED-96-159, Aug. 22, 1996).

[3]Why Can't the Federal Aviation Administration Learn? Creating a Learning Culture at the FAA, the Aviation Foundation, Falls Church, Virginia and the Institute of Public Policy, George Mason University, Fairfax, Virginia (July 10, 1996).

Commission

skill mix of the workforce of the 21st century, and recruit the necessary talent in a resource-constrained environment.[4] In the light of these studies' results, we would caution that the organizational and cultural changes envisioned by the Commission may require years of concerted effort by all parties concerned.

In connection with resource management, FAA's fiscal year 1998 budget request reveals some difficult choices that may have to be made among safety-related programs. For example, FAA proposes increasing its safety inspection workforce by 273 persons while decreasing some programs for airport surface safety, including a program designed to reduce runway incursions. The National Transportation Safety Board has repeatedly included runway incursions on its annual lists of its "most wanted" critical safety recommendations. FAA's budget request includes a reduction in the Runway Incursion program from $6 million in fiscal year 1997 to less than $3 million in fiscal year 1998. Although FAA set a goal in 1993 to improve surface safety by reducing runway incursions by 80 percent by the year 2000 from the 1990 high of 281, the results have been uneven; there were 186 runway incursions in 1993 and 246 in 1995. As was shown by the November 1994 runway collision in St. Louis, Missouri, between a commercial carrier and a private plane, such incidents can have fatal consequences—2 people lost their lives. It is unclear what progress will be made in this area, given the proposed budget cuts.

Similarly, we have reported since 1987 that the availability of complete, accurate, and reliable FAA data is critical to expanding the margin of safety.[5] However, funding for FAA's National Aviation Safety Data Analysis Center, a facility designed to enhance aviation safety by the rigorous analysis of integrated data from many aviation-related databases, is slated to be reduced from $3.7 million in fiscal year 1997 to $2 million in fiscal year 1998.

The Commission's report stresses that safety improvements cannot depend solely on FAA's hands-on inspections but must also rely on partnerships with the aviation industry in such areas as self-monitoring and certification. Several programs for the airlines' self-disclosure of safety problems have already contributed to identifying and resolving

[4] Challenge 2000: Recommendations for Future Aviation Safety Regulation, prepared for FAA's Office of Policy, Planning, and International Aviation by Booz•Allen & Hamilton, Inc. (Apr. 1996).

[5] Aviation Safety: Data Problems Threaten FAA Strides on Safety Analysis System (GAO/AIMD-95-27, Feb. 8, 1995); Department of Transportation: Enhancing Policy and Program Effectiveness Through Improved Management (GAO/RCED-87-3, Apr. 13, 1987).

Commission

some of these types of problems. [6] For example, one airline's program for reporting pilot events or observations—a joint effort by the airline, the pilot union, and FAA—has identified safety-related problems, the vast majority of which would not have been detected by relying solely on FAA surveillance. The discovery of these problems has resulted in safety improvements to aircraft, to the procedures followed by flight crews, and to air traffic patterns. As the Commission has recognized, however, such information will not be provided if its disclosure threatens jobs or results in punitive actions. However, FAA's role in some broader partnerships with industry has also raised some questions. For example, FAA's cooperative process working with Boeing on the 777 aircraft helped enable the manufacturer to meet the planned certification date, but FAA was also criticized by some FAA engineers and inspectors for providing inadequate testing of the aircraft's design.

In the case of self-disclosure programs, decisions will have to be made on which aviation entities are best suited to such partnership programs, how to monitor these programs and make effective use of the data they offer, how to balance the pressure for public disclosure against the need to protect such information, and how to standardize and share such information across the aviation industry. With broader cooperation between FAA and the aviation industry, the Congress and FAA need to be on guard that the movement toward partnerships does not compromise the agency's principal role as the industry's regulator.

Finally, it is important to point out that the costs associated with achieving the accident reduction goal and who should pay for these costs have not yet been determined. In accordance with the Commission's call for more government-industry partnerships, government, the industry, and the traveling public would likely share in these costs. For example, FAA's partnership programs involve significant costs for both the agency and the industry. In the case of equipping the cargo holds of passenger aircraft with smoke detectors, the cost would fall initially on the industry, while the costs associated with the recommendation that children under the age of 2 be required to have their own seats on airplanes would fall more directly on the traveling public.

Regardless of who bears the cost of the proposed improvements, the Commission has correctly recognized that additional safety improvements may sometimes be difficult to justify under the benefit-cost criteria applied

[6] Examples of ongoing or recent partnership programs include the American Airlines Safety Action Program for pilots as well as the USAir Inc. Altitude Awareness Program and the Alaska Airlines Altitude Awareness Program.

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to regulatory activities. The Commission recommended that cost not always be the determining factor or basis for deciding whether to put new aviation safety and security rules into effect. Specifically, the Commission notes that the potential reduction in the fatal accident rate merits a careful weighing of the options for improving safety in terms of the benefits that go beyond those traditionally considered in benefit-cost analyses. However, we also believe that it is important to recognize that the recommendation (1) represents a significant departure from traditional processes, (2) could result in significant cost increases for relatively modest increases in the safety margin, and (3) could rest on a limited empirical justification. In effect, this recommendation may increase the number of instances in which the primary factor determining whether or not to go forward with a safety or security improvement is what might be referred to as a public policy imperative rather than the result of a benefit-cost analysis. One instance of such a decision is the Commission's recommendation to eliminate the exemption in the Federal Aviation Regulations that allows children under 2 to travel without the benefit of an FAA-approved restraint.

Air Traffic Control Modernization

The Commission also reviewed the modernization of the air traffic control (ATC) system. FAA is in the midst of a $34 billion dollar, mission-critical capital investment program to modernize aging ATC equipment. This program includes over 100 projects involving new radars, automated data processing, and navigation, surveillance, and communications equipment. We believe this modernization is also important for attaining the next level of safety by replacing aging equipment and providing controllers and pilots with enhanced communication and better information.

Recognizing that new technology, such as satellite-based navigation and new computers in ATC facilities and in aircraft cockpits, offers tremendous advances in safety, efficiency, and cost-effectiveness for users of the ATC system and for FAA, the Commission recommended accelerating the deployment of this new technology. According to FAA's current plan, many of these elements would not be in place until the year 2012 and beyond. However, the Commission has recommended that these technologies be in place and operational by the year 2005—7 years ahead of FAA's planned schedule. The Commission's goal is commendable, but given FAA's past problems in developing new ATC technology and the technical challenges that lie ahead, there is little evidence that this goal can be achieved.

Commission

UNITED STATES DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

FAA AGING TRANSPORT NON-STRUCTURAL SYSTEMS PLAN

Complete 57 page report URL is:
http://www.faa.gov/apa/PUBLICAT/fatnspcov.htm
R Swain

July 1998

FAA AGING SYSTEMS PLAN

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FINDINGS

Based on on-site evaluations of three airplane models, meetings with FAA Principal Maintenance Inspectors (PMIs) and Boeing, and an analysis of aging systems using the FAA's National Aviation Safety Data Analysis Center (NASDAC) aviation safety databases, a plan has been formulated to address our aging transport airplane systems. The plan supports the recommendations made by the WHCSS and acknowledges that a more extensive examination of "aging" airplane systems is needed. More aging airplane models need to be evaluated and the wire analyzed in the laboratory to fully characterize the condition of the wire on our aging transport airplane fleet. Initiatives to improve maintenance training, inspections, and practices are incorporated into the plan. Also addressed are specific safety initiatives related to aging wire found in fuel tank conduits.

On-site inspections of three representative aging transport airplane models shows some deterioration of wiring components, namely, wire, wire bundles, connectors, grounds, clamps and shielding. As wire ages it becomes stiff and easily cracked if improperly handled or allowed to move unrestrained. Wire bundles are difficult to inspect in many areas. Contamination of wire bundles with metal shavings during maintenance is a common occurrence. In some areas, contamination of wire bundles with excessive dust and various fluids was noted. Isolated cracking of outer layers of multi-layer insulation can be seen in some wire types. Ground terminal were found with resistance measurements outside manufacturers specifications. Connectors are not normally disassembled during inspections, but where these could be observed, isolated incidences of corrosion on pins was observed.

Current maintenance practices do not adequately address wiring components (wire, wire bundles, connectors, clamps, grounds, shielding). Inspection criteria is too general. Typically a zonal inspection task card for wiring would state, "Perform a general visual inspection". Important details pertaining to unacceptable conditions are lacking. Airlines report shortcomings in the manufacturer's maintenance and repair manual on wire, Chapter 20. The current presentation and arrangement of standard practices make it difficult for an aircraft maintenance technician to locate and extract the pertinent and applicable data necessary to effect satisfactory repairs. Wire replacement criteria may not be adequate. Under current maintenance philosophy, wire in conduits is not inspected. On-site inspections and reporting from operators indicate many examples of improper installation and repair of wiring. A review of incident reports and maintenance records indicate current reporting system lacks visibility for wiring making it difficult to assess aging trends. There are no maintenance codes to identify wire failures.

In addition, there is currently no systematic process to identify and address potential catastrophic failures caused by electrical faults of wiring systems, aside from accident investigation associated activities. A process similar to the MSG-3 review process, which is used for mechanical and electrical components, is recommended to find and address potential catastrophic events associated with wiring system faults.

The class of airplanes evaluated during the study use primarily mechanical or hydraulic flight control systems. Although newer, the class of airplanes introduced in the

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early 1980s incorporating full authority electronic flight and engine controls have now been in service over fifteen years. The impact of aging on these flight-critical electronic control systems, their wiring, and their lightning and High Intensity Radiated Fields (HIRF) protection is also addressed in the aging airplane system plan. Additional evaluations should be performed to determine the scope of aging issues associated with these airplanes and their systems.

In the mechanical systems area, isolated observations of corrosion on flight control actuators, associated linkage, and hydraulic fittings were noted. Some flight control actuators contain uninspectable shafts. The aging non-structural systems plan calls for additional testing and better inspection criteria to address these observations.

The most current information was used in the development of the tasks and schedules contained in this plan. However, due to the complex nature of the tasks and the interrelationships between tasks, the plan may need to be revised periodically to reflect a change in scope or schedule.

This report contains six appendices:

(1) Appendix I: Summaries of On-Site Evaluations of "Aged" DC-10, DC-9, B727.

(2) Appendix II: Summaries of Principal Maintenance Inspector Workshop.

(3) Appendix III: Meeting minutes, Boeing.

(4) Appendix IV: NASDAC Study.

(5) Appendix V: Glossary of Acronyms.

(6) Appendix VI: Major Contributors to the FAA Aging Non-Structural Systems Plan.

THE FAA'S AGING SYSTEMS PROGRAM: STRATEGY AND PROBLEMS

Stewart R. Miller
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Abstract

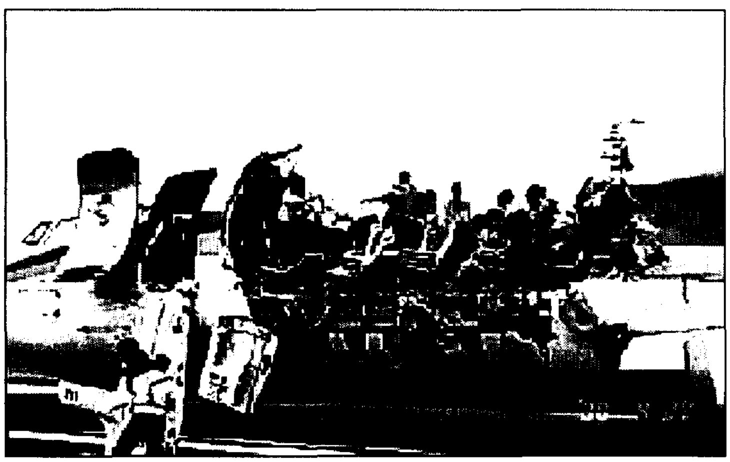
The FAA and the aviation industry have just begun their joint work in carrying out a comprehensive evaluation of the state of non-structural systems in the aging fleet of commercial transport airplanes. This is only one part of a larger strategic plan to address safety issues in aging transport airplanes, and builds on work that has already been accomplished in addressing the effects of aging on structural components of these airplanes. This paper describes activities that have been implemented or are planned for evaluating the wiring systems installed in older aircraft. The outcome of this evaluation will determine if changes are needed to improve the safety of the fleet by improving the current wire system design, inspection, maintenance, and training processes.

A Brief History of Aging Commercial Transport Airplane Issues

Aging Structures

The FAA's Aging Aircraft Program had its beginning with the event shown in Figure 1:

Figure 1. The Aloha Airlines 737 Accident, Honolulu, Hawaii, April 1988



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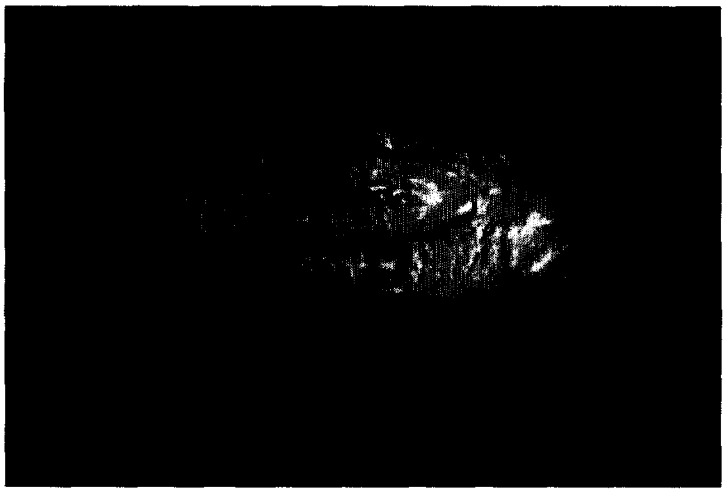
The photograph shows the Aloha 737 accident airplane that lost major portions of its fuselage structure due to failures of fuselage lap splices. The accident investigation revealed that hidden damage had occurred in the lap splices of the airplane due to disbonding of an adhesive used in the splices, and the resultant corrosion led to fatigue failure. Further investigations revealed that similar fatigue damage existed in the lap splices on numerous other older airplanes.

The event took place because the industry and authorities did not recognize that standard maintenance procedures at that time were overlooking a significant problem. We didn't know that the disbonding was a serious problem that could lead to other consequences, and we didn't know we had to inspect the interior of these lap splices for disbonding and for fatigue cracking. The FAA's Aging Airplane Program was formed to address these issues and others related to structures. The program's objective was to make changes to improve the maintenance programs through Airworthiness Directives, and to develop more robust processes for identifying and correcting aging effects, such as fatigue and corrosion.

Aging Systems

Why this paper on the FAA's Aging Systems Program? Figure 2 illustrates one of the reasons:

Figure 2. Power Cable to a Model 737 Fuel Pump.



The photograph shows the power cable to a Model 737 fuel pump. This cable runs through a conduit in the fuel tank. Note that the outer cover of the cable is worn through, as is the insulation on one phase of the power wire. This wear was generated by rubbing against the wall of the conduit; it was detected when the wire wore through the conduit and resulted in a fuel leak, but, fortunately, not a fire. As a result of the discovery, the FAA examined the wiring systems design of the transport fleet and issued a number of Airworthiness Directives to address this issue on several models of aircraft.

There are parallels between these actions concerning the wiring systems and the event that led to the initiation of the Aging Airplane Program. The FAA discovered an aging effect on a critical wire in a location that was inaccessible from a visual inspection standpoint. Fortunately, this event did not lead to an accident, but it did serve to call attention to the fact that

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the effects of age and exposure on the systems in transport airplanes needed to be examined in the same way that these effects on structures had been reviewed, to be sure that standard maintenance processes are adequate.

The remainder of this discussion will focus specifically on wiring system issues. Other systems components are also subject to aging and will be the subject of additional future work.

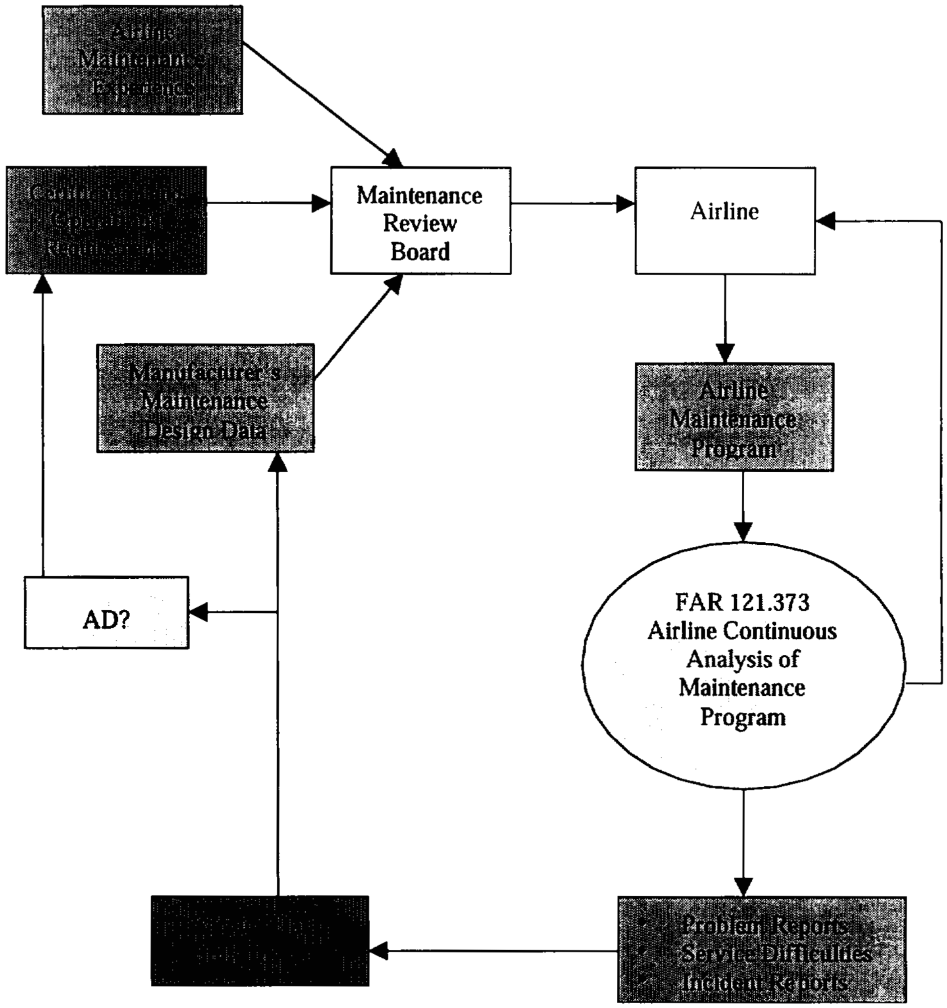
Wiring Systems: General Issues

It should come as no surprise that there are potential problems with aging wiring because wire is no different from any other engineering material. Each wire type is a compromise -- providing some desirable characteristics, while presenting some challenges because of its weak points. To make use of the good features, we must work around the bad features through design and maintenance procedures. Further, like all engineering materials, wire degrades over time through exposure to the environment, aeronautical chemicals, and wear and tear due to maintenance activities and other physical contact. We must, as an industry, recognize and deal with this natural state.

Our challenge in the aging systems area is to improve our inspection, maintenance, and training processes to ensure that they will detect and correct aging effects that can lead to unsafe conditions in the transport fleet.

We have processes in place for design, inspection, and maintenance of electrical systems on commercial airplanes. These processes involve the FAA, the manufacturers, and the operators. They start with the design stage of the airplane and continue through the life of the airplane. A brief outline of the processes is given in Figure 3:

Figure 3. Process for Design, Inspection, and Maintenance of Electrical Systems



While these processes generally have been effective in identifying and correcting wiring problems, several recent events have raised questions about the continuing adequacy of these processes as the average age of the transport airplane fleet increases. It is essential that these processes are capable of recognizing important aging effects of wiring, and taking corrective action in a timely manner. The issue is complicated by the number of wire types in service and their different properties, both good and bad.

In addition, the industry is involved in a major effort to reduce the accident rate by 80 percent. This effort will require improvements in all aspects of design and operation of transport airplanes. Wiring is obviously an element that must be addressed.

The industry's resources are finite and represent a limit on what can be achieved in the effort to improve safety. It is neither wise nor practical to tie up resources on relatively unimportant safety issues at the expense of more immediate and serious threats to safe operation

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of civil aircraft. The FAA and industry are involved in the Joint Safety Analysis Team's activities to identify the major threats to safety and direct resources to their alleviation.

The perceived aging systems threat is one of many potential safety problems that must be quantified and funded in relation to its importance in reducing the accident rate. Further, the subject of aging systems is a sizeable issue, not all parts of which are equally important. Even within the area of aging systems, we must prioritize our work according to the potential threat to safety.

How do we determine the potential threat? The FAA's approach is to first collect data on the health of the transport airplane fleet in order to provide the baseline for risk analysis and alleviation. Identified threats may range from serious safety issues requiring immediate action to lesser issues that can be corrected through longer-term changes to design, inspection, maintenance, and training processes. The goal is to match the speed of response to the seriousness of the problem, so that work may be distributed to match available resources with minimum financial impact.

History of Wire Types

The history of wire types in airplanes is one of continuing change as new products are developed and introduced into the fleet. The "general purpose" wire types used in pressurized areas in the commercial fleet since the early 1950's are shown in Figure 4.

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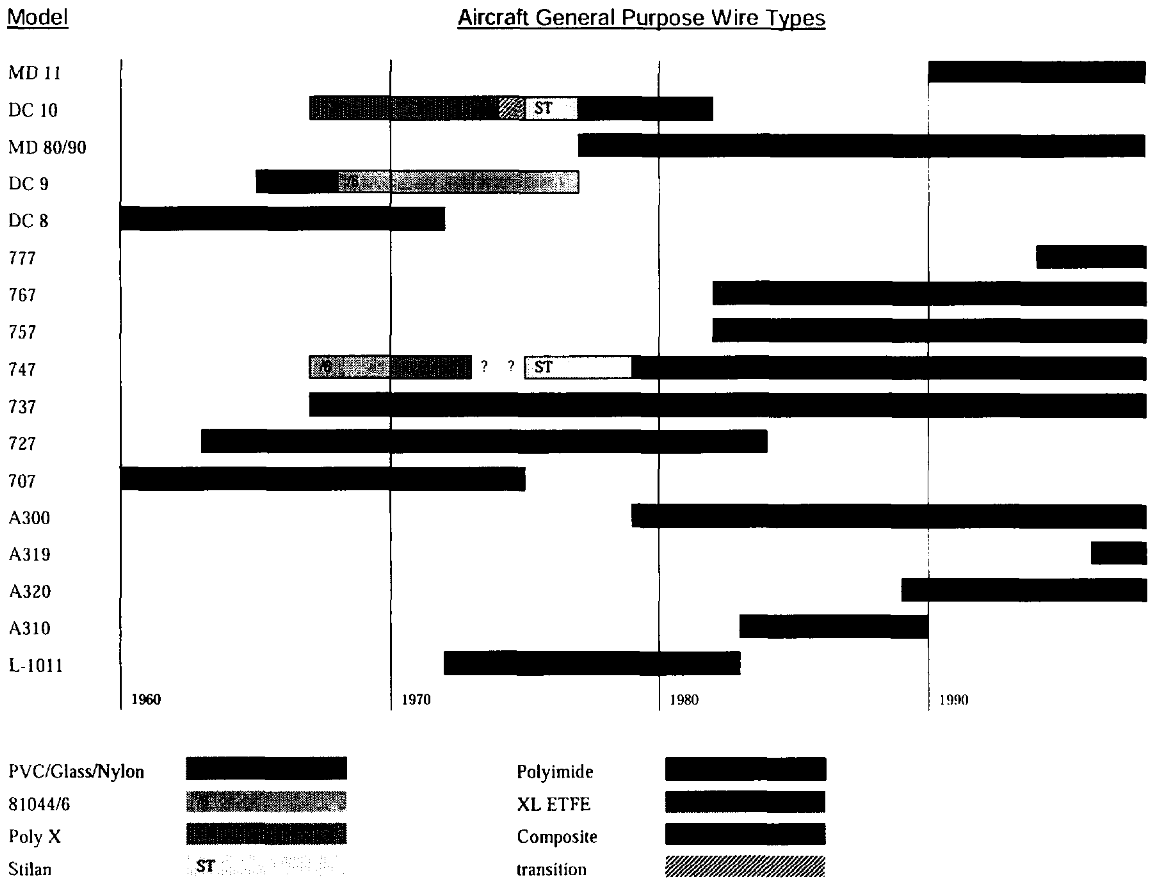
Figure 4. History of Wire Use in the Commercial Transport Fleet



This figure is intended to provide general information only. The changeover dates shown are only approximated and, since airplane manufacturers typically continue to use existing stock until it is exhausted, the actual changeovers may have taken considerable time. Thus, trying to determine the wire type installed based on the date of manufacture of an airplane is not necessarily accurate.

Nevertheless, it is obvious that quite a few wire types have been used in the commercial fleet over the years. Each of the wire types introduced was thought at the time of its introduction to be a major step forward in wire technology. While most actually were steps forward, some were almost immediately superseded by newer and better products.

Almost all wire types have developed one or more problems in service, which were unexpected at the time of introduction and which provided opportunity for the next improvement. These in-service problems were detected and are now controlled in both the commercial and military fleets through the industry's continuing inspection process and service difficulty review process.

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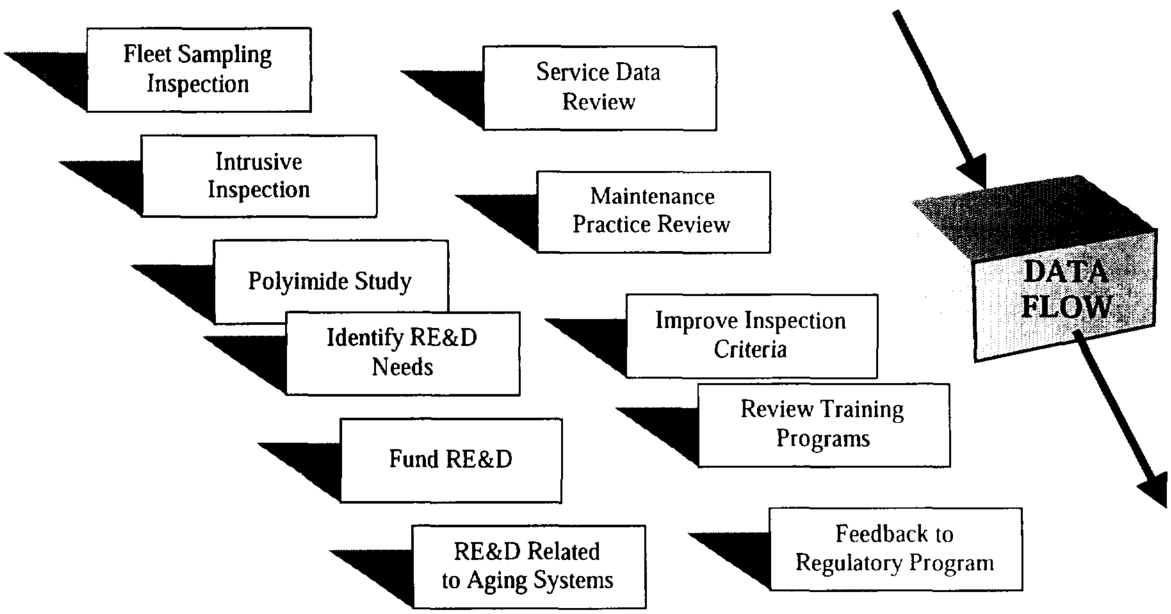
Based on this past experience, we should expect the newer wire types to start showing their own idiosyncrasies over time. We also can expect those problems to be different from what has been seen on earlier wire types. Accordingly, we need to be sure that our standard inspection techniques are capable of looking for and finding new and unexpected problems.

The FAA's Aging Systems Program

The FAA's Aging Non-Structural Systems Plan was developed in response to a recommendation of the White House Commission on Aviation Safety and Security that stated: *"In cooperation with airlines and manufacturers, the FAA's Aging Aircraft program should be expanded to cover non-structural systems."* The Commission expressed concern that *"existing procedures, directives, quality assurance, and inspections may not be sufficient to prevent safety-related problems caused by the corrosive and deteriorating effects of non-structural components of commercial aircraft as they age."*

To address the issues raised by the Commission, the FAA formed a team to inspect several older airplanes to determine the condition of the wiring and other systems components, and to determine what steps would be necessary to address any safety issues found. As a result, the team identified several areas of concern , most of which were associated with electrical systems, and developed a plan to address them.. The broad outline of the plan is illustrated in Figure 5:

Figure 5. Aging Systems Plan: Overview



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The plan is a data-driven approach to the problems identified. It is essential that any actions taken to revise maintenance, inspection, and training processes are based on real data concerning real problems with the commercial transport fleet.

The team's initial step was to gather data through fleet sampling inspections and a review of manufacturers' service data. These data will then serve as the basis for identifying any necessary follow-on actions to be taken, ranging from the design of additional inspections, to the issuance of necessary Airworthiness Directives, to the implementation of improvements in inspection, maintenance, and training programs. If the data indicate that no change is needed, this should be identified as well. The data also will be used to help guide a long-term research program and training improvements for FAA engineers and designees.

The heart of the plan is the "Aging Transport Systems Rulemaking Advisory Committee." The plan calls for the establishment of this Advisory Committee to serve as a means for obtaining public and industry input in discussions on both the magnitude of the aging systems problem and the means for alleviating any problems identified. Organizations represented on the Advisory Committee are identified in Table 1.

Table 1. Organizations Participating in Aging Transport Systems Rulemaking Advisory Committee

Federal Aviation Administration	FAA
European Joint Airworthiness Authorities	JAA
Transport Canada	TC
National Aeronautics and Space Administration	NASA
United States Air Force	USAF
United States Navy	USN
Aerospace Industries Association	AIA
General Aviation Manufacturers Association	GAMA
Air Transport Association	ATA
International Air Transport Association	IATA
European Association of Aerospace Industries	AECMA
International Association of Machinists	IAM
Air Line Pilots Association	ALPA
International Federation of Airworthiness	IFA
National Electrical Manufacturers Association	NEMA
Society of Automotive Engineers	SAE
Boeing	
Airbus	

- The Advisory Committee has been established to perform the same types of tasks that were carried out earlier by the Aging Airplane Working Group (AAWG) in their work to address structural issues in the wake of the Aloha accident. The Advisory Committee's specific tasks include:

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- inspection of older airplanes to determine the condition of their systems;
- review of service bulletins concerning systems to determine whether they should be made mandatory through the Airworthiness Directive process;
- review of maintenance practices and training programs in light of inspection results, and recommendations for changes to applicable maintenance practices; and
- improvement of standard wiring practice manuals.

The FAA has some additional tasks assigned: The major one of these is the establishment of a program of aging systems research, engineering, and development (RE&D). Other tasks include improving the quality of wiring installation drawings and service data for modifications to airplanes, and improving the reporting of accident/incident and maintenance activities related to wiring system components.

The tasks assigned to the Advisory Committee and to the FAA are shown in Figure 6.

Figure 6. Assigned Tasks

Tasks Assigned to the Advisory Committee:	**Tasks Assigned to the FAA:**
• Fleet sampling inspection	• Support to the Advisory Committee
• Service data review	• Research, engineering & development (RE&D)
• Maintenance and inspection improvements	• Improved problem reporting methods
• Update wiring practice manuals	• Improved wiring data definition for modifications
• Training improvements	

Progress on Aging Systems Plan Objectives

This section contains a brief report on the status of the FAA's Aging Systems Plan's organizational activities and progress on several of the plan's objectives. Specific objectives to be discussed include the fleet sampling inspections, intrusive inspections, service data review, and wire problem reporting improvement tasks. Information specifically concerning the FAA's RE&D program related to aging systems is contained in a separate report.

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Inspection Task and Results to Date

The Advisory Committee identified the need to evaluate the condition of wiring in the context of the commercial transport airplane certification, maintenance and operational environments. That is:

- What is the status of wiring in the aging fleet?
- What problems exist?
- How can the problems be remedied within the civil aviation environment?

This task also can be seen as an evaluation of the maintenance programs currently in place. The ideal maintenance program would preclude aging issues by identifying and correcting wiring problems before they become safety issues. An important product of the inspection program, therefore, is an evaluation of how well the existing maintenance environment performs these functions.

Each problem identified must be judged as to the likelihood of occurrence, the resultant effect on the airplane as a system, and the overall hazard resulting from the occurrence. If the problems found during the inspection phase, including intrusive inspections, are minor, then the maintenance processes may be adequate; however, an evaluation of this sort should be expected to turn up opportunities for further improvement of adequate systems.

This task envisioned a sampling inspection of U.S. commercial transport airplanes that were over 20 years old and a review of manufacturers' service information for significant problems. In accordance with an FAA suggestion, the Advisory Committee assigned the inspection and service review tasks to the Air Transport Association (ATA) Aging Systems Task Force (ASTF), in order to take advantage of work in this area that had already been done by industry. The ASTF was an independent program begun by ATA to inspect the electrical systems on older airplanes (i.e., of ATA member airlines) to determine whether inspection and maintenance changes might be needed. The Advisory Committee augmented the group with representatives from the Air Force, Navy, Transport Canada, International Air Transport Association (IATA), FAA, Joint Aviation Authorities (JAA) of Europe, Society of Automotive Engineers (SAE), National Electrical Manufacturers Association (NEMA), and a representative of the National Air Disaster Alliance/Foundation (NADA/F).

This expanded group has continued the work of the ASTF and has essentially completed the non-intrusive inspections of in-service airplanes. The group found no significant systemic problems related to safety as a result of their inspections. (Mr. Dave Marcontell of Airborne Express is the chair of the team. His discussion of inspection results to date appears in another paper and will not be repeated here.)

The ASTF's review of service data currently is under way. A list of key words has been developed with input from interested parties including the National Transportation Safety Board. The airplane manufacturers have conducted key word searches of service data to identify those documents that will need to be reviewed by teams for each major model of large turbofan airplane over 20 years old. The model-specific task groups in the ASTF are now evaluating the service data for problem significance. It should be remembered that this service information is part of the overall maintenance activities under scrutiny in the inspection task described above. If the process is working well, the problems covered in service data should not be observed during the inspections, because standard maintenance processes should have corrected any

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problems as a result of service data. If such corrections have not happened, the standard maintenance processes would need to be reviewed and adjusted if appropriate.

One interesting problem became evident in the initial review of service data on wiring. Revisiting Figure 4, note that, with the exception of the Lockheed L-1011, the airplanes over 20 years old are unlikely to have polyimide insulation, except as wiring added later during modification or refurbishment. Because of the almost universal use of this wire type after about 1980, and because there is some public controversy concerning this type of wire, it clearly would be prudent to study possible aging issues related to polyimide, even though the airplanes with polyimide wire may not have reached their design life goal at this time. The ASTF has recommended that a special effort be made to look at polyimide wire as part of the intrusive inspection process described below. The Advisory Committee has concurred with that suggestion and work currently is under way to plan appropriate inspection work.

The ASTF began its activities with a fleet survey inspection. While this ASTF effort was a good start and provided useful data for follow-on work, it was non-intrusive. This means that only close visual inspections were conducted, without disturbing wiring. While these inspections have generated a great deal of information, they cannot, by their nature, provide information on the condition of wiring in inaccessible areas or the condition of the interior of wire bundles. The ASTF recognized this problem early on. To offset it, they began identifying aircraft that were being taken permanently out of service, and planned to subject those airplanes to the invasive inspections, thus allowing collection of data that were not obtainable from in-service airplanes..

Initially, the ASTF had planned to do intrusive inspections of a number of airplanes, with the work actually being done by individual airlines. However, as a result of an ASTF recommendation to the Advisory Committee, the intrusive inspections are now being planned by another small working group and will be carried out by a contractor under the FAA's RE&D effort. Having one organization conduct the inspections will allow the inspection to be standardized, and will enable more more time and effort to be spent on this project than originally was budgeted by the airlines. In addition, it will allow the FAA to sample wiring for additional aging studies under the RE&D program.

The intrusive inspections will include all wire types available on the aircraft being scrapped. Thus, the inspection will provide data that is oriented towards the wire type, installation details, and environment issues, as opposed to merely model-specific issues. Special emphasis will be placed on newer wire types that were not seen in the non-intrusive inspections. Concentration will be on inspecting and testing wiring in situ, and then obtaining samples of these newer wire types in airplanes being extensively modified, such as the DC-10 airplanes currently undergoing conversion to the MD-10 two-person crew configuration and other airplanes being converted to freighter configurations.

Improvements in Wire Problem Reporting

While this task was assigned to the FAA's Office of System Safety and Aircraft Certification Service, another industry effort was needed to enable the FAA to begin its job. The codes used for problem reporting on commercial transports are derived from the ATA Specification 100 System Codes. This original philosophy of the code linked wire problems into specific systems, rather than reporting them specifically as wire problems. This has been corrected by issuance by ATA of System/Chapter 97, "Electrical Wiring Installations."

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Interested parties should contact ATA for further information about this document at their web site, www.air-transport.org.

The FAA's Office of System Safety administers the National Aviation Safety Data Analysis Center (NASDAC). This facility offers data search and analysis services for the FAA and, with some limitations on data available, for any interested user. The organization is in the process of defining advanced data search and sort services with improved display options. They are currently in the process of surveying users to define user data needs and presentation preferences. To accomplish this, they need information on our data analysis needs, the limitations of data bases, and potential future improvements in reporting. Interested organizations should contact the Office of System Safety through the FAA web site at www.faa.gov for additional information.

Conclusion

The FAA's Aging Systems Program discussed in this paper is intended to be a proactive program, focusing on ensuring that the right processes are in place throughout industry to make certain that, as wiring and other systems on aircraft age, safety is not compromised. It is a cooperative joint venture between the FAA, the airplane manufacturers, and the airlines. Each of these participants is a major "stakeholder" in the aviation safety goal to ensure that, as airplanes age, their structural and non-structural components are adequately inspected and maintained as long as an airplane remains in commercial service. While the current system has been very effective in making sure that the aging fleet of airplanes remains airworthy, the efforts of the Aging Systems Program aims to make this very safe system even safer.

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DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE

Copy: Swaim

10 September 1999

HQ USAF/SE
9700 Ave G SE, Suite 240
Kirtland AFB, NM 87117-5670

Mr. Thomas E. Haveter
National Transportation Safety Board
Chief Major Investigation Division
490 L'Enfant Plaza, SW
Washington, D.C., 20594

Dear Mr. Haveter

In response to questions which arose during the National Transportation Safety Board Public Hearing on 8-12 December 1997 regarding TWA Flight 800, please find the attached letter from HQ AFMC/JA. I hope this answers the questions for you.

Regarding questions h and i, please note that the programs to which we refer did not exist at the time the questions were asked in December, 1997. If you have any questions, please contact Col. Robert Osterholtz, HQ AFSC/SEF, at (505) 846-0644.

Sincerely

FRANCIS C. GIDEON, Jr.
Major General, USAF
Chief of Safety

Attachment:
HQ AFMC.JA Letter dated 30 Aug 99

USAF LETTER OF SEPT 10, 1999

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE OHIO

30 Aug 99

MEMORANDUM FOR HQ USAF/SE

FROM: HQ AFMC/JA

SUBJECT: Air Force Questions Resulting from the TWA 800 National Transportation Safety Board Hearing of 8-12 December 1997

1. In response to your 14 November 1997 memo, engineers from the Aeronautical System Center (ASC) and Air Force Research Laboratories (AFRL) participated in the National Transportation Safety Board (NTSB) TWA 800 Public Hearing in Baltimore, Maryland, on 8-12 December 1997. During the Air Force (AF) technical testimony, a series of follow-up questions were asked which could not be answered during the proceedings. The questions centered on indications that the center wing fuel tank of TWA 800, a 747-type aircraft, had exploded in-flight. An ignition source has yet to be identified, but concerns over wiring, fuel probes, and tank maintenance practices were at the center of the questioning. Following are all the unanswered questions, with answers provided.

a. *Why did the AF begin to look at fuel probes, and how did we come to find copper sulfide deposits in the first place?*

The earliest involvement by AFRL/MLSA resulted from a Sacramento Air Logistics Center (SA-ALC/MMIB) letter, 28 July 1989, referencing two fuel probe compensators removed from the T-37 because of possible electrical arcing evidence noted by maintenance. The T-37 probe did exhibit arcing evidence; however, it occurred with the probe on a test stand rather than being installed in the aircraft. In November 1989, the KC-135 SPO requested AFRL/MLSA examine fuel probes removed due to inaccurate fuel readings and arc-like residues. AFRL/MLSA established that what appeared to be arcing evidence was actually a conductive residue of copper and sulfur sufficient to cause errors in probe measurements.

b. *What are the electrical bonding requirements in tanks, and are there scheduled checks?*

There has never been any specific requirement in Electromagnetic Compatibility (EMC) standards mandating periodic checks for any EMC issue, including bonding. In general, bonding requirements for fuel tanks deal with preventing sparks due to static charging, power current faults, and lightning. Bonds are not normally checked unless a part is removed for maintenance. The E-4 and VC-25 electrical bonding requirements internal to fuel tanks are the same as those established by Boeing for the commercial fleet. Bonding checks are performed only if maintenance is performed in the area or when components are replaced. There are no scheduled periodic bonding checks.

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c. *Why did the USAF switch from JP-4 to JP-8?*

The USAF conversion program from JP-4 to JP-8 was initiated in October 1993. The advantages are improved safety, aircraft survivability, interoperability, and environmental compliance. The basic safety advantage of JP-8 over JP-4 is its lower volatility properties, thus making it more difficult to ignite at normal operating conditions. The Continental United States conversion to JP-8 also resulted in one universal military fuel being used by all North Atlantic Treaty Organization forces.

d. *For the record, what was the voltage and current level of the MD2A probe tester? How much energy was available? (This is in reference to the T-37 fuel probe that ignited fuel vapors when tested outside of the aircraft.)*

Specification MIL-T-4687B, 9 October 1967, Tester, Capacitor-Type Fuel-Quantity Gauge Tank Unit, Type MD-2A, paragraphs 3.4.8.2 and 3.4.8.3, states that direct current voltage shall not exceed 50 volts, and current shall not exceed 200 milliamps during resistance measurements. Since electrical power is applied continuously during the test, energy generated is a function of the length of the application. What is significant is the amount of energy that can be generated rapidly and can contribute to a hot spot or single event discharge. While this condition is difficult to quantify, one relevant measure is the amount of energy deposited before heat transfer effects start playing a significant role in dissipating the heat. For example, the application of the maximum voltage and current for an arbitrary time of 10 milliseconds (typical time for thermal equilibrium to occur in some circuitry) will provide an energy of 100 millijoules ($E=V*I*T$, $V=50$, $I=0.2$, $T=0.01$).

e. *Find out the differences between the AF center wing tank maintenance practices and Federal Aviation Administration (FAA) requirements. Primarily interested in discrepancies that could affect safety.*

The same center wing tank maintenance practices used by the commercial fleet (and thus per FAA requirements) are used for the E-4 and VC-25. There is no difference.

f. *How is information about fuel system problems transferred to the commercial sector (companies and FAA)? If you find a discrepancy in the fuel probes, or if you find a defect, how do you get this information to similar users in the civilian arena?*

Industry committees, such as the Society of Automotive Engineers and Electronic Industries Association committees, provide forums for exchange of general information and experience. The Government/Industry Data Exchange Program (GIDEP), operated by the Department of Defense (DoD), exists to exchange information among agencies and industry regarding nonconforming products that adversely affect safety and health, among others. Among the many participating organizations are the United States Army (USA), United States Navy (USN), United States Air Force (USAF), Defense Logistics Agency (DLA), and the FAA. In the case of E-4 and VC-25, Boeing is notified immediately of any discrepancy or defect related to the fuel system. Boeing in turn evaluates the impact on the commercial fleet and notifies the commercial customers and the FAA if necessary.

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g. *What interface is there at the government and industry level so the military and commercial experience, with respect to safety, can be transferred?*

The GIDEP, operated by DoD, exists to exchange information among agencies and industry regarding nonconforming products that adversely affect safety and health, among others. Among the many participating organizations are the USA, USN, USAF, DLA, and the FAA.

h. *Is there an aging wire program, and is there a predicted end of lifetime for wiring?*

Wire is typically designed to function for the life of the airframe. In many cases, this is assumed to be a 20-year life at maximum use temperature. Wiring rarely, if ever, reaches its maximum operating temperature and, therefore, should last much longer than 20 years. Wire is typically replaced because of upgrades to avionics, and in some cases due to high failures or for conditions that lead to safety of flight concerns in specific areas. The AF is flying many aircraft today that have wiring much older than 20 years. Inspection of aircraft that have been in the field for many years, have not identified any general aging issues (chemical changes) for wiring in those areas protected from severe wind and moisture (known as SWAMP areas), frequent flexing, or high maintenance. The Aging Aircraft Support Product Group has currently under contract the Enhanced Aircraft Wiring Integrity Test Station program. The purpose of the program is to identify fault isolation techniques to reduce the number of iterative cycles needed to isolate wiring faults such as frayed wires, opens, shorts, and insulation breakdown.

i. *How does the AF coordinate aging programs with the FAA and other organizations, and what types of programs are planned for electronics?*

The Joint FAA/DoD/NASA conference on Aging Aircraft, in its third year, provides a forum to bring together world leaders in aviation safety research, aircraft design and manufacturing, fleet operation, and aviation maintenance to disseminate information on current practices and advanced technologies. The FAA recently announced a multi-year plan to enhance safety of non-structural aging aircraft systems. This includes aging issues for electrical wiring, connectors, wiring harnesses, and cables; fuel, hydraulic and pneumatic lines; and electro-mechanical systems such as pumps, sensors, and actuators. For more information, refer to the FAA Office of Public Affairs Press Release titled "FAA Unveils Plan To Enhance Safety of Aging Aircraft Systems" October 1, 1998. It can be accessed at the FAA web site at *http://www.faa.gov/apa/pr*.

j. *Does the AF have a periodic inspection or replacement plan for fuel probes and fuel tank wiring?*

There is no general requirement for inspection or replacement of fuel probes and fuel tank wiring. Some individual aircraft programs have elected to institute inspections. For example, the C/KC-135 SPO began a rewire program in 1991 to replace its aged aircraft wiring. As a result of the rewire program, the aircraft wiring of all 25 KC-135 mission critical systems, including the electrically actuated fuel pumps and the Fuel Quantity Indicating System have been replaced. In 1994, for reasons of reliability of the probe and not safety, the AF began replacing the fuel probes in the wing tanks during depot maintenance.

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2. Request you formally transmit our responses to the National Transportation Safety Board to inclusion in their final report. Points of contact are Ms. Beatriz Rodriguez, ASC/ENFA, (937) 255-5908, Mr. Brennan Roberts, OC-ALC/LKRM, (405) 736-7993, and Mr. Scott McLennan, HQ AFMC/ENPM, (937) 257-5577.

SAMUEL R. HILKER
Principal Deputy
Staff Judge Advocate

USAF LETTER OF SEPT 10, 1999