IN-20

*NASA Conference Publication 10177*

# Third NASA Workshop on Wiring for Space Applications

(NASA-CP-10177) THIRD NASA WORKSHOP ON WIRING FOR SPACE APPLICATIONS (NASA. Lewis Research Center) 233 p

N96-17077
--THRU--
N96-17098
Unclas

G3/20 0092362

*Proceedings of a workshop held at*
*NASA Lewis Research Center*
*Cleveland, Ohio*
*July 18–19, 1995*

*NASA Conference Publication 10177*

# Third NASA Workshop on Wiring for Space Applications

*Proceedings of a workshop held at and sponsored by NASA Lewis Research Center Cleveland, Ohio July 18–19, 1995*

National Aeronautics and Space Administration

Office of Management

**Scientific and Technical Information Program**

1995

# PREFACE

This document contains the proceedings of the Third NASA Workshop on Wiring for Space Applications held at NASA Lewis Research Center (LeRC), Cleveland, Ohio, July 18-19, 1995. The workshop was sponsored by NASA Headquarters/Code XS Office of Space Access and Technology, Spacecraft Systems Division and hosted by the NASA LeRC Power Technology Division, Electrical Components and Systems Branch. The workshop addressed key technology issues in the field of electrical power wiring for space applications, and served as a vehicle for the transfer of information and technologies related to space wiring for use in government and commercial applications.

Overview and test results of the ongoing NASA space wiring program as well as related programs from other agencies were presented. In addition, this workshop provided a forum in which government and industry representatives were able to discuss issues relating to arc tracking phenomena, advancements in insulation materials and constructions, and new system topologies. The objective of these efforts is to enhance the safety and improve the reliability of space missions, and military and commercial aircraft applications.

The workshop chairmen express their appreciation to the session organizers, speakers, and participants, whose efforts contributed to the technical success of this event. Thanks are also due to Ms. Billie Hurt, Ms. Barbara Coles, and Ms. Audrey Gurski for their relentless efforts in providing a well prepared and very efficient and organized workshop.

Workshop Chairmen:

Ahmad N. Hammoud
Mark W. Stavnes

# TABLE OF CONTENTS

omit to p. 3

# THIRD NASA WORKSHOP ON WIRING FOR SPACE APPLICATIONS

## SUMMARY

The Third NASA Workshop on Wiring for Space Applications was held at NASA Lewis Research Center, Cleveland, Ohio, July 18-19, 1995. The workshop was sponsored by NASA Headquarters, Code XS, Office of Space Access and Technology, Spacecraft Systems Division and hosted by the NASA LeRC Power Technology Division, Electrical Components and Systems Branch. The workshop addressed key technology and development issues pertaining to electrical power wiring for space-based applications.

The workshop was organized into three sessions. Session I provided overviews of various organizations that support programs pertaining to wiring systems. A detailed overview of the NASA Office of Space Access and Technology organization, structure, charter, and operating plans was given. The NASA Wiring for Space Applications Program with the goal of providing a technology base for the development of lightweight, arc track-resistant and reliable wiring systems for aerospace applications was also presented. Other programmatic presentations that were made included the International Space Station wiring system; the U.S. Air Force efforts to develop reliable, lightweight wire insulation system for the aircraft environment; the European Space Agency program to understand the arc tracking phenomenon and develop detection techniques and qualify wiring constructions for the Columbus module. The Federal Aviation Administration as well as the Naval Air Warfare Center programs on wiring failures, testing techniques, and efforts in regard to wiring test standardization and qualification were also discussed in this section.

Session II focused on the results of the wiring tests performed by numerous organizations to address NASA and other unique testing requirements. Experimental investigations on the effect of space environmental stresses on the performance of electrical wiring were presented and discussed. These included exposure to atomic oxygen, vacuum, ultraviolet radiation, and high temperature. Electrical, mechanical, physical, and chemical properties were among those investigated as a function of singular and multi-stress test conditions. The effect of microgravity on the arc tracking behavior of several wiring constructions was also presented and discussed. A presentation was also made on the new hybrid wiring construction (Tensolite), which was reported to be used by Boeing Commercial Aircraft on its 700-Series fleet.

Arc track testing techniques, soft-fault detection, and aging mechanisms constituted some of the issues that were discussed in Session III. Presentations were also given by industry representatives on the state of the art development in the areas of high temperature, high performance, arc track resistant wiring insulation and dielectrics for aerospace applications. These included solid and liquid polymers as well as metal-clad fiber material. The effect of the wiring systems design on electromagnetic interference and control was also discussed.

The workshop was attended by approximately 50 individuals, from the United States and Germany, comprising government, aerospace industry , wiring manufacturers, and academia. A list of the attendees and the workshop agenda are included in these proceedings.

A discussion session was held at the conclusion of the workshop with the participation of most of the attendees. The general consensus indicated that the workshop was highly successful and future collaboration and coordination of efforts for the development of safe and reliable wiring systems for aerospace applications should be maintained. It was also concluded that:

1. Arc tracking in wiring systems is still a serious problem. Sometimes its failure can be catastrophic.
2. A definite need exists for the establishment of a standard test method taking into account the various operation environments.
3. Advanced circuit protection techniques and methodologies against arc tracking should be investigated and developed.
4. Key areas in wiring system design, installation and maintenance which improve the safety and reliability of space missions need to be identified.
5. Newly-developed insulation and wiring system configurations should be explored for suitability in NASA, military, and commercial flight applications.
6. Collaboration with the Department of Defense, Federal Aviation Administration, European Space Agency, aerospace industry, and other organizations is essential.

At present, plans to hold the Fourth NASA Workshop on Wiring for Space Applications have not been set. Announcements and detailed information will be furnished in the near future.

The organizers once again express their appreciation to the volunteers, speakers, and participants in making this workshop a very interesting and successful event. The support of NASA Headquarters, Mr. Norman Schulze (Code XS), and Dr. Dan Mulville (Code QW) for this program is gratefully acknowledged.

# THIRD NASA WORKSHOP ON WIRING FOR SPACE APPLICATIONS

## Agenda

July 18 - 19, 1995
NASA Lewis Research Center
NASA Administration Building (Bldg. No. 3)
Auditorium

**Tuesday, July 18**

**Session I: ORGANIZATIONS AND PROGRAMS**

| Time | Topic | Speaker | Organization |
|---|---|---|---|
| 8:15 - 8:45 | Registration | | |
| 8:45 - 9:00 | Opening Remarks | A. Hammoud | NASA/NYMA |
| 9:00 - 9:30 | NASA Wiring Program - An Overview | N. Schulze | NASA/HQ |
| 9:30 - 10:00 | International Space Station Wiring Program | T. May | NASA/JSC |
| 10:00 - 10:15 | Air Force Wiring Program | G. Slenski | Wright Lab/WPAFB |
| 10:15 - 10:30 | Break | | |
| 10:30 - 11:00 | ESA Wiring Program | H. Reher | DASA/ERNO |
| 11:00 - 11:30 | FAA Wiring Program | P. Cahill | FAA |
| 11:30 - 12:00 | NAVAIR Aircraft Wiring Program | R. Beach | NAWC |
| 12:00 - 1:00 | Lunch | | |

**Session II: WIRING TEST RESULTS**

| Time | Topic | Speaker | Organization |
|---|---|---|---|
| 1:00 - 2:00 | NASA Wiring Program - Test Results | M. Stavnes | NASA/NYMA |
| 2:00 - 2:30 | Comparison of Arc Tracking Test in Various Aerospace Environments | T. Stueber | NASA/NYMA |
| 2:30 - 3:00 | Break | | |
| 3:00 - 4:00 | Arc Tracking of Cables For Space Applications | J. Hanson | U. of Darmstadt |
| 4:00 - 4:30 | Tour | | |

## THIRD NASA WORKSHOP ON WIRING FOR SPACE APPLICATIONS

### Agenda

July 18 - 19, 1995
NASA Lewis Research Center
NASA Administration Building (Bldg. No. 3)
Auditorium

**Wednesday, July 19**

**Session III: INSULATION AND SYSTEM TECHNOLOGIES**

| Time | Topic | Speaker | Organization |
|---|---|---|---|
| 8:15 - 8:45 | Tufflite 2000 Insulation System | J. Beatty | Tensolite |
| 8:45 - 9:15 | NAVAIR Arc Track Testing | R. Beach | NAWC |
| 9:15 - 9:45 | Feature Extraction of Arc Tracking Phenomenon | J. Attia | U. of Prairie View |
| 9:45 - 10:15 | Accelerated Aging of Aerospace Wire Insulation Constructions | W. Dunbar | Boeing/Consultant |
| 10:15 - 10:45 | Robust 300°C Wire Insulation System | W. Wong | TRW |
| 10:45 - 11:15 | Metal Clad Aramid Fibers For Aerospace Wire and Cable | E. Tokarsky | DuPont |
| 11:15 - 11:45 | Evaluation of HT Polymers For Aerospace Wiring | K. Jayaraj | Foster Miller |
| 11:45 - 12:15 | New Wiring Insulation | R. Haghighat | Triton Systems |
| 12:15 - 12:30 | Wiring Design for the Control of EMI Interference | G. Kopasakis | NASA/LeRC |
| 12:30 - 1:30 | Lunch | | |
| 1:30 - 2:30 | Discussions | R. Cull | NASA/LeRC |

SESSION I

# ORGANIZATIONS AND PROGRAMS

N96- 17078



# NASA WIRING FOR SPACE APPLICATIONS PROGRAM

Norman Schulze
Office of Space Access and Technology
Spacecraft Systems Division
NASA Headquarters
Washington, DC

## SPACE TECHNOLOGY ENTERPRISE

## NASA Code XS Overview

- **ORGANIZATION**
- **CHARTER**
- **PROGRAMS**

## NASA Strategic Plan

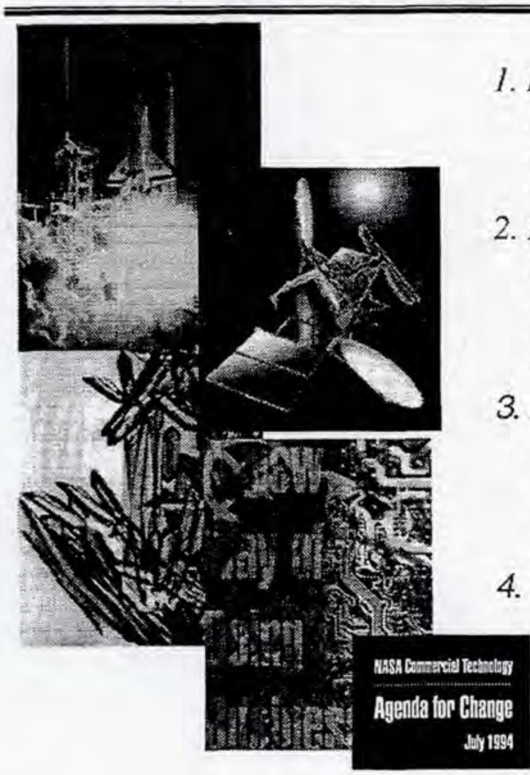
- Enterprises
  - Aeronautics
  - Mission to Planet Earth
  - Space Science
  - Human Exploration
  - **Space Technology**
- Function
  - Communications
  - Human Resources
  - Physical Resources

# SPACE TECHNOLOGY ENTERPRISE

## *Mission*

**Pioneer,With Industry, the Development and Use of Space Technology to Secure National Economic Competitiveness, Promote Industrial Growth and to Support Space Missions**

# *Space Technology Enterprise Goals*




1. *Reduce the Cost of Access to Space*
   - Reusable Launch Vehicle
   - Expendable Launch Vehicle
   - In-Space Transportation
2. *Provide Innovative Technologies to Enable Ambitious, Future Space Missions (ITP)*
   - Spacecraft Systems (Power, Propulsion, Structures, etc.)
   - Instrument Technologies
   - Operations
3. *Build Capability in the U. S. Space Industry Through Focused Space Technology Efforts*
   - Communications
   - Remote Sensing
   - Space Processing
4. *Share the Harvest of Space Technology with the U.S. Industrial Community*
   - Technology Transfer - "Agenda for Change" (New Way of Doing Business)

# Space Technology Enterprise

## *Operating Principles !*

- Meet the Customers Needs
- Work With Industry
- Reduce the Cost of Access to Space
- Commercialization of Space Is Essential to NASA
- Commercialization and Technology Transfer Is Everybody's Job
- Consider Commercialization at Technology Program Initiation
- Effectively Use Space Station

# CUSTOMERS

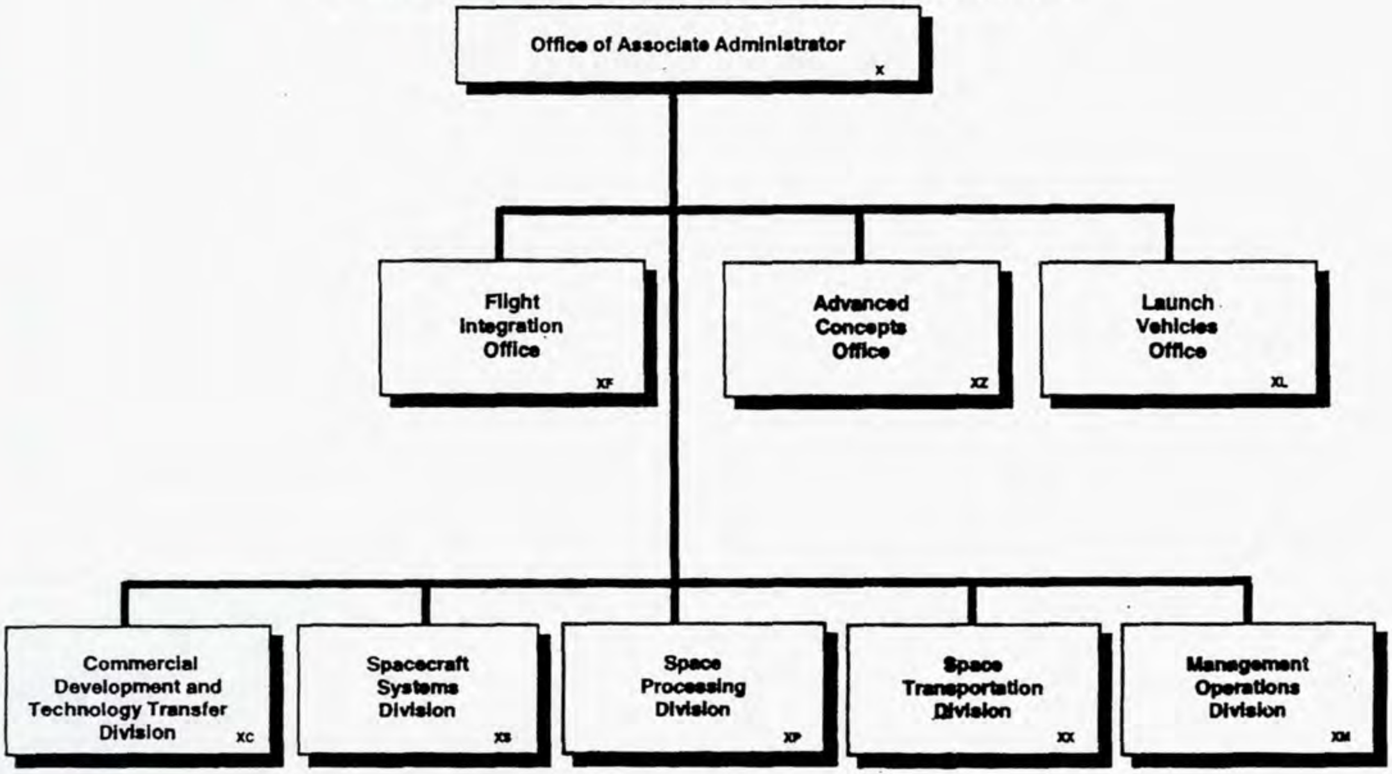
**MISSION ENTERPRISES** — *New Plateaus of Technical Capability*

**OTHER AGENCIES** — *Mission Enhancement*

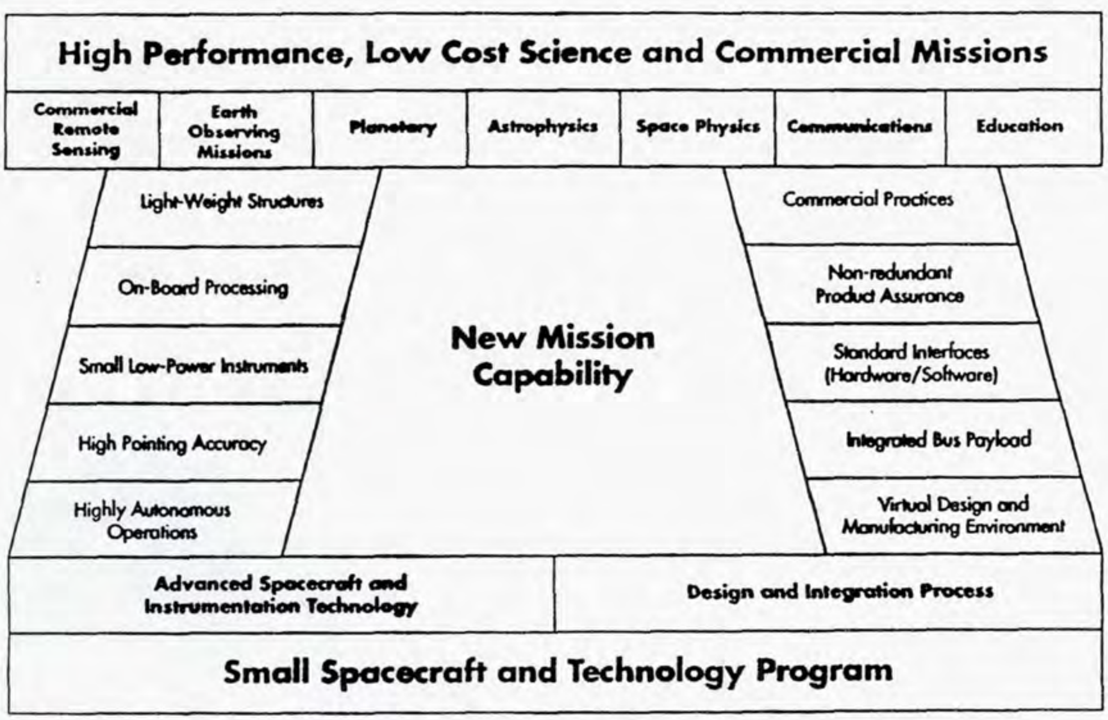
*Increased International Competitiveness* — **AEROSPACE INDUSTRY**

*New Products & Services* — **NON-AEROSPCE INDUSTRY**

## OFFICE OF SPACE ACCESS AND TECHNOLOGY




## *Foundation for Future Missions*



## NEW MILLENNIUM / ESSP

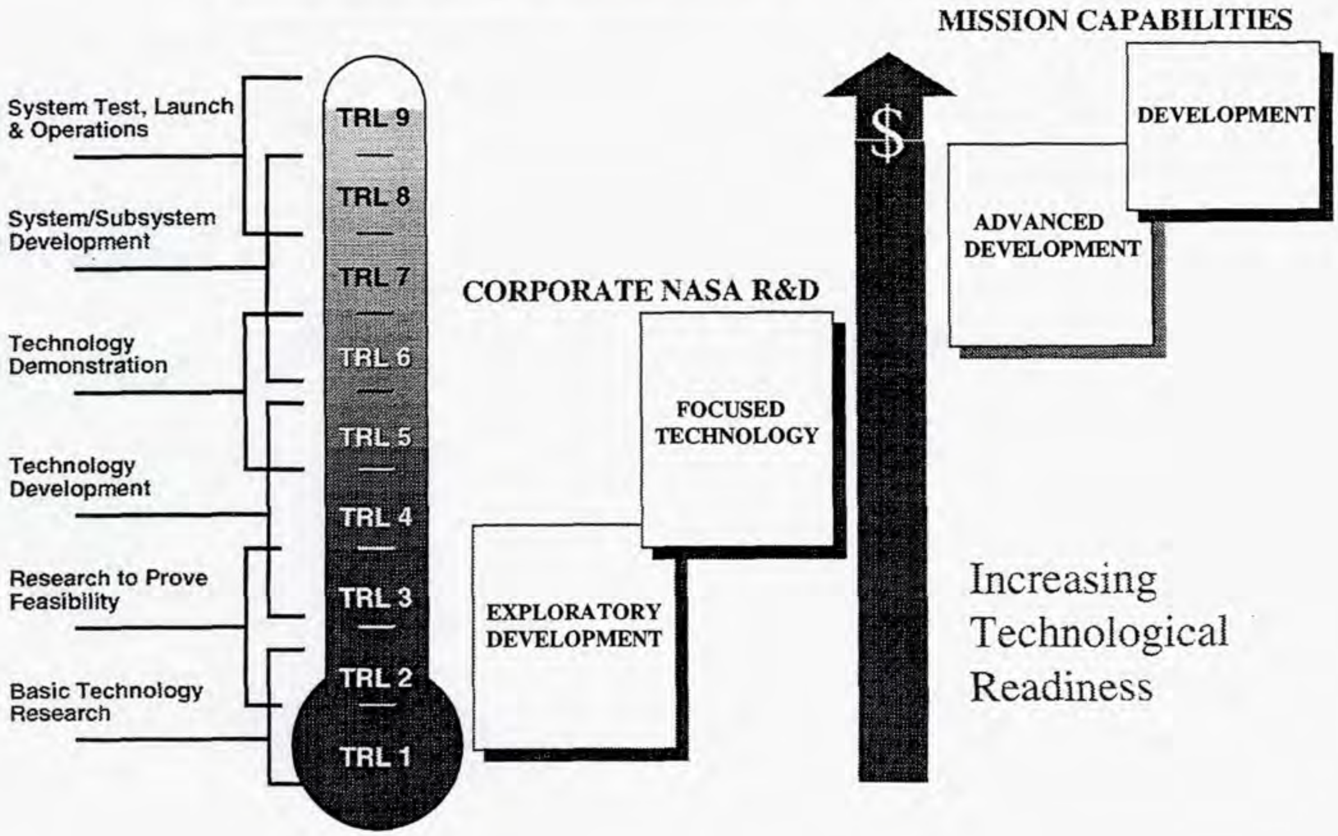
# CHALLENGES

- **Replace large, multi-instrument spacecraft with multiple small single instrument "sciencecraft"**
  - **Change focus from "instruments on a spacecraft" to "the instrument is the spacecraft"**
- **Return information, not data**
- **Wide, unconstrained interaction with users and information distribution to users**
- **Low initial cost, low operations cost**

# *Small Spacecraft Tech Initiative*

- **Lewis**
  - **Payloads**
    - **Hyper Spectral (30M, 358 Bands)**
    - **UV cosmic measurement**
    - **Cloud detection/editing**
  - **20 Technology Demonstrations**
    - **Integrated Thermal/Structural Design**
    - **Advanced power concepts**
    - **Autonomous on-orbit maintenance**
    - **Advanced C&DH and data bus arch.**
    - **Data compression**
- **Clark**
  - **Payloads**
    - **3-meter panchromatic (world view)**
    - **CO detection in atmosphere**
    - **Room temp. X-Ray detectors**
  - **36 Technology Demonstrations**
    - **Advanced attitude control**
    - **Advanced photovoltaic concepts**
    - **Advanced power management and distribution**
    - **On-board processing**
    - **No shock release devices**

# Technology Readiness Levels (TRLs)



# TECHNOLOGY ENTERPRISE STATUS

## Access to Space

- National Space Transportation Policy Issued, NASA Implementation Plan Approved by OSTP & OMB
- Cooperative Agreements for X-33 & X-34 Signed With Industrial Partners
- 2000 Hour Ground Test of Ion Flight Experiment Prototype Thruster Successfully Completed

## Innovative Technologies

- Parallel Contracts for SSTI Awarded, spacecraft construction started, launch date established and launch vehicle selection completed.
- New Millennium Spacecraft Technology Program Defined With Codes S & Y
- Mars Pathfinder Micro-Rover Fabrication Nearing Completion

## Space Applications

- ACTS Fully Operational
- Commercial Remote Sensing Program Has Leveraged $38.5M of Industry Funding, and Led to the Creation of 25 New Products, Over 140 New Jobs, and Revenues Exceeding $66M and Is Developing Hyperspectral Capability Which Will Enable Movement Into New Markets
- Starting Large Animal Trials on Diabetes Treatment, Based on in-Space Developed Technology of Microencapsulation

## Technology Transfer

- Agenda for Change Plan Approved, Agency-Wide Team Established, Performance Measurement Metrics Collected, and Technology Transfer Principle Added to NASA Strategic Plan

# SPACE TECHNOLOGY ENTERPRISE

## *SUMMARY IMPLEMENTATION STRATEGY!*

- **Develop Technology in Cooperation With and Responsive to User Requirements, With Upfront Consideration of Dual Use**
- **Proactively Transfer Technology to NASA Missions, Other Agencies and Aerospace and Non-Aerospace Industries**

# Background

*SPACE MISSIONS WITH ELECTRICAL WIRING SYSTEM FAILURE*

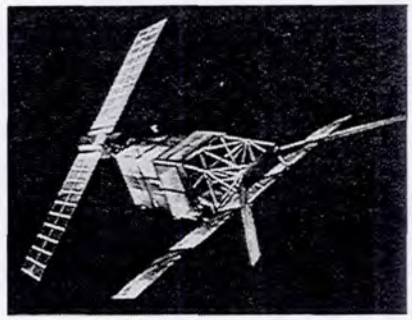
| Mission | Cause | Result |
|---|---|---|
| Gemini 8 | Electrical Wiring Short | Shortened Mission - Near Loss of Crew |
| Apollo 204 | Damaged Insulation, Electrical Spark, 100% $O_2$ | Fire, 3 Astronauts Lost |
| Apollo 13 | Damaged Insulation/Short Circuit/Flawed Design | Oxygen Tank Explosion, Mission Incomplete |
| STS - 6 | Abrasion of Insulation/Arc Tracking | Wire Insulation Pyrolysis 6 Conductors Melted |
| STS - 28 | Damaged Insulation/Arc Tracking | Teleprinter Cable Insulation Pyrolysis |
| Magellan | Wrong Connection, Wiring Short | Wiring Insulation Pyrolysis - Ground Processing |
| Spacelab | Damaged Insulation/Arc Tracking | Wiring Insulation Pyrolysis During Maintenance |
| Delta 178/GOES-G | Mechanical or Electrochemical Insulation Damage | Loss of Vehicle |
| ESA - Olympus | Electrical Wiring Short | Loss of Solar Array |

# NASA Wiring for Space Applications Program

- **OBJECTIVES:**
  - Improve safety, performance, and reliability of wiring systems for space applications
  - Develop improved wiring technologies for NASA flight programs and commercial applications

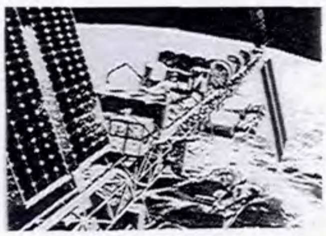
## ELECTRICAL POWER WIRING PROGRAM

GOAL: TO PROVIDE A TECHNOLOGY BASE FOR THE DEVELOPMENT OF LIGHTWEIGHT, ARC TRACK-RESISTANT AND RELIABLE WIRING SYSTEMS FOR AEROSPACE APPLICATIONS.



### APPROACH

- IDENTIFY MISSION REQUIREMENTS AND APPLICATION ENVIRONMENTS
- EVALUATE POTENTIAL WIRING SYSTEMS AND ESTABLISH A DATABASE
- INVESTIGATE ADVANCED TECHNOLOGIES RELEVANT TO WIRING FAILURE PREVENTION, DETECTION, AND ISOLATION.
- ESTABLISH GUIDELINES AND RECOMMENDATIONS

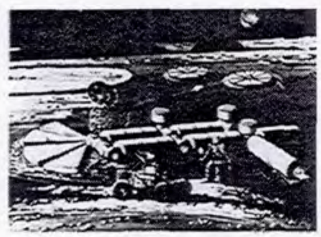


### TECHNOLOGICAL DEVELOPMENTS

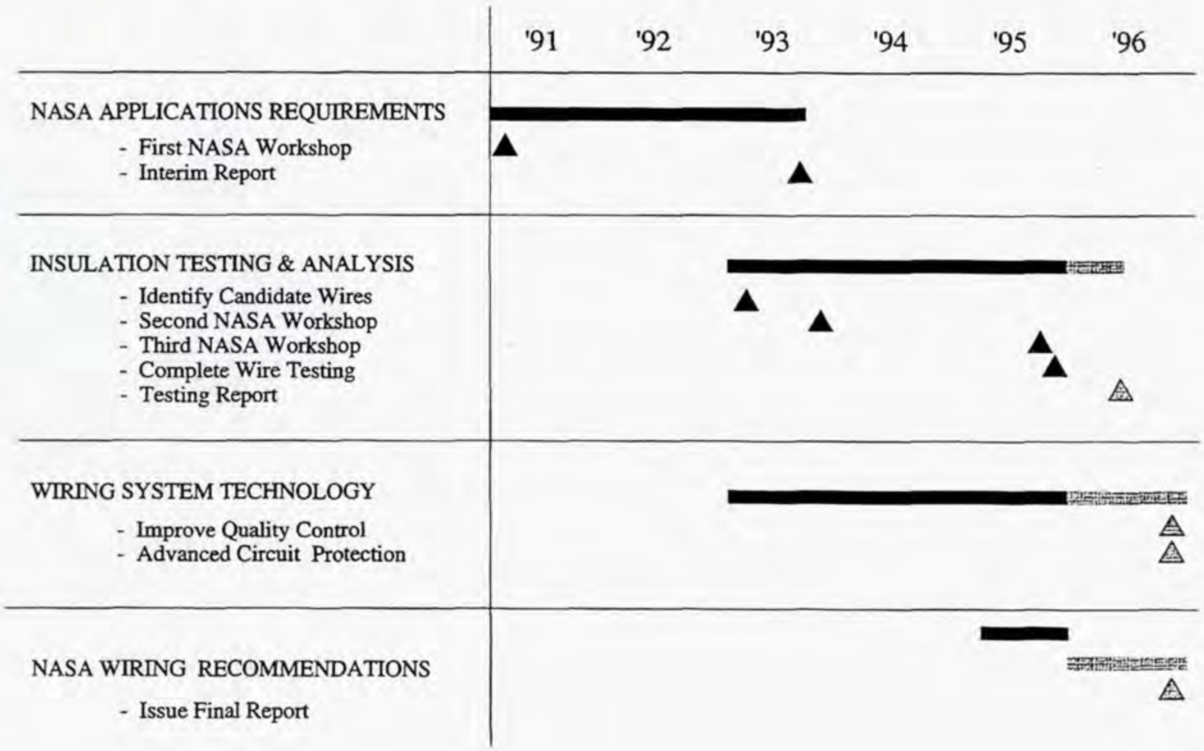
- NEW INSULATING MATERIALS
- NEW WIRING CONSTRUCTIONS
- IMPROVED SYSTEM DESIGN
- ADVANCED CIRCUIT PROTECTION

### APPLICATIONS

- PRESSURIZED MODULES
- TRANS-ATMOSPHERIC VEHICLES
- LEO/GEO ENVIRONMENTS
- LUNAR AND MARTIAN ENVIRONMENTS



# NASA Wiring for Space Applications Program




- **<u>ACCOMPLISHMENTS:</u>**

  - First Workshop, July 1991:
    - Wiring system operational experience
    - NASA wiring requirements
    - Wire manufacturing technologies

    **Proceedings: "First NASA Workshop on Wiring for Space Applications", NASA CP-10145, July, 1994**

  - Interim Report, June 1993:
    - NASA spacecraft environments
    - NASA unique testing requirements
    - Related wiring programs

    **Report: "Operational Environments for Electrical Power Wiring on NASA Spacecraft", NASA TM-106655, June 1994**

  - Second Workshop, July 1993:
    - Program overviews: NASA, AF, NAWC, ESA
    - Space wiring failures
    - Candidate wiring constructions
    - New wiring insulation
    - Test methodology and standardization

    **Proceedings: "Second NASA Workshop on Wiring for Space Applications", NASA CP-3244, October, 1993**

# NASA Wiring for Space Applications Program

- **R & D PROGRAMS:**
  - System design
  - Candidate wiring constructions
  - New insulating materials
  - Protection techniques
  - Quality control

- **ORGANIZATIONS:**
  - NASA
  - DOD laboratories
  - FAA
  - Aerospace Industry
  - ESA
  - Academia
  - Technical committees

ORIGINAL PAGE
COLOR PHOTOGRAPH

## Tests Performed vs. Wiring Constructions Matrix.

| Construction \ Test | Examine Product | Workmanship | Wire Wall Thickness | Conductor Diameter | Finished Diameter | Finished Weight | Wire Surface Markability | Impulse Dielectric | Insulation Resistance | Spark Test | Dry Dielectric Test | Voltage Withstand | Dielectric Constant | CIV/CEV (AC & DC) | Surface Resistance | Time/Current to Smoke | Wire Fusing Time | Dry Arc Resistance | BSI Dry Arc Resistance | Arc Tracking - SSF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIL-W-81381/7 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ |
| MIL-W-81381/11 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ |
| MIL-W-22759/12 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |
| MIL-W-22759/16 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🔴 |
| MIL-W-22759/18 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |
| MIL-W-22759/32 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |
| MIL-W-22759/34 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🔴 |
| MIL-W-22759/43 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ |
| MIL-W-16878 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🔴 |
| SSQ-21652 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🔴 |
| SSQ-21656 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🔴 |
| MP571-0086 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🔴 |
| Filotex - TKT | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ |
| Tensolite - TKT | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ |
| Thermatics - TKT | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🔴 |
| Gore HS-725 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚪ | ⚫ | ⚫ | ⚪ | ⚪ | 🟢 | ⚫ | 🔴 |
| Nema #3 - TKT | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ |
| Barcel - TKT | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | ⚫ | ⚫ |
| Nema #2 - TKT | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | ⚫ | ⚫ |
| DuPont (P-FP) | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | ⚫ | ⚫ |
| Brand Rex - TKT | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | ⚫ | ⚫ |
| Champlain - TKT | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | ⚫ | ⚫ |
| TRW - PFPI | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚪ | ⚫ | ⚪ | ⚫ | ⚪ | ⚫ | ⚪ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |

| Construction \ Test | Arc Tracking - NHB Method | Arc Tracking - MIL-W-2223 | Dielectric Strength | Abrasion | Dynamic Cut Through | Flex Life | Notch Propagation | Stiffness and Springback | Crush Resistance | Insulation Impact Resistance | Tensile Strength | Wire to Wire Rub | Aging Stability | Thermal Index | Thermal Shock | Thermal Aging | Cold Bend | Thermal Cycling | Flammability - Aircraft | Toxicity - Burning | Smoke Quantity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIL-W-81381/7 | ⚪ | ⚪ | ⚪ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚪ | 🟢 | 🟢 | 🟢 |
| MIL-W-81381/11 | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚪ | 🟢 | 🟢 | 🟢 |
| MIL-W-22759/12 | ⚪ | ⚪ | ⚪ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚪ | ⚫ | ⚫ | ⚫ |
| MIL-W-22759/16 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |
| MIL-W-22759/18 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |
| MIL-W-22759/32 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |
| MIL-W-22759/34 | ⚪ | ⚪ | ⚪ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚪ | ⚫ | ⚫ | ⚫ |
| MIL-W-22759/43 | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | 🟢 | 🟢 | 🟢 |
| MIL-W-16878 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |
| SSQ-21652 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |
| SSQ-21656 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |
| MP571-0086 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ |
| Filotex - TKT | ⚪ | ⚪ | ⚪ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚪ | 🟢 | 🟢 | 🟢 |
| Tensolite - TKT | ⚪ | ⚪ | ⚪ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚪ | 🟢 | 🟢 | 🟢 |
| Thermatics - TKT | ⚪ | ⚪ | ⚪ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚪ | 🟢 | 🟢 | 🟢 |
| Gore HS-725 | ⚫ | ⚫ | ⚪ | ◍ | ◍ | ◍ | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | ⚫ |
| Nema #3 - TKT | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | 🟢 | 🟢 | 🟢 |
| Barcel - TKT | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | ⚫ |
| Nema #2 - TKT | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | ⚫ |
| DuPont (P-FP) | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | ⚫ |
| Brand Rex - TKT | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | ⚫ |
| Champlain - TKT | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | 🟢 | 🟢 | ⚫ |
| TRW - PFPI | ⚪ | ⚪ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚫ | ⚪ | ⚫ | ⚫ | ⚫ |



PRECEDING PAGE BLANK NOT FILMED

**Tests Performed vs. Wiring Constructions Matrix (Cont'd).**

| Construction \ Test | Flame Propagation | Flash Point of Liquids | Wire Flammability | Odor Assessment | Offgassing | Arc Tracking - 30% $O_2$ | Wet Arc Tracking (ASTM) | Hydrolysis (ASTM) | Wet Arc Tracking (SAE) | Fluid Immersion | Forced Hydrolysis (SAE) | Humidity Resistance | Wicking | Impact of LOX and GOX | Fluid Compatability | Gas Compatability | Weight Loss | CIV/CEV - Vacuum | Outgassing (VCM) | Arc Tracking - Vacuum | Weathering Resistance | VUV Exposure | VUV/AO Exposure | Radiation Exposure | AO Exposure | Arc Tracking - μg | Flame Spread Rate - μg | Corona Discharge - Plasma | Debris Impacts | Electrostatic Dust |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIL-W-81381/7 | ○ | ● | R | ○ | r | ○ | ● | ● | G | G | G | G | G | ● | ○ | ○ | G | ○ | ○ | ○ | G | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MIL-W-81381/11 | R | ● | R | ● | ○ | ● | G | G | G | G | G | G | G | R | ● | ● | G | ● | R | ● | G | ○ | ● | ● | ○ | ● | ● | ● | ● | ● |
| MIL-W-22759/12 | ● | ● | R | ● | R | ○ | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ● | ● | ● | ● | ○ | ○ | ○ | ● | ● | ● |
| MIL-W-22759/16 | ● | ● | R | ● | ● | ● | G | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| MIL-W-22759/18 | R | R | R | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | R | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| MIL-W-22759/32 | R | ● | R | ● | R | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| MIL-W-22759/34 | ● | ● | R | ● | ● | ○ | G | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ● | ○ | ● | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MIL-W-22759/43 | ● | ● | ● | ● | ● | ● | ● | ● | G | G | G | G | G | ● | ● | ● | G | ● | ● | ● | G | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| MIL-W-16878 | R | R | R | R | R | ● | ● | ● | ● | ● | ● | ● | ● | R | ● | ● | ● | ● | R | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| SSQ-21652 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | R | ● | ● | ● | ● | R | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| SSQ-21656 | ● | ● | R | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | R | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| MP571-0086 | ● | ● | R | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Filotex - TKT | ○ | ● | ○ | ○ | ○ | ○ | ● | ● | G | G | G | G | G | ● | ○ | ○ | G | ○ | ○ | ○ | G | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Tensolite - TKT | ○ | ● | ○ | ○ | ○ | ○ | ● | ● | G | G | G | G | G | ● | ○ | ○ | G | ○ | ○ | ○ | G | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Thermatics - TKT | ○ | ● | ○ | ○ | ○ | ○ | ● | ● | G | G | G | G | G | ● | ○ | ○ | G | ○ | ○ | ○ | G | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Gore HS-725 | ○ | ● | ○ | ○ | ○ | ● | ● | ● | ● | G | ● | ● | ● | R | ○ | ● | ● | ● | ○ | ● | ● | ○ | ○ | ● | ● | ● | ● | ● | ● | ● |
| Nema #3 - TKT | ● | ● | ● | ● | ● | ● | ● | ● | G | G | G | G | G | ● | ● | ● | G | ● | ● | ● | G | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Barcel - TKT | ● | ● | ● | ● | ● | ● | ● | ● | ● | G | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Nema #2 - TKT | ● | ● | ● | ● | ● | ● | ● | ● | ● | G | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| DuPont (P-FP) | ● | ● | ● | ● | ● | ● | ● | ● | ● | G | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Brand Rex - TKT | ● | ● | ● | ● | ● | ● | ● | ● | ● | G | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Champlain - TKT | ● | ● | ● | ● | ● | ● | ● | ● | ● | G | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| TRW - PFPI | ○ | ● | ○ | ○ | ○ | ○ | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Key:

- G — Tests performed by DOD programs [11 - 13]
- g — Some DOD testing, more necessary [11 - 13]
- R — Tests performed by NASA programs [26, 56, 57]
- r — Some NASA testing, more necessary [26, 56, 57]
- ● — Tests not required for this program
- ○ — Additional tests to be performed

# NASA Wiring for Space Applications Program

- **ACTIVITIES:**

  - Third Workshop, July 1995:

    - Program status: NASA, AF, NAWC, FAA, ESA
    - Wiring test results
    - Advancements in materials and constructions
    - New system topologies

  - Final Report, 1996:

    - Comprehensive test results
    - Recommendations and guidelines

  - Transfer Technology to NASA Flight Programs and Aerospace Industry

- **CONCLUSIONS:**

  - Wiring system failures in space and commercial applications have shown the need for arc track resistant wiring constructions

  - Preliminary data indicates the performance of the Tensolite and Filotex hybrid constructions are the best of the various candidates

  - One construction will be recommended after comprehensive evaluation and analysis of all testing data

  - Detailed presentations of the test efforts and results to date will follow

# Wiring Workshop Charge

Determine next steps for:

- s/c wiring
- new wiring advances
- circuit protection
- improvement in quality control measures

# INTERNATIONAL SPACE STATION WIRE PROGRAM

Todd May
NASA Lyndon B. Johnson Space Center
Houston, Texas

## Agenda

- **Introduction**
- **Hardware Provider Wire Systems**
- **Current Wire Insulation Issues**
  - Silicone Wire Contamination
  - Tefzel Cold Temperature Flexibility
  - Russian Polyimide Wire Insulation
- **Conclusion**

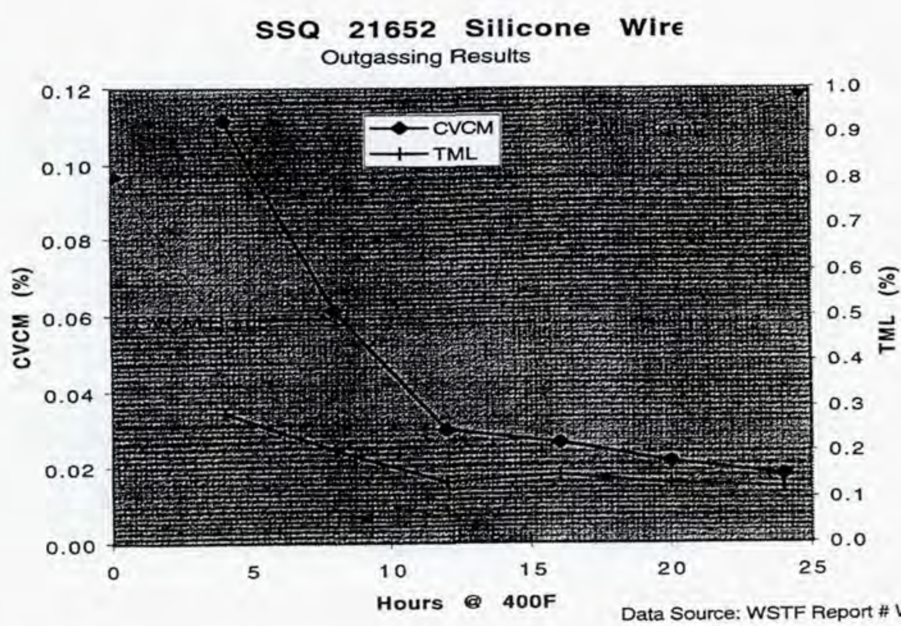
## Hardware Provider Wire Systems

| | TFE (Teflon) | ETFE (Tefzel) | Silicone | Polyimide (Kapton) | Teflon/ Kapton/ Teflon (TKT) |
|---|---|---|---|---|---|
| PG-1 McDonnell Douglas | I | E | E | | |
| PG-2 Rocketdyne | | E | E | | |
| PG-3 Boeing Defense & Space Group | I, E | E | E | | |
| Italian Space Agency (ASI) | I, E | | | | I, E |
| European Space Agency (ESA) | I, E | | | | |
| Japanese Space Agency (NASDA) | I | E | E | | |
| Canadian Space Agency (CSA) | E | E | E | | E |
| Russian Space Agency (RSA) | I, E | | | I, E | |

**I=Internal, E= External**

# ISS Wire Insulation Issues

- **Silicone wire contamination**
  - **McDonnell Douglas baselined silicone wire for truss power applications because of its flexibility**
  - **Wire passes JSC-SP-R-0022 (ASTM E 595) thermal vacuum stability testing requirements**
    - At elevated cure (24 hr. @400F)
    - TML = .123
    - CVCM =.018
  - **Due to large usage ($1X10^6$ cm$^2$.) material significantly fails integated outgassing deposition rate requirements (MOLFLUX)**
    - Required Rate <= $1X10^{-14}$ g/cm$^2$/s
    - Calculated Rate = $2X10^{-11}$ g/cm$^2$/s
  - **PG-1 has developed Project Directive #130 to limit use of silicone wire for ISS applications**
  - **Current plan is to use Tefzel wire with spliced silicone pigtails**
    - Splicing design under evaluation
    - ISS Program requirements for splicing being established




Data Source: WSTF Report # W27323, W27324

# ISS Wire Insulation Issues (cont.)

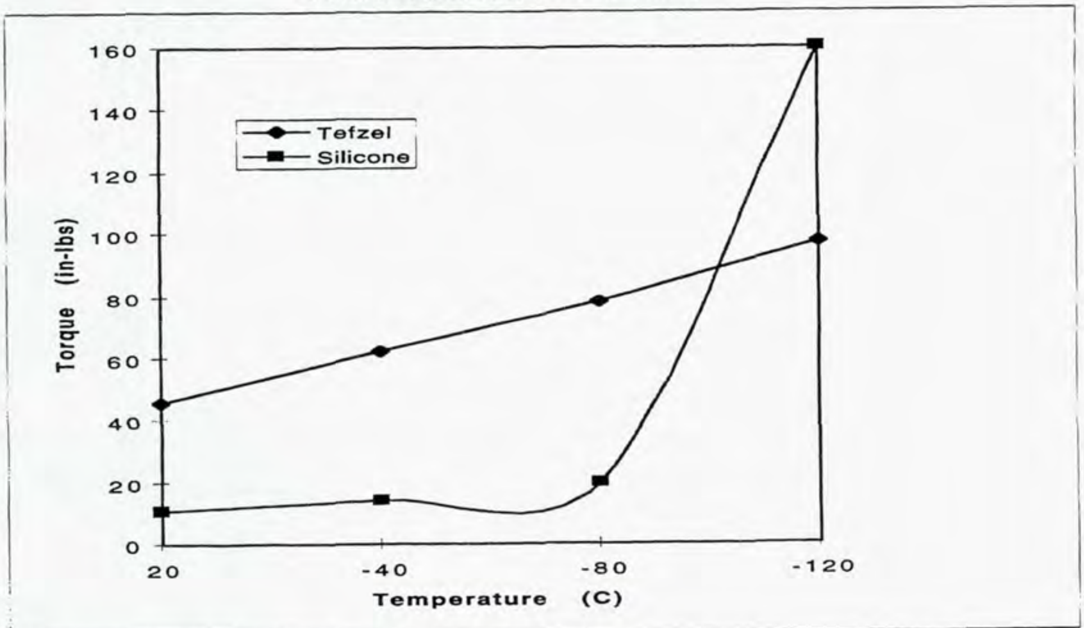
| | Silicone | Silicone (baked) | Tefzel | Silicone (wrapped) |
|---|---|---|---|---|
| Measured 25C dep. rate (g/cm2sec) | 6.0E-10 | 8.0E-11 | 8.0E-12 | 3.0E-13 |
| @ measurement time (hr.) | 10 | 77 | 110 | 87 |
| View factor to QCM | .6 | .6 | .6 | .6 |
| Outgassing rate (g/cm2sec) | 1.0E-9 | 1.3E-10 | 1.3E-11 | 5.0E-13 |
| Total cable area assumed (cm2) | 1.1E6 | 1.1E6 | 1.1E6 | 1.1E6 |
| Avg. dep. on ATCS radiator (g/cm2sec) | 9.0E-12 | 1.2E-12 | 1.2E-13 | 4.5E-15 |
| Dep. on attached payload (g/cm2sec) | 2.0E-11 | 2.6E-12 | 2.6E-13 | 1E-14 |

**Source: JSC/ES5/M. Pedley**

- **Tefzel cold temperature flexibility**
  - ***Tefzel known to have less flexibility than silicone wire at room*** **temperature, however silicone has Tg at approx -110C**
  - **Recent thermal vacuum tests revealed that at very cold temperatures (-100F), astronauts could not manipulate test wire harnesses**
    - "Freezes" in cooling/conditioning position
    - No "memory" when heated back to room temperature
  - **McDonnell Douglas parametric studies**
  - **More parametric studies planned (function of temperature)**
  - **STS 72 flight experiment planned**
    - 9 configurations of silicone and Tefzel wire
    - -60F to -80F

# ISS Wire Insulation Issues (cont.)

### Power Cable Cold Bend Tests




**Maximum Torque to bend 180 degrees**
**(Single 1/0 wire, 11" moment)**

### Tefzel EVA Handling Tests

| Harness Contents: | Total dia. | -120C | -100C | -75C | -50C | -25C | 0C | 25C |
|---|---|---|---|---|---|---|---|---|
| 2ea. @ 4ga.<br>1ea. @ 8ga. | 0.681 | * | * | * | * | * | * | * |
| 7ea. @ 8ga. | 0.907 | * | * | * | * | * | * | * |
| 4ea. @ 4ga.<br>2ea. @ 8ga. | 0.994 | | | | | | * | * |
| 2ea. @1/0ga.<br>1ea. @ 4ga. | 1.090 | | | | | | | |
| 4ea. @1/0ga. | 1.374 | | | | | | | |

**Shaded : Unnacceptable**
**Unshaded: Acceptable**
*** : Operation could be performed with one hand**
**Source: MDSSC Technical Report #9500837**

## ISS Wire Insulation Issues (cont.)

- Russians revealed February 1995 that they intend extensive use of polyimide wire
- Russian polyimide wire testing at WSTF for arc-tracking
  - Standard NHB 8060.1 Test 18
    - 200V AC
  - Nonstandard testing (DC)
    - 5 to 120V, 9 to 300A
- Russian comments to NHB 8060.1 Test Methods
  - Why AC for DC systems?
  - Wire cutting technique
  - Arc initiation method (induced failure)
- Russian circuit protection philosophy
  - Physical separation of +/- wires
  - Floating ground
  - Quick-blow fuses
- Russian wire characteristics
  - 48 Extruded layers (1.5 μm ea.)
  - Small gages only (<= 20 gauge)

## SSQ Status

| Spec. Number | Title | Insulation Materials | Remarks |
|---|---|---|---|
| SSQ 21652 | Wire and Cable, Electric, Silicone-Insulated, Nickel Coated Cu or Cu Alloy, General Specification for | Silicone | |
| SSQ 21653 | Cable, Coaxial, Twinaxial, and Triaxial, Flexible and Semirigid, General Specification for | Teflon (TFE)<br>Teflon (FEP) | |
| SSQ 21654 | Cable, Single Fiber, Multimode, Space Quality, General Specification for | Fiber Optic | |
| SSQ 21655 | Cable, Electrical, MIL-STD-1553 Data Bus, Space Quality, General Specification for | Teflon (TFE)<br>Teflon (FEP) | |
| SSQ 21656 | Wire and Cable, Electric, Fluoropolymer-Insulated, Nickel Coated Cu or Cu Alloy, General Specification for | Teflon (TFE)<br>Teflon (FEP)<br>Tefzel (ETFE) | |

# Conclusion

- ISS is a complex program with hardware developed and managed by many countries and 100s of contractors
- Most of the obvious wire insulation issues are known by contractors and have been precluded by proper selection
- New issues will continue to arise as Program progresses
- We'll keep charging the windmills until they are all defeated

LIFE PREDICTION OF AGING AIRCRAFT WIRING SYSTEMS

George Slenski
U.S. Air Force
Wright Patterson Air Force Base, Ohio

# LIFE PREDICTION OF AGING AIRCRAFT WIRING

## PROGRAM GOAL

**Develop a Computerized Life Prediction Model Capable of Identifying Present Aging Progress and Predicting End of Life for the Wire**

## SPECIFIC PHASE I OBJECTIVES

A. **Identify Critical Aircraft Wiring Properties**

B. **Relate Most Common Failures Identified to Wire Mechanism Causing Failure**

C. **Assess Wiring Requirements, Materials & Stress Environment for Fighter Aircraft**

D. **Demonstrate Feasibility of a Time - Temperature - Environment Model**

# LIFE PREDICTION OF AGING AIRCRAFT WIRING SYSTEMS

## SUMMARY OF PHASE I PROGRAM TASKS

I. Identify critical aircraft wiring failure mechanisms

II. Relate most common failures (identified in Task I) to the wire mechanism causing failure

III. Select fighter aircraft for assessing wiring requirements, materials and overall stress environments

IV. Demonstrate that a time-temperature-environment (stress, fluids etc.) model can be developed

# LIFE PREDICTION OF AGING AIRCRAFT WIRING SYSTEMS

## SUMMARY OF ACCOMPLISHMENTS TO-DATE

- Visits made to Tyndall, Eglin and Warner Robbins AF Bases to
  - Interview AF maintenance personnel
  - Gather wiring degradation and failure data based on field activity

- Comprehensive effort to identify failure mechanisms of Kapton insulation based on current knowledge base
  - Analyze tab run data
  - Interview Air Force maintenance personnel.

*Chaffing appears to be the predominant failure mode, followed by insulation cracking and topcoat flaking/cable jacket delamination.*

- Site visit made to Davis Monthan AFB in Tucson, AZ to
  - Inspect F-15 and F-16 aircraft predominantly deployed in relatively dry conditions, coastal areas and mixed climate
  - Examine field records
  - Draw representative wire and harness samples from landing gear, avionics bay and other appropriate areas for in-house experimental observations and analysis.

Table I: Wiring Problem Areas Per Narrative Provided By Maintenance Personnel

| AIRCRAFT | PLUG | CONNECTOR BACKSHELL | CONTACTS | WIRE BROKE/LOOS | WIRE CHAFFED/SHORTED | SPRT/TIE | TAPE | GROMMET | RELAY/BWI | FUSEHOLD |
|---|---|---|---|---|---|---|---|---|---|---|
| F-15 | 21 (14%) | 31 (21%) | 3 (2%) | 6 (4%) | 22 (15%) | 10 (7%) | 46 (31%) | 4 (3%) | 3 (2%) | 1 |
| F-16 | 9 (4%) | 3 (1%) | 9 (4%) | 103 (46%) | 67 (30%) | 31 (14%) | 0 | 1 | 1 | 0 |

### Table II: Wiring Problem Areas Per H-MAL Codes

| Aircraft | How-Mal Code | Description of How-Mal Code | Percent Problems |
|---|---|---|---|
| F-15 | 105 | Loose/Damaged | 33 |
| | 799 | No Defects | 22 |
| | 070 | Broken | 12 |
| | 020 | Chaffed | 11 |
| | 450 | Open | 3 |
| | 615 | Short | 3 |
| | 730 | Loose | 3 |
| | 750 | Missing | 2.5 |
| | 800 | No Defect | 2.5 |
| | 242 | Failed to Open | 2 |
| F-16 | 105 | Loose/Damaged | 28 |
| | 070 | Broken | 21 |
| | 020 | Chaffed | 10 |
| | 242 | Failed to Operate | 8 |
| | 615 | Short | 4 |
| | 127 | Improper Adjustment | 3 |
| | 884 | Broken Lead | 3 |
| | 127 | Improper Adjustment | 3 |
| | 255 | Incorrect Output | 2 |
| | 450 | Open | 2 |

# LIFE PREDICTION OF AGING AIRCRAFT WIRING SYSTEMS

## AIRCRAFT INSPECTED AT DAVIS MONTHAN AFB

| A'CRAFT TYPE & TAIL NO. | DELIVERY DATE | RETIRED DATE | TOTAL FLIGHT HOURS | CHRONOLOGY | TOTAL MONTHS WET | DRY |
|---|---|---|---|---|---|---|
| | | | | F-15A | | |
| 74-127 | JULY'76 | MAY'92 | 3045 | Langley, VA: 110 Mo<br>Eglin, FL: 22 Mo.<br>Hickham, HI: 36 Mo.<br>Korea: 22 Mo. | 0 | 190 |
| 74-128 | JULY'76 | MAR'92 | 3215 | Luke, AZ: 117 Mo.<br>Dobbins, GA & Warner-Robbins,GA: 72Mo. | 117 | 72 |
| 74-135 | JULY'76 | APR'92 | 3429 | Unknown: 41 Mo<br>Luke, AZ: 73 Mo.<br>Elmendorf,AK: 23 Mo.<br>Hickham, HI: 40Mo.<br>Korea: 15 Mo. | 96 | 55 |
| 75-034 | OCT'76 | JAN'94 | 3398 | Langley, VA: 57 Mo<br>Eglin, FL: 36 Mo.<br>Tyndall,FL: 114 Mo. | 0 | 207 |

## AIRCRAFT INSPECTED AT DAVIS MONTHAN AFB

| A'CRAFT TYPE & TAIL NO. | DELIVERY DATE | RETIRED DATE | TOTAL FLIGHT HOURS | CHRONOLOGY | TOTAL MONTHS WET | DRY |
|---|---|---|---|---|---|---|
| | | | | F-16A | | |
| 78-007 | MAY'79 | SEPT'94 | 3517 | Hill, UT: 45 Mo<br>Luke, AZ: 30 Mo.<br>Hill,UT: 23 Mo.<br>Luke, AZ: 23 Mo.<br>Hill,UT: 49 Mo. | 177 | 0 |
| 79-353 | DEC.'80 | AUG.'93 | 2652 | McDill, FL: 152 Mo. | | 152 |
| 79-355 | DEC.'80 | AUG.'93 | 3145 | McDill, FL: 54 Mo.<br>Hill, UT: 96 Mo. | 96 | 54 |
| 79-359 | DEC.'80 | AUG.'94 | 3271 | Hill, FL: 42 Mo.<br>McDill, UT: 60 Mo.<br>Hill, UT / Tinker, OK: 96 Mo. | 102 | 60 |

# LIFE PREDICTION OF AGING AIRCRAFT WIRING

## ANTICIPATED PHASE I RESULTS

- Most Common Wiring Failure Causes in F-15, F-16, & B-1B will be Identified
- New (Baseline) and Representative Aged Wire Samples from High Failure
Areas will be Procured for Environmental Analysis
- Test Matrix will be Defined to Simulate Aging/Degradation Process
- Initial Environmental Exposure and Resulting Degradation Evaluation will be Completed to Define Rudiments of a Physical Model for Remaining Life Prediction

PHASE II PROGRAM:
- DEFINITION OF A COMPREHENSIVE PHYSICAL MODEL
- FINE-TUNING, AND
- β-SITE TESTING AT AF BASES FOR MODEL VALIDATION

A TURN-KEY ALGORITHM TO BE DELIVERED TO USAF AT THE CONCLUSION OF THE PHASE II PROGRAM

N96- 17081

# WIRING TEST PROGRAM INSULATION MATERIAL RELATED PROPERTIES

Heinz-Josef Reher
Daimler-Benz Aerospace AG
Raumfahrt-Infrastrukstur
Bremen, Germany

54-33
6325
P. 9

## TABLE OF CONTENTS



## INTRODUCTION

- Electrical wires are considered as EEE-parts and are covered within the ESA SCC specification series (ESA SCC 3901/XXX).
- Specifications define the principal properties of the wires including insulation/lay-up, electrical properties etc.
  Some additional space related materials requirements also included such as outgassing and silver plating thickness.
- If a project has additional materials requirements over and above those covered by the relevant SCC specification then additional testing is required.

  This is especially the case for manned spacecraft.

## INTRODUCTION

Additional requirements for manned spacecraft:

- The following additional properties, specific to manned spacecraft (i.e. Columbus and Hermes) require evaluation of:

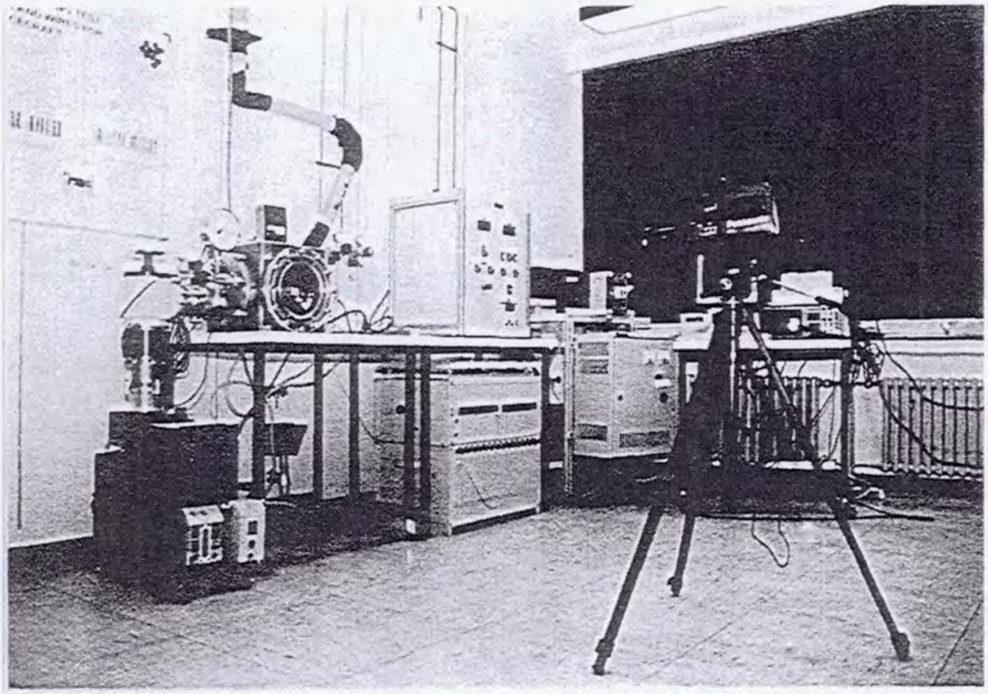
| | | |
|---|---|---|
| 1. | Flammability | Test Method ESA-PSS-01-721 Issue 2 |
| 2. | Offgassing | Test Method ESA-PSS-01-729 Issue 2 |
| 3. | Arc-tracking | Test Method under evaluation by Dasa-RI in conjunction with Technical University, Darmstadt (see also separate presentation) |
| 4. | Thermal Decomposition | Test Method defined based on that originating from CERTSM, France |
| 5. | Microbial Surface Growth | Test Method defined based on that originating from SINTEF/SI, Norway |

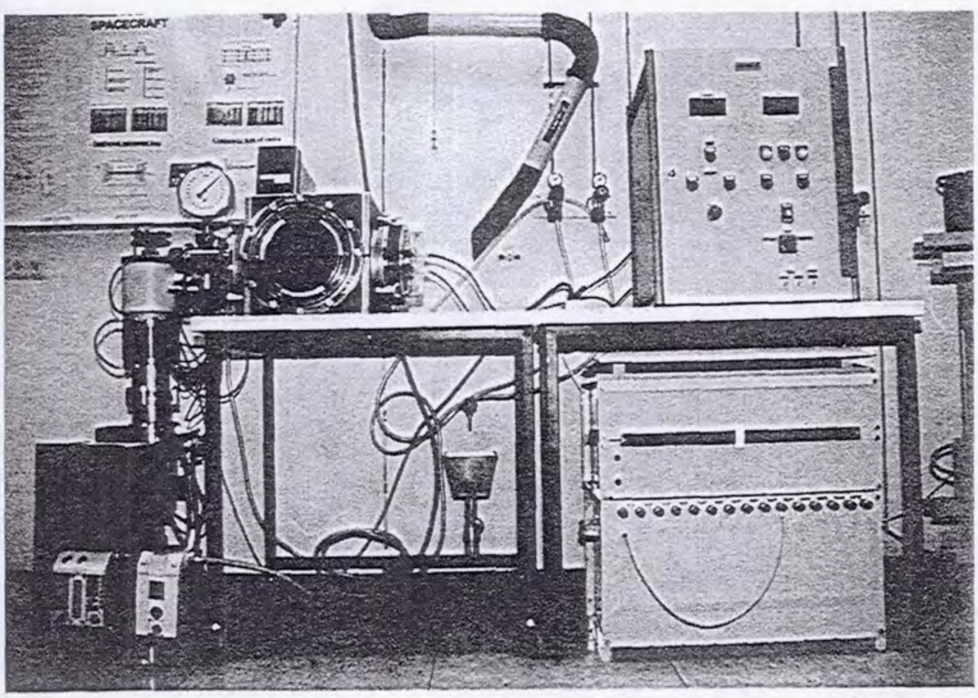
Note: 4. and 5. are Test Methods derived in the frame of the Columbus Project (Critical Technologies Program)

- In addition, the effects of ageing on certain of these properties require investigation.

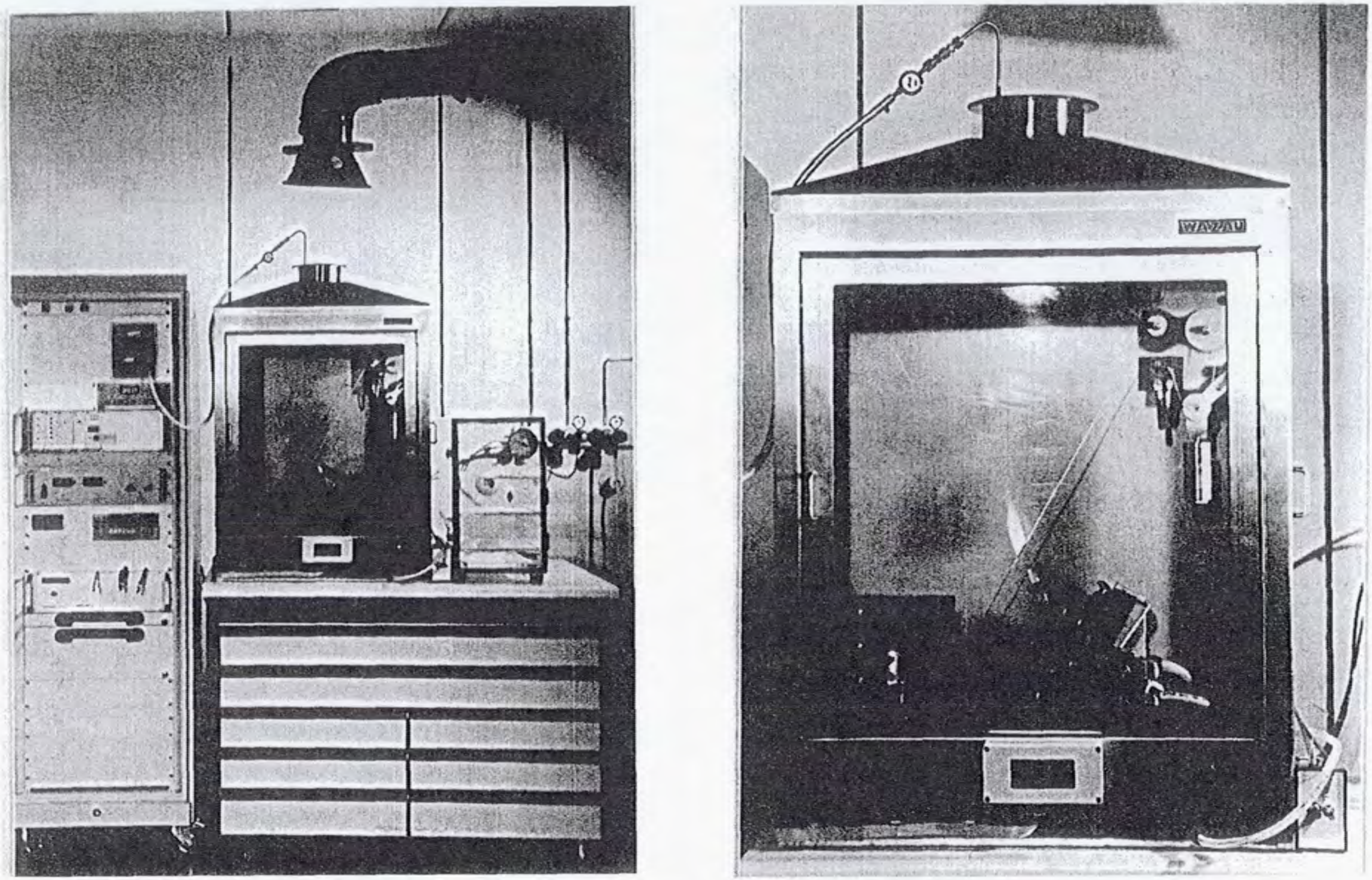
## OVERVIEW OF ACTIVITIES AT DASA-RI (since last Workshop)

- o Establishment of test facilities at Dasa-RI
  - Arc-tracking test of wires
  - Flammability test of wires
- o Arc-tracking: Technical University Darmstadt / Dasa-RI activities
  - Extension of database (see also presentation of THD)
  - Design of test equipment to assess effects of microgravity
- o Performance of wiring testing at Dasa-RI
- o Performance of studies, e.g. ageing of wires, different angles of wire inclination of flam-of-wires test
- o Performance of wiring testing in the frame of Columbus Critical Technologies Program (CTP)
- o Activities concerning standardization of test methods (British Standard, ISO)






**Arctracking Test of Wire at Dasa-RI**



**Electrical Wire Insulation Flammability Test at Dasa-RI**

## ARC-TRACKING: THD / DASA-RI ACTIVITIES UNDER ESA/ESTEC CONTRACTS

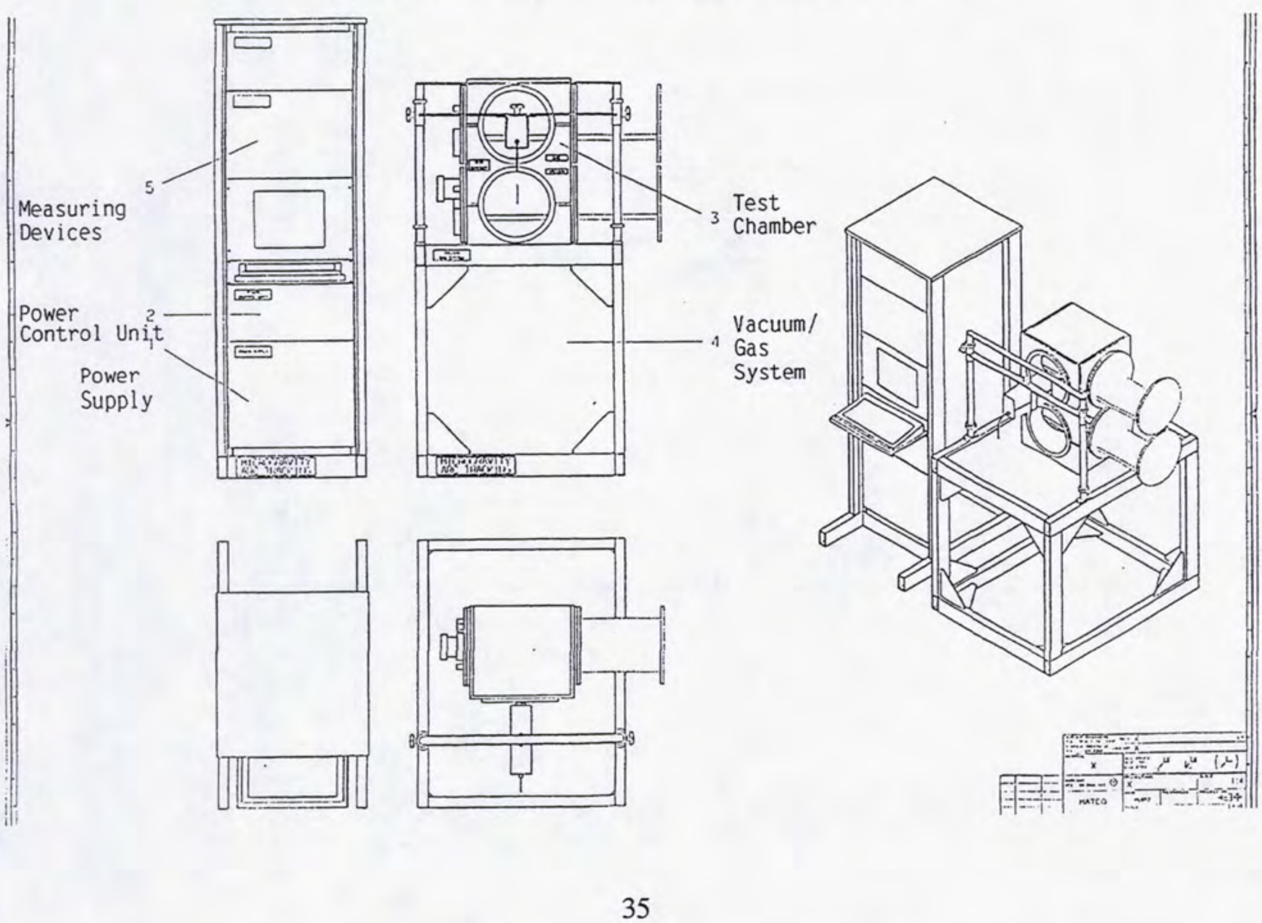
Arc-Tracking Test Equipment / Test Method

- o Two test equipments are existing (at THD and at Dasa-RI)
- o Test method developed by THD (already presented)
  Work has led to a new approach to assessing degree of susceptibility of wires to arcing failure
- o Lot of testing has been performed (see separate presentation by THD)

Mircrogravity Test

- o Test equipment is being designed, procurement and manufacturing started
- o Parabolic flight is scheduled during 1996

## ARC-TRACKING: MICROGRAVITY TEST EQUIPMENT



## WIRING TESTING AT DASA-RI

First Test Results [AWG 20]

| Wire Specification | Insulation | Performance of Tests | |
|---|---|---|---|
| SCC-3901-001 | PI/PI/PI | Upward propagation test | ) Prior and after ageing |
| SCC-3901-007 | PI/PI/PTFE | Flam of wire test | ) of 60 days in air |
| SCC-3901-009 | PTFE/PI/PI | Arc-tracking test | ) at 150° C |
| MIL-W-22759 | ETFE | | |

- o All wires (new and aged) passed the upward propagation and flam of wire test according to ESA-PSS-01-721, Issue 2
- o Arc-tracking test results using Dasa-RI inhouse test procedure PSP 0121 009 showed clear differences between different wire types.
  Accept/Reject Criteria have to be reconsidered.

## WIRING TESTING IN THE FRAME OF COLUMBUS CRITICAL TECHNOLOGIES PROGRAM (CTP)

- o 10 different wire/cable types have been subjected to different tests, selected from the so called "Columbus EEE Preferred Parts List"

| Sample No. | Sample Name | Chemical Nature |
|---|---|---|
| 1901 | 1871-1-20 | PI (2 tapes)/ PI coating |
| 1903 | FA 3901-1-120 | PI (2 tapes)/ PI coating |
| 1904 | FA 3901-2-120 | PI (1 tape)/ PI coating |
| 1908 | SPA-10-24-9 | PI/PI/PTFE |
| 1909 | SPB-10-20-6 | PTFE/PI/PI/PTFE |
| 1910 | SPC 10-24-N | PTFE/PI PI |
| 1911 | MTV 1 20-A | PTFE (ext) PI coating |
| 1912 | Coaxcal Cable 50 CIS | PTFE/Ag/Al |
| 1913 | Coax Cable R59 | PI/ext. FEP |
| 1914 | 1872-1-20 | PI (1 tape)/ PI coating |

- o Cables/Wires passed the following tests:
  - Upward propagation test )
  - Flammability of wire ) performed
  - Odor ) according to
  - Offgassing ) ESA-PSS-Specs.
  - Outgassing )

## WIRING TESTING IN THE FRAME OF COLUMBUS CRITICAL TECHNOLOGIES PROGRAM (CTP)

- o Additional tests have been performed
  - Microbial Growth (Fungi) (short duration test up to 4 weeks)

| Material No. | Chem. Nature | Class |
|---|---|---|
| 1901 | PI, PI Coating | 3 |
| 1903 | PI, PI Coating | 3 |
| 1904 | PI, PI Coating | 4 |
| 1909 | PTFE/PI/PI/PTFE | 4 |
| 1910 | PTFE/PI/PI | 0 |
| 1911 | PTFE/PI Coating | 3-4 |
| 1912 | PTFE/Ag/PI | 0 |
| 1913 | PI/FEP | 4 |
| 1914 | PI/PI Coating | 3 |

Rating: (Growth of fungi)

| | |
|---|---|
| 0 + 1 | No constraints on materials (no growth) |
| 2 + 3 | Materials to be used in dry accessible areas (cleaning) |
| 4 + 5 | Materials should not be used in manned closed space habitate (heavy growth) |

## WIRING TESTING IN THE FRAME OF COLUMBUS CRITICAL TECHNOLOGIES PROGRAM (CTP)

- o Additional tests have been performed
  - Thermal Decomposition (at 200° C or max. operating temperature and at 500° C; Atmosphere 24,5 Vol % $O_2$)

| Material Group or Form | Mat. Ident. No. | Tradename | Toxicity Class at 200° C | Toxicity Class at 500° C |
|---|---|---|---|---|
| WIRES | 1901 | Wire Type: 1871 | T0 | T2 |
| | 1903 | Wire Type: 3901/1 | T0 | T2 |
| | 1904 | Wire Type: 3901/2 | T0 | T2 |
| | 1908 | Wire Type: SPA 2110 | T0 | T3 |
| OR | 1909 | Wire Type: SPB 2110 | T0 | T3 |
| | 1910 | Wire Type: SPC 2110 | T0 | T2 |
| | 1911 | Wire Type: MTV | T0 | T3 |
| CABLES | 1912 | Coax Cable 50 CIS | T0 | T2 |
| | 1913 | Coax Cable R 59 | T0 | T3 |
| | 1914 | Wire Type: 1872 | T0 | T2 |

| Critical Quantity of Materials - QCM ($g/m^3$) | TOXICITY CLASS |
|---|---|
| < 0,10 | T 5 |
| 0,10 - 1 | T 4 |
| 1 - 10 | T 3 |
| 10 - 100 | T 2 |
| 100 - 1000 | T 1 |
| > 1000 | T 0 |

## ACTIVITIES CONCERNING STANDARDIZATION

Arc-Tracking and Flam of Wire Test Methods

- o Methods will be proposed to

  ISO Technical Committee TC 20, Aircraft and Space Vehicles, SC 14, Working Group 1

- o Flam of wire test method acc. to ESA-PSS-01-721

  - is under evaluation by British Standard for incorporation into their aircraft wire spec.,
  - now being incorporated into ESA SCC 3901 series of spec's.

Space Systems -
Arc Tracking Test,
Cables and Wires

Space Systems -
Wire Flamm Test,
Electrical Wire Insulation

## FUTURE ACTIVITIES

- o Further investigations (on going) to flam of wire test, e.g. angle of wire inclination
- o Extension of database on arc-tracking tests, e.g. test of fungi contaminated wires, variation of test parameters (current, voltage, etc.)
- o Reconsideration of Accept/Reject Criteria for arc-tracking test method
- o Standardization of test methods
- o Request from Russia to perform arc-tracking tests with 4 polyimide insulation wires delivered by RSC-Energia, Moscow (comparison of test methods / test results)
- o Performance of Parabolic Flight (1996): Influence of microgravity on arc-tracking

# ELECTRICAL SHORT CIRCUIT AND CURRENT OVERLOAD TESTS ON AIRCRAFT WIRING

Patricia Cahill
Federal Aviation Administration
Atlantic City Airport, New Jersey



## PURPOSE.

The purpose of this paper is to present the findings of electrical short circuit and current overload tests performed on commercial aircraft wiring.

## BACKGROUND.

The fire potential resulting from electrical faults on transport category aircraft is illustrated by three fires that have occurred during the past several years. A description of each follows:

On January 18, 1990, a USAir MD-80, en route to Cleveland from Buffalo, was forced to return to Buffalo when the cockpit filled with smoke from overheated electrical wire insulation. The left generator tripped off-line and the captain turned the right generator control switch to the "Off" position. He selected emergency power and initially was able to clear the smoke. The captain then started the auxiliary power unit (APU) and the cockpit again started to fill with smoke. The APU electrical power was then shut off and the emergency electrical power was turned back on. The aircraft returned to Buffalo with no further reports of smoke. It was found that the left generator phase B power feeder cable terminal, which is connected to a plastic terminal strip, had melted from intense arcing. The terminal, approximately 15 inches of the cable, and the terminal stud had melted. The second source of smoke came from a fire started by the molten metal that sprayed an area forward of, and below the terminal strip. The only circuit breaker to trip was the cabin temperature control. This incident was caused by improper torquing of the phase B terminal.

On March 17, 1991, a Delta L-1011 en route from Frankfurt, Germany, to Atlanta, Georgia, was forced to make an unscheduled landing in Goose Bay, Labrador, Canada. About 7.5 hours into the flight, flames erupted from the base of the left cabin sidewall panel to the height of the seatback tray at the next to last row of passenger seats. The fire was extinguished and a precautionary landing was made. The ignition source of this fire was not determined; however, a possible source of ignition appeared to be an electrical fault. Some of the wires in a fifteen wire bundle located in the fire area exhibited evidence of arcing. Five circuit breakers connected to this wire bundle had tripped.

On November 24, 1993, an SAS MD-87 experienced smoke and a subsequent fire upon touchdown. The fire damage was severe, including a 1-foot-diameter hole through the fuselage skin. Investigation found that two wires, one 115 volts (V) and one 28V, had been pinched together and were arcing to the fuselage structure. Neither the 10-ampere (amp) circuit breaker (28V line) nor the 15-amp circuit breaker (115V line) tripped.

It is apparent from these three incidents that certain questions present themselves:

a. Are ticking faults more likely to start a fire than the hard direct short?

b. Do circuit breakers provide adequate protection?

c. Is there anything definitive an investigator can look for to help determine if electrical failure was the cause?

## DESCRIPTION OF TESTS AND RESULTS.

### CURRENT OVERLOAD TESTS.

A series of bench-scale tests were conducted to evaluate circuit breaker response to overcurrent and to determine if the wire showed any visible signs of thermal degradation due to overcurrent. Three types of wire used in commercial aircraft were evaluated:

| | | |
|---|---|---|
| a. | MIL-W-22759/34 | 150°C (302°F) rated |
| b. | MIL-W-81381/12 | 200°C (392°F) rated |
| c. | BMS 1360 | 260°C (500°F) rated (hybrid construction) |

All wires were 20 American Wire Gauge (AWG). This gauge was chosen because it is one of the most commonly used sizes. In this test, a 7.5-, 10-, and a 15-amp circuit breaker (all standard aircraft thermal breakers) were subjected to 135 percent of their current rating and time-monitored when the breaker tripped. All tests were conducted at room temperature (23°C, 73°F). Figure 1 shows a diagram of the test circuit. Each wire segment rested on thermal/acoustic insulation (fiber glass with polyester film cover). This test, which is a calibration test used by circuit breaker manufacturers, references the International Electrotechnical Commission (IEC) 934, Circuit Breakers for Equipment, and the Underwriters Laboratories Incorporated (UL) 1077, Supplementary Protectors for use in Electrical Equipment. This test calls for wire rated at 600V and 105°C (221°F). The following is a section of the wire gauge table derived from IEC 934 for this test:

| Amp Rating | AWG |
|---|---|
| < than 1 | 20 |
| 1 through 6 | 18 |
| >6 through 13 | 16 |
| >13 through 20 | 14 |

The circuit breaker rating (in amps) and allowable wire gauge used in commercial aircraft are different from those given above. The Federal Aviation Administration (FAA) approved electrical wire charts and tables specify 20 AWG wire to carry a maximum current of 7.5 amps in conduit or bundled and 11 amps in free air. This is because the temperature ratings of transport category aircraft wiring are much higher than the 105°C (221°F) wire specified in the above test method. The use of a 7.5-amp circuit breaker to protect 20 AWG wire was based on aerospace industry testing and computer modeling. This breaker and wire size are also specified in MIL-W-5088 Wiring, Aerospace Vehicle. This specification is approved for use by all departments and agencies of the Department of Defense (DoD). While a 10- and 15-amp circuit breaker would not be used to protect 20 AWG aircraft wiring, this size was selected for testing to determine if any thermal degradation of the insulation occurred that would be apparent or verifiable by microscopic techniques as a result of an overload situation. Table 1 gives the results. The data show that all the breakers tripped well within the one-hour time frame specified in this test method. The wires tested were examined and then cut open to inspect the conductor and other layers of insulation, if applicable, by microscope. There were no signs of degradation internally or externally due to heat such as discoloration, warpage, or embrittlement; and the thermal/acoustic installation showed no signs of heat damage.

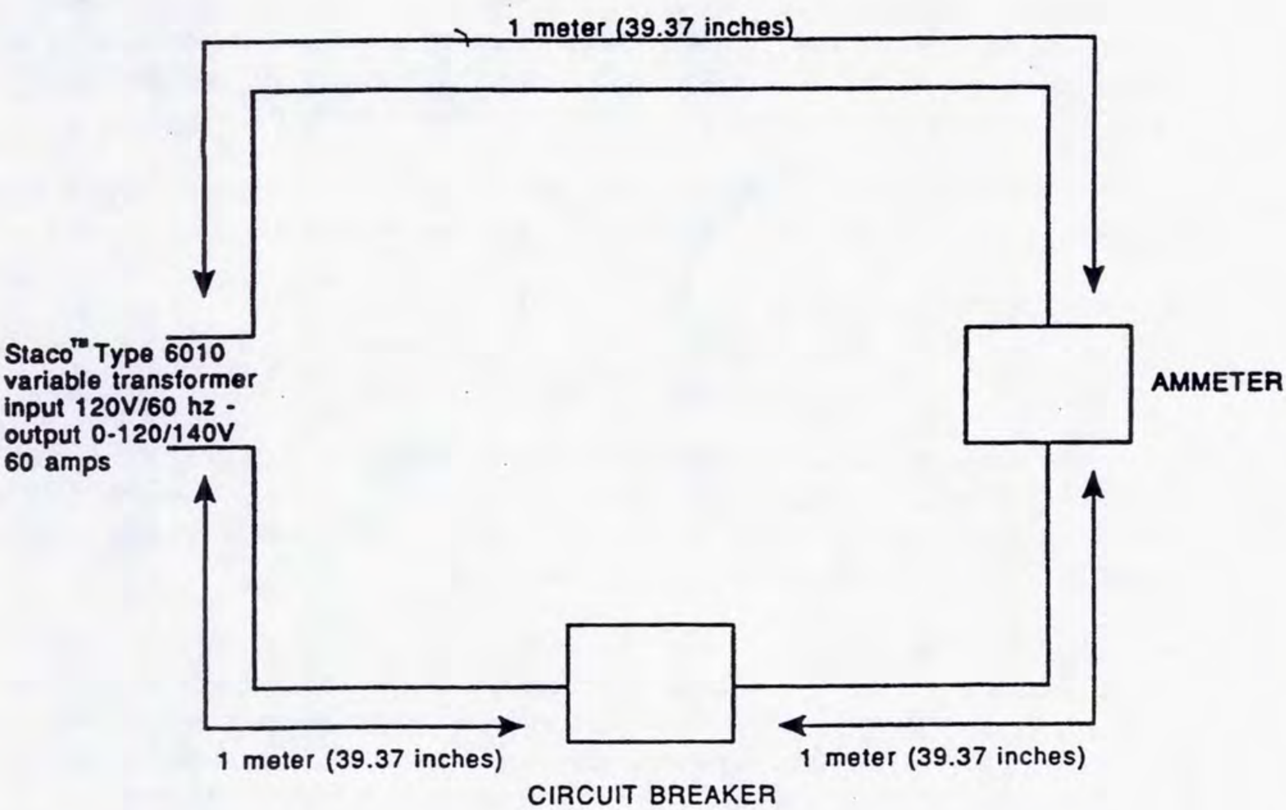



FIGURE 1. TEST CIRCUIT

TABLE 1. OVERCURRENT DATA

| Wire Type | Circuit Breaker Rating | 135 Percent Current Rating | Time to Trip |
|---|---|---|---|
| MIL-W-81381/12 | 7.5 amps | 10.1 amps | 2 minutes 10 seconds |
| MIL-W-22759/34 | 7.5 amps | 10.1 amps | 4 minutes 8 seconds |
| BMS 1360 | 7.5 amps | 10.1 amps | 3 minutes |
| MIL-W-81381/12 | 10 amps | 13.5 amps | 8 minutes 30 seconds |
| MIL-W-22759/34 | 10 amps | 13.5 amps | 16 minutes |
| BMS 1360 | 10 amps | 13.5 amps | 11 minutes 40 seconds |
| MIL-W-81381/12 | 15 amps | 20.2 amps | 6 minutes 20 seconds |
| MIL-W-22759/34 | 15 amps | 20.2 amps | 2 minutes 45 seconds |
| BMS 1360 | 15 amps | 20.2 amps | 5 minutes 5 seconds |

RESULTS OF CURRENT OVERLOAD TESTING VS. FIRE-EXPOSED WIRES.

Each of the three test wires was then subjected to current overload without a circuit breaker in-line. Three feet of each wire type (20 AWG) was connected to a variable transformer and placed on thermal/acoustic insulation with polyester film cover. The current for each wire type was determined by previous testing to cause complete thermal degradation of the wires.

These tests were run for approximately 12 minutes to compare them with the same type of wires subjected to fire for approximately 12 minutes. The values are as follows:

| | | |
|---|---|---|
| MIL-W-81381/12 | 9.6V | 41 amps |
| MIL-W-22759/34 | 7.2V | 33 amps |
| BMS 1360 | 10.8V | 51 amps |

The thermal/acoustic insulation was charred where the wire rested, and the polyester film smoked and shrunk. Ignition of the polyester film occurred in some areas. Each wire was compared to a wire of the same type which had been placed in a cardboard box with paper shavings and ignited. The duration of this fire was approximately 12 minutes at 982°C (1800°F).

In comparing the BMS 1360 and the MIL-W-81381/12 wires subjected to overcurrent with those subjected to the fire, no visible differences were detected. The charred remains of the wrapped films were present. The MIL-W-22759/34 wire subjected to the overcurrent also looked the same as the MIL-W-22759/34 wire exposed to the fire. The insulation material was consumed in both cases, exposing the tin-plated conductor. The common denominator found for all three wire types was the brittleness of the conductor. By flexing the cables, it was found that the wires that were subjected to the fire were more brittle than those exposed to the overcurrent.

## SHORT CIRCUIT TESTING.

In this series of bench-scale tests, circuit breaker response to short circuits and ticking faults was evaluated. These tests were also meant to determine if the three test wires behaved differently under the above conditions and if a short circuit or ticking fault could start a fire.

Two wires, each three feet long, were connected to a 220V/115V 400-cycle, three-phase generator rated at 18.75 kilo volt amps (kVA); one wire was connected to a "leg" of the wye connection; and one wire was connected to the neutral. This configuration results in a 115V potential (single-phase power) between the two wires. A 7.5-amp aircraft circuit breaker rated at 500 amps of interrupting current at 120V AC-400 Hz was in-line with the "hot" leg. Each of the wires had approximately 1/2 inch of insulation stripped from their ends, and the wire strands were twisted together and suspended vertically with the stripped ends separated approximately one inch. A piece of non fire-retarded polyurethane foam was then placed approximately 1/4 inch behind the two wires. Using a wooden grasping device, the two wires touched intermittently (ticking faults). They were also brought and held together to cause a direct short circuit. This same test was repeated using 208V (phase-to-phase) with a 7.5-amp circuit breaker protecting each leg. Tables 2 and 3 summarize the test results.

The data indicates that the circuit breakers did not protect the wire against ticking faults in both the 115V and 208V testing. In each case, the temperature generated by the arcs during each successive ticking fault ignited the nearby materials. Therefore, the minimal duration of metal-to-metal contact (time factor) along with the limited *current* due to the "instantaneous" arc would explain why the circuit breakers did not trip.

In all the 115V and 208V tests the circuit breakers protected the wire against direct shorts. While sparks were observed as the two conductors were brought together, fusion occurred almost instantaneously, resulting in the circuit breaker tripping. The data show that there was no ignition of the foam during any test. While the current might have been very high (hundreds or thousands of amps), the voltage was low. Therefore, available power was small (P = EI).

These tests did not evaluate the effects of molten metal (pieces of conductor which spewed forth during some ticking faults) as ignition sources. It is likely, however, that they could ignite a flammable material upon impingement, as was the case in the MD-80 fire discussed earlier in this report.

## APPEARANCE OF CONDUCTORS.

In all the 115V and 208V cases, fusion of the conductors occurred upon direct short-circuit testing. (Remembering that a 20 AWG conductor is composed of 19 strands of wire, fusion in this case does not imply that each strand of each conductor melted and joined.) Fusion in this testing implies that any number of strands fused, resulting in a complete short circuit that tripped the breaker. No "bead" formation occurred during this testing; however, there were discrete areas of melted conductor which appeared layered. The insulation materials showed no effect from the "heat" of fusion; however, they were slightly warm.

In some instances, the wires in the ticking fault testing (115V and 208V) showed weld formation on discrete areas of both conductors. These welds were not formed due to the fires but from the heat generated during ticking fault testing. Some of the strands in each of the two wires fused together and appeared dull in color. During one 208V test, the exposed conductors vaporized up to the insulation material after the third ticking fault. Since the fires propagated up the foam, very little wire insulation was subjected to the fire. There was some scorching and soot on the insulation materials that were briefly subjected to the fire.

TABLE 2. 115 VOLT TEST DATA

| Wire Type | Ticking Faults | Circuit Breaker Tripped | Notes |
|---|---|---|---|
| MIL-W-81381/12 | 6 | No | Sparks, some arcing, on sixth fault severe arcing ignited the foam and totally consumed it, "Beads" on the ends of both conductors, approximately 3/16 to 4/16 inch of conductor left |
| MIL-W-22759/34 | 5 | No | Sparks, some arcing, on fifth fault severe arcing ignited the foam and totally consumed it, "Beads" on the ends of both conductors, approximately 3/16 to 4/16 inch of conductor left |
| BMS 1360 | 5 | No | Sparks, some arcing, on fifth fault severe arcing ignited the foam and totally consumed it, "Beads" on the ends of both conductors, approximately 3/16 to 4/16 inch of conductor left |
| **Wire Type** | **Direct Short** | **Circuit Breaker Tripped** | **Notes** |
| MIL-W-81381/12 | 1 | Yes | Sparks (spit), fusion of the two conductors |
| MIL-W-22759/34 | 1 | Yes | Sparks, fusion of the two conductors |
| BMS 1360 | 1 | Yes | Sparks, fusion of the two conductors |

TABLE 3. 208 VOLT TEST DATA

| Wire Type | Ticking Faults | Circuit Breaker Tripped | Notes |
|---|---|---|---|
| MIL-W-81381/12 | 3 | No | During the first fault most of the conductors vaporized leaving approximately 2 to 3/16 inch of conductor remaining , severe arcing, the foam ignited and was totally consumed during the third ticking fault, exposed conductors totally vaporized |
| MIL-W-22759/34 | 3 | 1. Yes, one breaker on first fault<br>2. No, on the third fault that ignited the foam | During the first fault, fusion occurred, cut and stripped both conductors, severe arcing, foam ignited and was totally consumed on third fault |
| BMS 1360 | 3 | No | Severe arcing, sparks, crater formed in foam, on third fault, foam ignited and was totally consumed |
| **Wire Type** | **Direct Short** | **Circuit Breaker Tripped** | **Notes** |
| MIL-W-81381/12 | 1 | Yes | Some sparks, conductors fused |
| MIL-W-22759/34 | 1 | Yes | Some sparks, conductors fused |
| BMS 1360 | 1 | Yes | Some sparks, conductors fused |

CONCLUSIONS.

1. Circuit breakers provided reliable overcurrent protection.

2. Circuit breakers may not protect wire from ticking faults but can protect wire from direct shorts.

3. These tests indicated that the appearance of a wire subjected to a current that totally degrades the insulation looks identical to a wire subjected to a fire; however, the "fire exposed" conductor was more brittle than the conductor degraded by overcurrent.

4. Preliminary testing indicates that direct short circuits are not likely to start a fire.

5. Preliminary testing indicated that direct short circuits do not erode insulation and conductor to the extent that ticking faults did.

6. Circuit breakers may not safeguard against the ignition of flammable materials by ticking faults.

7. The flammability of materials near ticking faults is far more important than the rating of the wire insulation material.

GLOSSARY.

ARC: A luminous discharge of electricity through a gas, and/or a prolonged electrical discharge or series of prolonged discharges between two electrodes (no physical contact between them).

CIRCUIT BREAKER: A device used to open and close a circuit by non-automatic means as well as to open a circuit automatically on predetermined overcurrent without damaging itself (when properly applied within its rating).

EFFECTIVE VOLTAGE (or CURRENT): Effective value of sinusoidal voltage or current is 0.707 times the peak value. Also designated root mean square (rms) value. With AC voltage, effective value is understood unless otherwise noted.

OVERCURRENT: In a circuit, the current that will cause an excessive or even dangerous rise in temperature in the conductor or its insulation.

PHASE-TO-PHASE: Voltage measured between two "corners" of a delta connection or between any two "legs" of a wye connection.

SHORT CIRCUIT: Also called a short. An abnormal connection of relatively low resistance between two points of a circuit. The result is a flow of excess (often damaging) current between these points.

SPARK: The discharge of electric current through air or another insulator. An electrical spark is virtually instantaneous.

TICKING FAULT: An intermittent metal-to-metal event (conductor-to-conductor, conductor-to-structure, etc.) that results in the discharge of sparks and arcing events.

WIRE DESCRIPTIONS:

BMS 1360: Composite insulation, polytetrafluoroethylene (PTFE) fluorocarbon, aromatic polyimide and an outer layer of PTFE. Normal weight, nickel-coated copper conductor.

MIL-W-22759/34: Crosslinked modified ethylene-tetrafluoroethylene copolymer (ETFE). Normal weight, tin-coated copper conductor.

MIL-W-81381/12: Fluorocarbon/aromatic polyimide insulated. Medium weight, nickel-coated copper conductor.

N96- 17083

# AIRCRAFT WIRING PROGRAM STATUS REPORT

56-33
6327
p, 6

Rex Beach
Naval Air Warfare Center
Aircraft Division
Indianapolis, Indiana

## PROGRAM OVERVIEW

**- NAWC AD Indianapolis is the technical arm for the NAVAIR Aircraft Wiring Program**

**- Primary Functions include:**

- **Component Engineering**
  - **Qualification and Evaluation**
  - ***Specification Development and Maintenance***
- **Systems Engineering**
- **Lead Maintenance Activity for Aircraft Wiring**

## Component Engineering Activities

**General Activities:**

**Implementing Secretary of Defense Perry's initiatives on use of commercial specifications and standards for NAVAIR's aircraft wiring program**

- **Conversion of specifications to performance specification**
- **Cancellation and supercession of many critical military standards**
- **Technical input for DoD specifications and standards surveys being conducted by NAWC AD Lakehurst on all NAVAIR prepared specifications and standards**

**Establishing procedures for QPL/QML manufacturers to utilize SPC and inprocess data in lieu of endproduct QC testing**

**Establishing procedures to utilize ISO-9000 series or other appropriate commercial quality and reliability audit approvals as an alternative to military unique quality and reliability audit requirements (such as MIL-STD-790 and MIL-I-45208)**

**Evaluating other procedures to reduce costs of qualification and retention of qualification testing for manufacturers with superior process controls and quality systems**

## Component Engineering Activities

Wire and Cable Activities:

- Published MIL-W-22759/80-/92 for PTFE/Polyimide insulated "hybrid" insulation wires
- Published Mil-STD-2223 test methods 3006 and 3007 for Dry and Wet Arc Track Propagation Resistance
- Beginning to reference MIL-STD-2223 for insulated wire test methods and MIL-C-29606 for stranded conductor requirements in military wire specifications
- Planning revisions of MIL-C-85485 filter line cable and MIL-W-22759 wiring specifications and working with the Air Force and DISC to update MIL-C-27500 aerospace cable specification
- Finalizing test report on Thermo-Gravimetric Analysis (TGA) as a possible means to determine temperature ratings on aerospace wires

## Component Engineering Activities

Other Component Activities:

- Completed testing of metal/plastic composite connectors exposed to $SO_2$ Salt Spray
- Planning revisions of MIL-C-5015 circular and MIL-C-81659 rectangular connector specifications and MIL-C-85049 connector accessory specification
- Planning conversion of MIL-C-5809 thermal circuit breaker specification from QPL to QML
- Working with SAE-AE8C1 to write a nongovernment standard with a military QPL for molded components

## System Engineering Activities:

- Maintenance of MIL-W-5088 aerospace vehicle wiring installation specification
- Providing support for F18E/F program including wiring system inspections
- V-22 conventional and Organized Wiring System (OWS) support
- Joint Advanced Strike Technology (JAST) aircraft program OWS study
- Fiber optics support including F-22 and RAH-66 issues

### Aircraft Wiring Lead Maintenance Activity:

Determining the extent of remaining insulation life for MIL-W-81381 polyimide insulated wires in many Navy aircraft including the S-3 Viking and EA-6B Prowler

Actively participating with the Naval Vehicle Wiring Action Group (NAVWAG)
- Maintenance procedures to extend thermal circuit breaker life by cycling
- Developing portable heat guns for maintenance on fueled aircraft
- Evaluating wire marking systems (Excimer laser, ink jet, hot stamp, etc... )
- Developing improved wire strippers for all wire types in Navy aircraft inventory

Continuing to compile aircraft wiring maintenance data from Navy field activity databases. Wiring systems are one of the top systems for maintenance actions on most Navy and Marine aircraft.

### NAVAIR/NASA Interface:

NAVAIR is the preparing activity of many specifications used by NASA. NASA is designated as a custodian of some NAVAIR specifications and standards and can submit essential comments

NAWC AD Indianapolis aircraft wiring program will continue to share knowledge and expertise with NASA and other agencies and contractors involved with space vehicle wiring

NAWC AD Indianapolis wiring component and installations specification writing and testing expertise can be utilized by other military or federal agencies or by commercial activities in support of government programs

### Base Realignment and Closure (BRAC) Commission Recommendations:

NAWC AD Indianapolis has been recommended for closure by no later than 1999 by the BRAC Commission and the DoD; However .........

Original recommendation is to move about 60 % of the jobs primarily to NSWC Crane, IN and secondarily to NAWC China Lake, CA and NAWC AD Patuxent River, MD

The BRAC Commission and local government are voicing strong support for a partial or full privatization plan that might keep many of the jobs after the closure at the same geographic site at Indianapolis

It is anticipated the NAVAIR Aircraft Wiring Program will be on ongoing program under any of the various BRAC scenarios

The closure/move/privatization issue for NAWC AD Indianapolis may not be resolved for some time yet

## NAWC AD INDIANAPOLIS

### WIRING TEAM SPECIFICATIONS

| SPECIFICATION | ITEM | REQUIRES QUALIFICATION BY NAWC | PROJECT AREA |
|---|---|---|---|
| MIL-STD-104 | Insulation Color Limits | | 100 |
| MIL-STD-704 | Aircraft Electrical Power Characteristics | | 117 |
| MIL-STD-1344 | Connector Test Methods | | 101 |
| MIL-STD-1646 | Service Tools, connectors & contacts | | 102 |
| MIL-STD-1651 | Inserts M5015 & MS22992 | | 103 |
| MIL-STD-1653 | Power Cable Assemblies | | 104 |
| MIL-STD-1671 | DC Power Connector Schematic | | 105 |
| MIL-STD-1672 | Connector, Umbilical, insert | | 106 |
| MIL-STD-1674 | Connector, Insert M85028 | | 107 |
| MIL-STD-2223 | Wire Test Methods | | 116 |
| MS3493 | Connector Plug & Cap, ground | | 79 |
| MIL-B-3990 | Bearing, Roller, Needle, Airframe | Q | 48 |
| MIL-B-4523/14 | Switch, Boot | | 113 |
| MIL-C-5015 | Circular Connector | Q | 01 |
| MIL-W-5086 | Polyvinyl Chloride Insulated Electric Wire | Q | 13 |
| MIL-W-5088 | Wiring, Aerospace Vehicle | | 53 |
| WS5127 | Backpanel (1-layer /.1 & 2 in. ctr) | | 66 |
| MIL-F-5372 | Fuse, Current Limiter Type, Aircraft | Q | 23 |
| MIL-F-5373 | Fuseholder, Block Type, Aircraft | Q | 49 |
| MIL-S-5594 | Toggle Switch | | 34 |
| MIL-S-5676 | Splicing, Cable Process | | 110 |
| MIL-T-5683 | Terminal, Tie Rod, Threaded | | 83 |
| MIL-C-5756 | Power Cable and Wire | Q | 14 |
| MIL-C-5809 | Circuit Breaker | Q | 35 |
| MIL-B-6038 | Bearing, Bellcrank (No QPL) | | 32 |
| MIL-C-6100 | Connector, Recepticle | | 84 |
| MIL-R-6106 | Electromagnetic Relay (Engineering only) | | 36 |
| WS6118/6119 | Wire Wrap/Process (.1 & .2 in. ctr) | | 67 |
| MIL-W-6370 | Wire, Antenna | | 85 |
| MIL-N-6748 | Nipple, Electrical Terminal | | 92 |
| MIL-R-6749 | Aircraft Power Rheostat | | 20 |
| | | | 21 |
| | | | 22 |
| MIL-S-6852 | Electric Conductor Splice | | 11 |
| MIL-W-7072 | Aluminum Electric Wire | Q | 15 |
| MIL-C-7078 | Electric Cable, Aerospace (Canceled) | | 62 |
| MIL-E-7080 | Electric Equipment Selection | | 109 |
| MIL-T-7099 | Crimp Style Terminal | Q | 09 |
| | | | 42 |
| MIL-T-7928 | Lug and Splice Terminal | Q | 10 |
| MIL-B-7949 | Bearings, Ball, Airframe, Antifriction | Q | 54 |
| MIL-A-7965 | Antenna, Components | | 86 |
| MIL-C-7974 | Cable Assemblies | Q | 37 |
| MIL-R-8903 | Variable Resistor | | 24 |
| MIL-B-8914 | Bearing, Self Aligning | Q | 56 |

| SPECIFICATION | ITEM | REQUIRES QUALIFICATION BY NAWC | PROJECT AREA |
|---|---|---|---|
| MIL-B-8952 | Bearing, Rod End | Q | 40 |
| | | | 38 |
| MS14135 | Drawer Assembly, Rack Mounted | | 115 |
| WS15660 | Vertical Door Buses/connectors | | 68 |
| MS17155-57, 72 | Terminal Studs | | 82 |
| MS18029 | Cover Assembly for MS27212 | | 76 |
| MIL-F-21608 | Shield Terminating/Ferrule | Q | 12 |
| MIL-C-22520 | Crimping Tool, Terminal | Q | 30 |
| MIL-C-22529 | Plastic Grommet (First Article) | | 25 |
| WS22749 | Backpanel (2-layer/ .1 in. ctr.) | | 65 |
| MIL-W-22759 | Fluoropolymer Insulated Electric Wire | Q | 16 |
| MIL-C-22909 | Crimping Tool, Hydraulic | | 58 |
| MIL-J-23013 | Junction, Box | | 93 |
| MIL-S-23053 | Insulation Sleeving, Electrial Heat Shrinkable | | 111 |
| MIL-S-23190 | Cable Straps and Clamps | Q | 26 |
| MIL-W-25038 | High Temperature Electrical Wire | Q | 17 |
| MS25064-67 | Ferrule, Flexable conduit, RF & Accessories | | 73 |
| MS25226 | Link, Terminal Connecting | | 78 |
| MIL-C-25516/24 | Connector, Coaxial | | 94 |
| MS27212 | Terminal Board Assembly Molded-in Stud | | 77 |
| MIL-C-28754 | Electrical Modular Connectors | Q | 61 |
| MIL-C-28859 | Electrical Backplane Connectors, Printed Wiring | Q | 60 |
| MIL-A-28870 | Assemblies, Backplane | Q | 74 |
| MIL-C-29600 | Connector, Composite Circular | Q | 64 |
| MIL-W-29606 | Conductor, Stranded | | 114 |
| MIL-C-38999 | Circular Connector (Series 4) | Q | 02 |
| MIL-C-39029 | Electrical Connector Contact | Q | 04 |
| MIL-T-55155/29-32 | Terminal, Stud | | 75 |
| MIL-W-81044 | Electrical Wire | Q | 18 |
| | | | 39 |
| MIL-T-81306 | Tools, Forming, for strap | Q | 52 |
| MIL-W-81381 | Polyimide Insulated Electric Wire | Q | 19 |
| MIL-T-81490 | Cable, Transmission Coaxial | | 108 |
| MIL-C-81511 | Circular High Density Connector | Q | 05 |
| MIL-M-81531 | Marking of Electrical Insulation | | 88 |
| MIL-C-83538 | Connector, Umbilical, MIL-STD-1760 | Q | 112 |
| MIL-I-81550 | Insulating Compound, Silcon | | 95 |
| MIL-S-81551 | Switch, Toggle, Hermetic | | 55 |
| MIL-C-81582 | Bayonet Coupling Electrical Connector | Q | 06 |
| MIL-M-81594 | Hot Stamp Printing Foil | | 27 |
| MIL-S-81619 | Switch, Solid State Transducer | | 89 |
| MIL-C-81659 | Rectangular Electrical Connector | Q | 07 |
| MIL-C-81703 | Circular Electrical Connector | Q | 08 |
| MIL-T-81714 | Terminal Junction System | Q | 29 |
| MIL-I-81765 | Insulating, Molded, Heat Shrink | | 90 |
| MIL-C-81790 | Aircraft External Power Connector | Q | 41 |

| SPECIFICATION | ITEM | REQUIRES QUALIFICATION BY NAWC | PROJECT AREA |
|---|---|---|---|
| MIL-W-81822 | Solderless Wrap Wire (First Article) | | 63 |
| MIL-S-81824 | Environmental Splice | Q | 45 |
| MIL-T-81914(AS) | Tubing, Plastic | | 81 |
| MIL-I-81969 | Tool, Installing & Removal | Q | 43 |
| MIL-C-83413/4, /5, /8 | Connectors & Assemblies, Electrical, Aircraft Grounding | Q | 33 |
| MIL-T-83507 | Tool Kit | | 46 |
| MIL-C-85028 | Rectangular Electrical Connector | | 28 |
| DoD-C-85045 | Fiber Optic Cable | | 31 |
| MIL-C-85049 | Connector Accessory | Q | 44 |
| MIL-I-85080/2 | Insulation Sleeve, Non-heat | | 96 |
| MIL-S-85242 | Switch, Stepping | | 91 |
| MIL-C-85485 | Cable, Filter Line | Q | 51 |
| MIL-S-83519 | Shield Termination, Solder Type | Q | 57 |
| MIL-C-85528 | Connector Mounting Device (Canceled) | | 03 |
| MIL-F-85731 | Fastener, Positive Locking | Q | 59 |
| MIL-S-85848 | Sleeving For ID Mark, Heat Shrink | | 80 |
| #2465230 | Ribbon Cable | | 71 |
| #3202740 | Connector (Type II-Type II) | | 70 |
| #5932026 | Laminated Bus Bar | | 69 |
| | Special Evaluations (Non-QPL Work) | | 50 |
| | Special Evaluations (Trident) | | 72 |
| | | | 47 |
| | | | 87 |
| | | | 97 |
| | | | 98 |
| | | | 99 |

SESSION II

omit

# WIRING TEST RESULTS

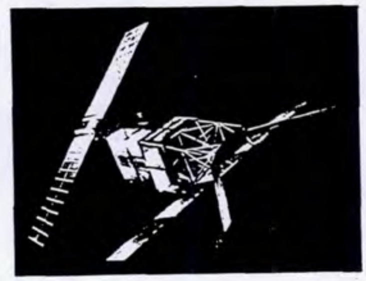
# NASA WIRING FOR SPACE APPLICATIONS PROGRAM TEST RESULTS

Mark Stavnes and Ahmad Hammoud
NYMA, Inc.
NASA Lewis Research Center
Cleveland, Ohio



## ELECTRICAL POWER WIRING PROGRAM

GOAL: TO PROVIDE A TECHNOLOGY BASE FOR THE DEVELOPMENT OF LIGHTWEIGHT, ARC TRACK-RESISTANT AND RELIABLE WIRING SYSTEMS FOR AEROSPACE APPLICATIONS.



**APPROACH**

- IDENTIFY MISSION REQUIREMENTS AND APPLICATION ENVIRONMENTS
- EVALUATE POTENTIAL WIRING SYSTEMS AND ESTABLISH A DATABASE
- INVESTIGATE ADVANCED TECHNOLOGIES RELEVANT TO WIRING FAILURE PREVENTION, DETECTION, AND ISOLATION.
- ESTABLISH GUIDELINES AND RECOMMENDATIONS

**TECHNOLOGICAL DEVELOPMENTS**

- NEW INSULATING MATERIALS
- NEW WIRING CONSTRUCTIONS
- IMPROVED SYSTEM DESIGN
- ADVANCED CIRCUIT PROTECTION

**APPLICATIONS**

- PRESSURIZED MODULES
- TRANS-ATMOSPHERIC VEHICLES
- LEO/GEO ENVIRONMENTS
- LUNAR AND MARTIAN ENVIRONMENTS

## NASA Wiring for Space Applications Program

- ***Test Program*:** Evaluate potential wiring constructions and establish a database of testing information.
  - Identify and prioritize NASA wiring requirements
  - Select candidate wiring constructions
  - Develop test matrix and formulate test program
  - Coordinate and conduct tests
  - Establish guidelines and recommendations

# NASA Wiring for Space Applications Program

- ***NASA Mission Environments:***
    - Pressurized Module
    - LEO/GEO Applications
    - Trans-Atmospheric Vehicles
    - Lunar Surface
    - Martian Surface

## OPERATIONAL ENVIRONMENTS

| | Pressurized Modules | Low Earth Orbit | GEO | Trans-atmospheric | Lunar Surface | Martian Surface | Military Aircraft |
|---|---|---|---|---|---|---|---|
| **Electrical** | | | | | | | |
| Voltage | 28 - 120 V | 28 - 160 V | | 28 - 270 V | 28 - 160 V | | 28 V |
| Frequency | DC | | | | DC - 20 kHz | | DC - 400 Hz |
| **Mechanical** | | | | | | | |
| Vibration | 1 - 10 g<br>137 - 145 dB SPL | | | | | | 25 μm amplitude<br>500 Hz |
| Impacts | N/A | 11 - 26 impacts/m²/yr (Function of Altitude) | < LEO | LEO → GEO (Function of Altitude) | 0.01 - 0.5 impacts/m²/yr | Very Low Probability | N/A |
| **Environmental** | | | | | | | |
| Temperature | 18.3°C - 26.7°C | -65°C → 120°C<br>6000 cycles/yr | -196°C → 128°C<br>90 cycles/yr | -200°C → 260°C<br>Cycles Altitude Dependent | -171°C → 111°C<br>13 cycles/yr | -143°C → 27°C<br>356 cycles/yr | -65°C → 230°C |
| Atmosphere | Earth → 30% $O_2$ | Earth → Very Low $O_2$ | | | | Earth → 0.13% $O_2$, 95.3% $CO_2$ | Earth Atmosphere |
| Gas/Fluid Comp. | 25 → 75% RH<br>100% RH Salt Fog<br>Space Fluids | 100% RH Salt Fog<br>Space Fluids | | | | | 25 - 75% RH<br>100% RH Salt Fog<br>Aerospace Fluids |
| Pressure | 517 - 760 Torr | $10^{-5} \rightarrow 10^{-10}$ Torr | $7.5 \times 10^{-14}$ Torr | $760 \rightarrow 7.5 \times 10^{-14}$ Torr | $10^{-8} \rightarrow 10^{-12}$ Torr | 4.4 → 11.4 Torr | 49 - 760 Torr |
| EM Radiation | N/A | 2220 → 5800 ESH/yr (Altitude Dependent) | 8760 ESH/yr | 8760 ESH/yr (Altitude Dependent) | 8760 ESH/yr | 1656 ESH/yr | Earth UV |
| Particulate Radiation | N/A | Protons, α particles, and electrons | | | | N/A | N/A |
| Atomic Oxygen | N/A | $10^{20}$ atoms/cm²/yr (Altitude Dependent) | < LEO | LEO → GEO (Altitude Dependent) | N/A | N/A | N/A |
| Reduced Gravity | $10^{-3} \rightarrow 10^{-6}$ g | $10^{-3} \rightarrow 10^{-6}$ g | | $1 \rightarrow 10^{-6}$ g | 0.165 g | 0.38 g | N/A |
| Charged Plasma | N/A | $0.3 \rightarrow 45 \times 10^{4}$ atoms/cm³<br>0.1 → 0.2 eV | 0.24 → 1.12 atoms/cm³<br>120 → 295 keV | LEO → GEO | N/A | $10^{3} \rightarrow 10^{5}$ atoms/cm³ | N/A |

KEY: N/A = Not Applicable

# TESTING PROGRAM APPROACH

- **Determine Required Test Matrix**
  - NASA Operational Environments
  - NASA Unique Test Requirements

- **Leverage Existing Testing Database**
  - Air Force Programs
  - Navy Programs
  - NASA Programs

- **Identify and Evaluate Candidate Wiring Constructions**
  - Military Standard Wires
  - Hybrid Insulation Constructions

- **Utilize (Inter)National Expertise**
  - External Review of All Plans
  - Experienced Testing Organizations

## NASA Wiring for Space Applications Program

- ***Candidate Systems:***
  - Filotex (PTFE/PI/FEP)
  - Thermatics (PTFE/PI/PTFE)
  - Tensolite (PTFE/PI/PTFE)
  - Gore (PTFE/HSCR PTFE/PTFE)
  - MIL-W-81381/7 (FEP/PI)
  - MIL-W-22759/12 (TFE)
  - MIL-W-22759/34 (XL-ETFE)
  - New Insulation (PFPI)

- ***Configuration:***
  - MIL-W-81381/7 constructions
  - AWG: #12, #20
  - Single wire
  - Twisted pair

## NASA Wiring for Space Applications Program

- ***Summary of Results Reported in 2nd NASA Workshop on Wiring for Space Applications:***

  - Arc tracking, mechanical, electrical, flammability, fluid reactivity, thermal vacuum stability, atomic oxygen, and ultra-violet radiation performed on 8 candidate samples of both # 12 and # 20.

  - Candidate constructions down-selected to 3 most promising candidates, single wire gauge (# 20), and further tests were defined.

  - New insulation materials were identified and will be investigated

(Information reported in NASA Conference Publication 3244 - "Second NASA Workshop on Wiring for Space Applications)

## NASA Wiring for Space Applications Program

### FY '94 - '95 Testing Activities

- ***Down-selected Samples:***

  *Gauge:*

  - AWG # 20

  *Constructions:*

  - Tensolite (PTFE/PI/PTFE)
  - Thermatics (PTFE/PI/PTFE)
  - Filotex (PTFE/PI/FEP)
  - MIL-W-81381/7 (FEP/PI)
  - MIL-W-22759/12 (TFE)
  - MIL-W-22759/34 (XL-ETFE)
  - New Insulation (PFPI)

## NASA Wiring for Space Applications Program

**FY '94 - '95 Testing Activities**

- ***Participating Organizations:***

  - NASA
    - LeRC
    - MSFC
    - JSC
  - McDonnell Douglas/TRW
  - University of Buffalo

## NASA Wiring for Space Applications Program

**FY '94 - '95 Testing Activities**
**NASA LeRC**

- ***Objective:*** Perform comparative analysis of arc-tracking of the candidate constructions under atmospheric, vacuum, and μgravity conditions.

- ***Tests:*** Arc-tracking
  - Ambient conditions
  - $5 \times 10^{-5}$ torr
  - $10^{-2}$ g

- ***Principal Investigator:*** Thomas J. Stueber
  NYMA, Inc.
  NASA Lewis Research Center

## NASA Wiring for Space Applications Program

**FY '94 - '95 Testing Activities**
**NASA MSFC**

- ***Objective:*** Investigate the effects of AO, UV, and AO with UV synergistic effects on wire insulation materials.

- ***Tests:***
  AO: ~$10^{21}$ atoms/$cm^2$
  UV: ~10,000 ESH

- ***Principal Investigator:***
  Jason A. Vaughn
  Space Environmental Effects Branch
  George C. Marshall Space Flight Center

# NASA WIRING FOR SPACE APPLICATIONS PROGRAM TEST RESULTS

Jason A. Vaughn
George C. Marshall Space Flight Center
Materials and Processes Laboratory
Engineering Physics Division
Marshall Space Flight Center, Alabama



## Presentation Outline

- Objective
- Atomic Oxygen System Description
- Results of Wire Insulation Exposure to 5 eV Atomic Oxygen Atoms
- Discussion of Ultraviolet Radiation Test Procedure
- Results of Ultraviolet Radiation Exposure on Materials

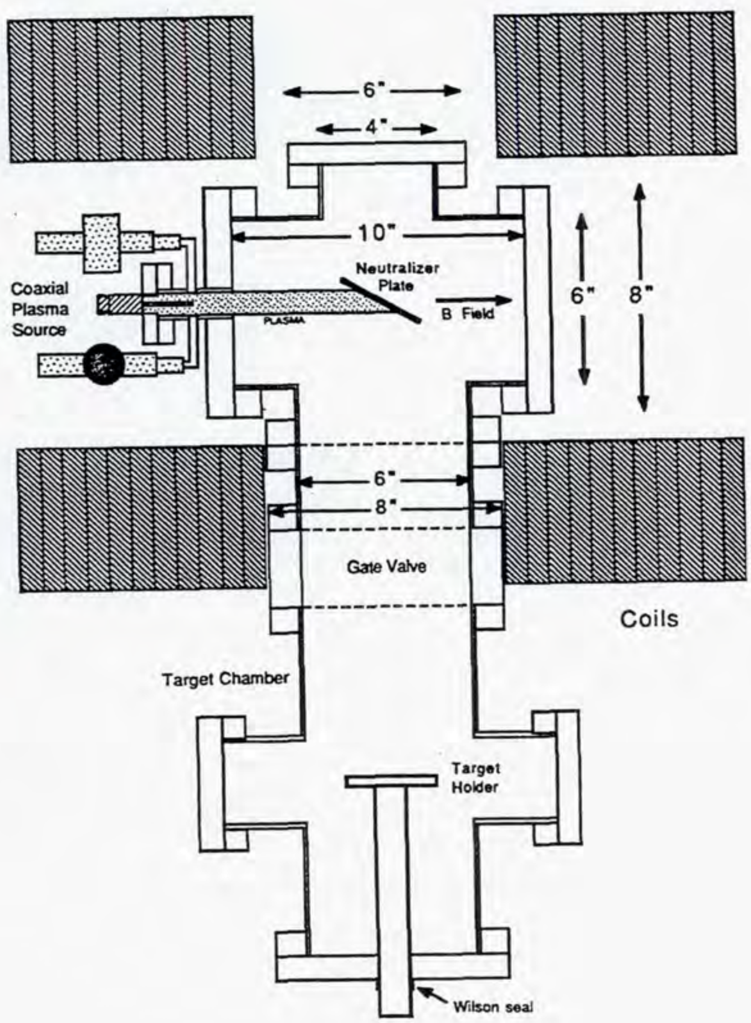
## Objective

Investigate the effects of AO, UV and AO with UV synergistic effects on wire insulation materials. Atomic oxygen exposure to be on the order of $10^{21}$ atoms/cm$^2$ and VUV radiation to be on the order of 10,000 ESH.

PPPL 5 eV Atomic Oxygen System Characteristics

- Developed under contract with MSFC (H-83097B)
- Produces 5 eV atomic oxygen neutral atoms at a flux of $10^{16}$ atoms/cm$^2$
- Fluence Levels of $10^{21}$ atoms/cm$^2$ require exposure times of approximately 40 hrs.
- Simultaneously produces Vacuum Ultraviolet radiation at 130 nm 200 times as intense as the equivalent solar VUV dose.

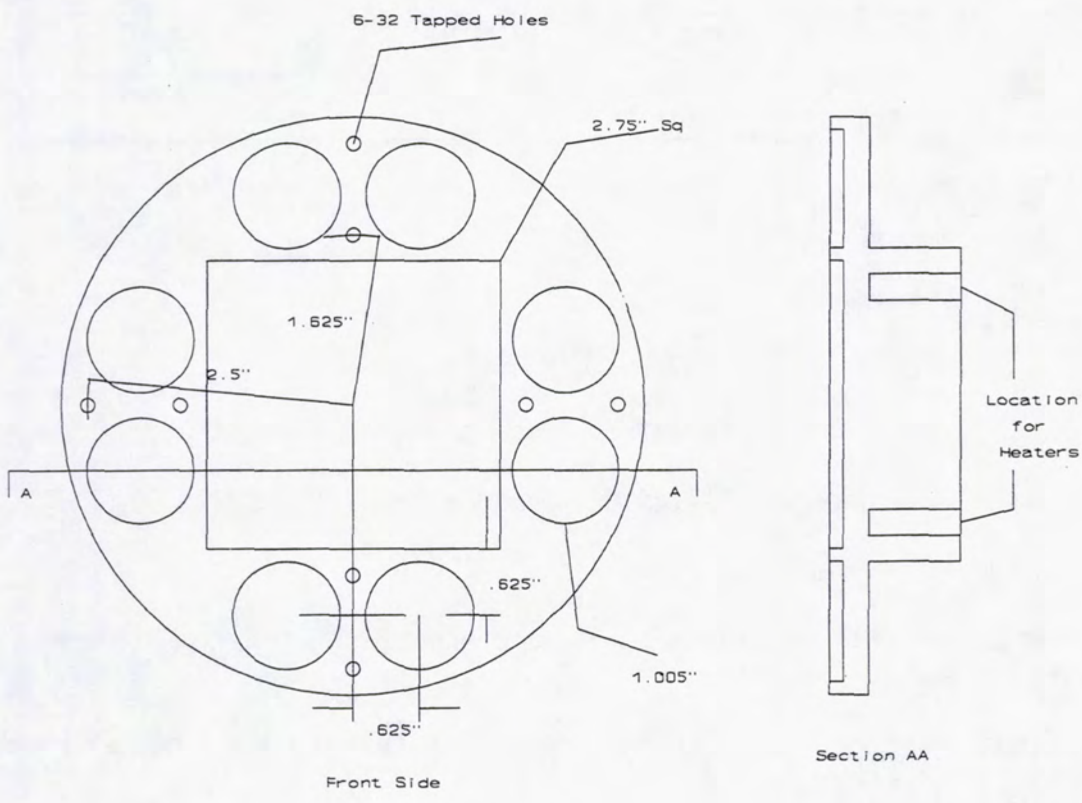
PPPL 5 eV Atomic Oxygen System Schematic



Wire Insulation Materials Exposed to 5 eV Atomic Oxygen

- TRW PFPI--Partially Fluorinated Polyimide
- MIL-W-22759/12-TFE Teflon Outer Material
- MIL-W-22759/34-XL-ETFE (TFE Teflon Material)

Wire Insulation Sample Fixture for AO Exposure



## Atomic Oxygen Testing Visual Observations

- After completion of tests all wire materials showed no signs of eroding to the conductor or discoloration of the wire material.
- All wire samples had a powdery residue left on the surface.

**NASA Electrical Wiring Test Program**

**Mass Loss Summary of Wire Exposed to $8.5x10^{20}$ atoms/cm$^2$ Fluence AO and 8200 ESH VUV**

| | Average Δmass (mg) | Average Δthickness (μm) | Computed Re (cm³/atom) |
|---|---|---|---|
| TRW-PFPI (awg #20) | 6.26 | 47.2 | $5.6x10^{-24}$ |
| MIL-W-22759/12 (awg #20) | 7.47 | 34.8 | $4.1x10^{-24}$ |
| MIL-W-22759/34 (awg #12) | 3.12 | 14.5 | $1.7x10^{-24}$ |

## Ultraviolet Test Set-Up

- Four Samples of Each Wire Were Used For Statistical Average.
- Samples Exposed in $10^{-7}$ Torr Vacuum for a Period of 1033 hrs.
- Samples were controlled at Temperature of 120°C
- An Enhanced Ultraviolet Radiation Lamp with a Mercury-Xenon Bulb was used to radiate the samples.
- Source Produce Four (4) UV suns over the wavelength region of 200 nm to 400 nm per hour.
- Total Sample Exposure 4132 Equivalent Sun Hours.

Ultraviolet Radiation Test Materials

- Teledyne Thermantics (awg #20 and #12)--TFE/FEP Co-Polymer
- Tensolite (awg #20 and #12)-- TFE teflon outer material
- Champlain (awg #20)--FEP/TFE Co-polymer
- Barcel M81381-7 (awg #20)--Kapton
- HSCR Gore (awg #20 and #12)--TFE Teflon material Outercoat
- M81381-11 (awg #20 and #12)--Kapton Outer Material
- Filotex (awg #20 and #12)--TFE Teflon Outer Material

**NASA Electrical Wiring Test Program**
**Mass Loss Summary of Wire to 4000 ESH UV Radiation**

| | Average ΔMass (mg) | Percent Average ΔMass (% ) |
|---|---|---|
| Filotex (awg #20) | 0.327 | 0.069 |
| Filotex (awg #12) | 0.517 | 0.023 |
| Teledyne Therm. (awg #20) | 0.153 | 0.033 |
| Teledyne Therm. (awg #12) | 0.530 | 0.025 |
| Tensolite (awg #20) | 0.197 | 0.041 |
| Tensolite (awg #12) | 0.443 | 0.021 |
| Champlain (awg #20) | 0.233 | 0.048 |
| HSCR Gore (awg #20) | 0.267 | 0.057 |
| HSCR Gore (awg #12) | 0.510 | 0.023 |
| M81381-11 (awg #20) | -0.180 | -0.035 |
| M81381-11 (awg #12) | -0.720 | -0.034 |
| Barcel M81381-7 (awg #20) | -0.044 | -0.010 |

## Summary of Atomic Oxygen and VUV Exposure of Wire Insulation Material

- TRW - Partially Fluorinated PolyImide (PFPI) has higher AO reactivity. Uncertain to cause.

- Fluorinated Polymers have a high Synergistic VUV and Atomic Oxygen reactivity.

- The True Reason for the Increased Fluorocarbon Reactivity Is Not Known But is Believed to be Caused by the Increased VUV Radiation Rate.

- VUV Exposure Alone on Fluorocarbon Materials Causes Them to Lose Mass.

N96- 17086

# NASA WIRING FOR SPACE APPLICATIONS PROGRAM TEST RESULTS

Harry T. Johnson
NASA Laboratories Office
NASA Lyndon B. Johnson Space Center
Houston, Texas

and

David Hirsch
AlliedSignal Aerospace
Albuquerque, New Mexico

59-20
6330
P- 16

## NASA Wiring for Space Applications Program

**FY '94 - '95 Testing Activities**
**NASA JSC/WSTF**

- ***Objective:*** Perform NASA specified testing for compatibility with enclosed spacecraft environments.

- ***Tests:***
  Flammability: 30% $O_2$, 200°C
  Odor: 25.9% $O_2$, 50°C
  Aerospace Fluids Compatibility: $N_2O_4$, $N_2H_4$, $N_2H_3CH_3$
  Offgassing: 25.9% $O_2$, 50°C
  Thermal Vacuum Stability: $5 \times 10^{-5}$ torr, 125°C, 24 hrs.

- ***Principal Investigators:***
  Dr. Harry T. Johnson - NASA Laboratories Office
  David Hirsch - AlliedSignal Aerospace

# Background

NASA Lewis Research Center Requested NASA Johnson Space Center White Sands Test Facility to Conduct Flammability, Odor, Offgassing, Thermal Vacuum Stability, and Compatibility Tests with Aerospace Fluids of Several Wire Insulations

Wire Insulations Evaluated:

- Partially Fluorinated Polyimide
- Extruded ETFE
- Extruded PTFE
- PTFE Tape
- PTFE/Kapton

Tests Performed:

- Per NHB 8060.1C
  - Flammability (Tests 1 and 4)
  - Odor (Test 6)
  - Compatibility with Aerospace Fluids (Test 15)
- Per NHB 8060.1B
  Offgassing (Test 7)
- Per SP-R-0022A (ASTM E 595)
  Thermal Vacuum Stability

# Test 1 (Upward Flame Propagation)

Test Approach:

- Exposed Vertical Sample to Ignition Source That Provided 750 Calories for Approximately 25 s
- Three Samples Tested for Each Test Condition

Observations Made:

- Ignitability
- Burn Length
- Ignition of a Witness Material by Transfer of Burning Debris

## Test Conditions:

30% Oxygen in Nitrogen at 10.2 psia

## Results:

| Materials | Sample Burn Length (cm) | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Partially Fluorinated Polyimide | 5.3 | 8.6 | 4.3 |
| Extruded ETFE | 18.3 | 5.8 | 8.9 |
| Extruded PTFE | 5.6 | 6.1 | 5.3 |
| PTFE Tape | 3.6 | 5.6 | 2.5 |
| PTFE/Kapton | 4.6 | 4.8 | 4.6 |

Note: Only the extruded ETFE insulated wire failed the test

# Test 4 (Wire Insulation Flammability)

Test Approach:

- Oriented Wire Sample 15 Degrees to Vertical, Internally Heated Sample, and Exposed Sample to Ignition Source Providing 750 Calories for Approximately 25 s
- Tested Three Samples for Each Test Condition

Observations Made:

- Ignitability
- Burn Length
- Ignition of a Witness Material by Transfer of Burning Debris

## Test Conditions:

- 30% Oxygen in Nitrogen at 10.2 psia
- Internal Wire Temperature 200 °C

## Results:

| Materials | Single Wire Burn Length (cm) for Samples Tested at 200 °C | | |
|---|---|---|---|
| Partially Fluorinated Polyimide | 2.5 | 3.3 | 4.1 |
| Extruded ETFE | 30.5 | 30.5 | 30.5 |
| Extruded PTFE | 3.0 | 3.3 | 3.6 |
| PTFE Tape | 3.3 | 3.6 | 3.3 |
| PTFE/Kapton | 1.5 | 2.5 | 2.0 |

Note: Only the extruded ETFE insulated wire failed the test.

## Test 6 (Odor Assessment)

Test Approach:

- Subject Sample to Thermal Exposure for 72 Hours at 120 °F, 25.9% Oxygen at 11.9 psia
- Odor Panel Members Administered with at Least 30 cc of Gas from Sample Container

| Odor Scale Rating | |
|---|---|
| Undetectable | 0 |
| Barely Detectable | 1 |
| Easily Detectable | 2 |
| Objectionable | 3 |
| Revolting | 4 |

Results:

| Material | Odor Rating* |
|---|---|
| Partially Fluorinated Polyimide | 0.4 |
| Extruded ETFE | 1.4 |
| Extruded PTFE | 1.3 |
| PTFE Tape | 1.0 |
| PTFE/Kapton | 0.6 |

*Average Result of 5 Responses

## Test 7 (Determination of Offgassed Products)

Test Approach:

- Subjected Sample to Thermal Exposure for 72 Hours at 120 °F, 25.9% Oxygen at 11.9 psia

- After Each Sample Container Was Cooled, Determined Identity and Quantity of Each Analyzable Offgassed Product

### Maximum Amount of Material Used in Habitable Areas of Spacecraft Must Meet Toxic Hazard Index Requirement of ≤ 0.5

Material: Partially Fluorinated Polyimide

| Component | Toxic Limit (μg/g) | Quantity (μg/g) |
|---|---|---|
| 1-Methyl-2-Pyrrolidone | 0.14 | 0.05 |
| 2-Butoxyethanol | 34.68 | 0.005 |
| 2-Ethylhexanol | 230 | 0.04 |
| Acetaldehyde | 6 | 0.02 |
| Acetone | 1018 | 0.03 |
| Acetophenone | 350 | 0.005 |
| Benzaldehyde | 247 | 0.005 |
| Butene | 7.17 | 0.005 |
| Butyraldehyde | 168.99 | 0.005 |
| C10 Unsaturated aliphatic hydrocarbon | 7.17 | 0.005 |
| C6 Aldehyde | 3.44 | 0.005 |

# Test 7
# (Determination of Offgassed Products), Cont'd

Material: Partially Fluorinated Polyimide - Cont'd

| Component | Toxic Limit ($\mu g/g$) | Quantity ($\mu g/g$) |
|---|---|---|
| C8 Aldehydes | 0.14 | 0.007 |
| Carbon Monoxide | 14 | 0.05 |
| Decamethylcyclopentasiloxane | 271.6 | 0.009 |
| Dichloromethane | 72 | 0.005 |
| Ethyl alcohol | 134 | 0.01 |
| Hexamethylcyclotrisilozane | 324 | 0.08 |
| Isopropyl alcohol | 215 | 0.02 |
| Methyl alcohol | 13 | 0.01 |
| Methyl ethyl ketone | 43 | 0.005 |
| n-Butyl alcohol | 173 | 0.005 |
| n-Propyl alcohol | 140 | 0.01 |

Material: Partially Fluorinated Polyimide - Cont'd

| Component | Toxic Limit ($\mu g/g$) | Quantity ($\mu g/g$) |
|---|---|---|
| Nonanal | 42 | 0.007 |
| Octamethylcyclotetrasiloxane | 217.39 | 0.03 |
| Styrene | 60.9 | 0.005 |
| t-Butyl alcohol | 173 | 0.006 |
| Toluene | 86 | 0.01 |
| Trimethyl silanol | 57 | 0.005 |
| Xylenes | 315 | 0.005 |

Material: Extruded ETFE

| Component | Toxic Limit ($\mu g/g$) | Quantity ($\mu g/g$) |
|---|---|---|
| Acetaldehyde | 6 | 0.02 |
| Acetone | 1018 | 0.02 |
| Acrolein | 0.04 | 0.03 |
| Butene | 7.17 | 0.40 |
| C7 Ketone | 33.68 | 0.006 |
| Carbon monoxide | 14 | 0.33 |
| Cyclohexanone | 86 | 0.01 |
| Difluorodimethyl silane | 0.14 | 0.06 |
| Ethyl alcohol | 134 | 0.005 |
| Fluoroaliphatic hydrocarbons | 0.14 | 0.06 |
| Hexamethylcyclotrisiloxane | 324 | 0.01 |

# Test 7
# (Determination of Offgassed Products), Cont'd

Material: Extruded ETFE - Cont'd

| Component | Toxic Limit ($\mu$g/g) | Quantity ($\mu$g/g) |
|---|---|---|
| Isobutane | 339 | 0.009 |
| Isobutyraldehyde | 63.05 | 0.03 |
| Isopropyl alcohol | 215 | 0.005 |
| Methyl alcohol | 13 | 0.005 |
| Methyl ethyl ketone | 43 | 0.10 |
| n-Butyl alcohol | 173 | 0.005 |
| n-Propyl alcohol | 140 | 0.005 |
| Octamethylcyclotetrasiloxane | 217.39 | 0.02 |
| Propionaldehyde | 136 | 0.005 |
| t-Butyl alcohol | 173 | 0.06 |
| Toluene | 86 | 0.02 |
| Trimethyl silanol | 57 | 0.005 |

Material: Extruded PTFE

| Component | Toxic Limit ($\mu$g/g) | Quantity ($\mu$g/g) |
|---|---|---|
| Acetaldehyde | 6 | 0.008 |
| Acetone | 1018 | 0.005 |
| C10 Saturated and unsaturated aliphatic hydrocarbons | 166.23 | 0.03 |
| C5 Saturated aliphatic hydrocarbon | 7.17 | 0.005 |
| Carbon monoxide | 14 | 0.05 |
| Hexamethylcyclotrisiloxane | 324 | 0.01 |
| n-Butyl alcohol | 173 | 0.005 |
| n-Propyl alcohol | 140 | 0.005 |
| Octamethylcyclotetrasiloxane | 217.39 | 0.01 |
| Toluene | 86 | 0.009 |
| Trimethyl silanol | 57 | 0.005 |

# Test 7
# (Determination of Offgassed Products), Cont'd

Material: Extruded ETFE

| Component | Toxic Limit (μg/g) | Quantity (μg/g) |
|---|---|---|
| Acetaldehyde | 6 | 0.02 |
| Acetone | 1018 | 0.02 |
| Acrolein | 0.04 | 0.03 |
| Butene | 7.17 | 0.40 |
| C7 Ketone | 33.68 | 0.006 |
| Carbon monoxide | 14 | 0.33 |
| Cyclohexanone | 86 | 0.01 |
| Difluorodimethyl silane | 0.14 | 0.06 |
| Ethyl alcohol | 134 | 0.005 |
| Fluoroaliphatic hydrocarbons | 0.14 | 0.06 |
| Hexamethylcyclotrisiloxane | 324 | 0.01 |

Material: PTFE Tape

| Component | Toxic Limit (μg/g) | Quantity (μg/g) |
|---|---|---|
| Acetaldehyde | 6 | 0.005 |
| Acetone | 1018 | 0.005 |
| Allyl alcohol | 1.43 | 0.009 |
| alpha-Methylstyrene | 17 | 0.006 |
| Butene | 7.17 | 0.005 |
| C10 Saturated aliphatic hydrocarbons | 7.17 | 0.02 |
| C11-C13 Saturated and unsaturated aliphatic hydrocarbons | 7.17 | 1.1 |
| Carbon monoxide | 14 | 0.05 |
| Decamethylcyclopentasiloxane | 271.6 | 0.008 |
| Decane | 333 | 0.04 |

# Test 7
# (Determination of Offgassed Products), Cont'd

Material: PTFE Tape - Cont'd

| Component | Toxic Limit ($\mu$g/g) | Quantity ($\mu$g/g) |
|---|---|---|
| Dodecane | 398.74 | 0.26 |
| Ethyl alcohol | 134 | 0.005 |
| Hexamethylcyclotrisiloxane | 324 | 0.06 |
| Hexamethyldisiloxane | 138.43 | 0.02 |
| Methyl alcohol | 13 | 0.005 |
| n-Propyl alcohol | 140 | 0.005 |
| Octamethylcyclotetrasiloxane | 217.39 | 0.03 |
| Toluene | 86 | 0.005 |
| Trimethyl silanol | 57 | 0.02 |
| Undecane | 436 | 0.26 |

Material: PTFE/Kapton

| Component | Toxic Limit ($\mu$g/g) | Quantity ($\mu$g/g) |
|---|---|---|
| 2-Phenyl-2-propanol | 47 | 0.005 |
| Acetaldehyde | 6 | 0.005 |
| Acetone | 1018 | 0.005 |
| Acetophenone | 350 | 0.005 |
| Allyl alcohol | 1.43 | 0.005 |
| alpha-Methylstyrene | 17 | 0.005 |
| C10 Saturated aliphatic hydrocarbon | 7.17 | 0.005 |
| C11-C12 Saturated and unsaturated aliphatic hydrocarbons | 67 | 0.02 |
| C8 Alcohol | 0.14 | 0.005 |
| Carbon monoxide | 14 | 0.05 |

## Test 7
## (Determination of Offgassed Products), Cont'd

Material: PTFE/Kapton - Cont'd

| Component | Toxic Limit (μg/g) | Quantity (μg/g) |
|---|---|---|
| Decamethylcyclopentasiloxane | 271.6 | 0.01 |
| Ethyl alcohol | 134 | 0.005 |
| Hexamethylcyclotrisiloxane | 324 | 0.07 |
| Isopropyl alcohol | 215 | 0.005 |
| Methyl alcohol | 13 | 0.005 |
| n-Propyl alcohol | 140 | 0.005 |
| Octamethylcyclotetrasiloxane | 217.39 | 0.03 |
| Trimethyl silanol | 57 | 0.01 |

## Test 15
## (Reactivity of Materials in Aerospace Fluids)

Test Approach:

- During Phase I, Evaluated Gross Compatibility by Exposing Material to Fluid at Ambient Temperature for 2 Hours
- During Phase II, Exposed Material to Fluid for 48 Hours at Maximum System Temperature or 160 °F (Whichever Was Higher)
- Observed Pressure Rise, Fluid Composition, and Material Changes When Compared with Reference Material Exposed to Same Fluid

## Test 15
## (Reactivity of Materials in Aerospace Fluids), Cont'd

Immersion Data in Liquid Phase of Dinitrogen Tetroxide

| Material | Gas Pressure (psia) Sample | Gas Pressure (psia) Reference | Material Changes | Fluid Visual Changes |
|---|---|---|---|---|
| Partially Fluorinated Polyimide | ND | ND | Partial Dissolution | None |
| Extruded ETFE | 128 | 128 | White to Yellow | None |
| Extruded PTFE | 125 | 126 | Lettering Disappeared | None |
| PTFE Tape | 126 | 128 | White to Slight Orange | None |
| PTFE/Kapton | 125 | 127 | Brown to Orange | None |

Immersion Data in Liquid Phase of Dinitrogen Tetroxide

| Material | Posttest Fluid Analysis (Non-volatile Residue), mg Sample | Posttest Fluid Analysis (Non-volatile Residue), mg Reference |
|---|---|---|
| Partially Fluorinated Polyimide | ND | ND |
| Extruded ETFE | 6.5 | 2.7 |
| Extruded PTFE | 16.7 | 9.1 |
| PTFE Tape | 1.3 | 1 |
| PTFE/Kapton | ND | 0.7 |

# Test 15
## (Reactivity of Materials in Aerospace Fluids), Cont'd

### Immersion Data in Liquid Phase of Hydrazine

| Material | Gas Evolut. Rate (sccm/hr/$cm^2$ x 10E4) Sample | Reference | Material Changes | Fluid Visual Changes |
|---|---|---|---|---|
| Partially Fluorinated Polyimide | ND | ND | Complete Degradation | Brown, Particulate |
| Extruded ETFE | 15 | 8 | White to Grey | None |
| Extruded PTFE | 16 | 9 | None | None |
| PTFE Tape | 29 | 8 | White to Slight Yellow | Yellow |
| PTFE/Kapton | 32 | 6 | Brown to Yellow | Yellow |

### Immersion Data in Liquid Phase of Hydrazine - Posttest Fluid Analysis

| Material | Purity (%) | $CO_2$ (ppm) | Non-Volatile Residue (mg) | Chloride (μg) | Fluoride (μg) |
|---|---|---|---|---|---|
| Partially Fluorinated Polyimide | ND | ND | ND | ND | ND |
| Reference | ND | ND | ND | ND | ND |
| Extruded ETPE | 99.7 | 10 | 0.6 | 12 | 48 |
| Reference | 99.7 | 10 | 0.8 | 37 | ND |
| Extruded PTFE | 99.7 | 10 | 0.7 | 35 | 4.6 |
| Reference | 99.7 | 10 | 0.9 | 35 | 2.3 |
| PTFE Tape | 99.7 | 10 | 35.1 | 44 | ND |
| Reference | 99.8 | 9 | 1 | 44 | ND |
| PTFE/Kapton | 99.7 | 9 | 1.2 | 41 | ND |
| Reference | 99.7 | 9 | 0.5 | 41 | ND |

# Test 15
# (Reactivity of Materials in Aerospace Fluids), Cont'd

## Immersion Data in Liquid Phase of Monomethylhydrazine

| Material | Gas Evolut. Rate ($sccm/hr/cm^2$ x 10E4) Sample | Reference | Material Changes | Fluid Visual Changes |
|---|---|---|---|---|
| Partially Fluorinated Polyimide | ND | ND | Complete Degradation | Brown |
| Extruded ETFE | 2 | 1 | White to Light Yellow | Light Yellow |
| Extruded PTFE | 1 | 1 | None | None |
| PTFE Tape | 2 | 1 | White to Yellow | Yellow |
| PTFE/Kapton | 1 | 2 | Brown to Brown/Yellow | Yellow |

Immersion Data in Liquid Phase of Monomethylhydrazine - Posttest Fluid Analysis

| Material | Purity (%) | $CO_2$ (ppm) | Non-Volatile Residue (mg) | Chloride (μg) | Fluoride (μg) |
|---|---|---|---|---|---|
| Partially Fluorinated Polimide | ND | ND | ND | ND | ND |
| Reference | ND | ND | ND | ND | ND |
| Extruded ETFE | 99.7 | 5 | 0.7 | 6.9 | 160 |
| Reference | 99.7 | 2 | 0.3 | 4.6 | ND |
| Extruded PTFE | 99.8 | 4 | 0.1 | 2.3 | ND |
| Reference | 99.8 | 3 | 0.3 | 4.6 | ND |
| PTFE Tape | 99.7 | 2 | 49.1 | 6.9 | ND |
| Reference | 99.7 | 2 | 0.3 | 6.9 | ND |
| PTFE/Kapton | 99.7 | 2 | 27.8 | 6.9 | 2.3 |
| Reference | 99.7 | 2 | 0.3 | 2.3 | ND |

## NASA Wiring for Space Applications Program

### Test 15 Results

- PFPI was very reactive to Hydrazine and MMH, others slightly reactive

- Pictures of pre- and post-test samples will be printed in the final test report

## VCM Test

Total Mass Loss and Collected Condensable Materials from Outgassing in a Vacuum Environment

Test Approach:

- Conditioned Sample for 24 Hours at 23 °C and 50% RH
- Weighed Conditioned Sample and Exposed Sample to Vacuum for 24 Hours (At Least 5 x 10E-5 Torr) and 125 °C
- Condensed Portion of Vapors on Preweighed Collector Maintained at 25 °C
- Posttest Collector and Sample Weight Measurements Yielded Weight Loss and Collected Volatile Condensable Material
- Further Conditioning of Sample for 24 Hours at 23 °C and 50% RH and Weighing Yielded Water Vapor Recovery Values

# VCM Test, Cont'd

Results:

| Material | Weight Loss (%) | VCM (%) | WVR (%) |
|---|---|---|---|
| Partially Fluorinated Polyimide | 3.44 | 0.00 | 0.40 |
| Extruded ETFE | 0.31 | 0.01 | 0.04 |
| Extruded PTFE | 0.01 | 0.00 | 0.01 |
| PTFE Tape | 0.29 | 0.00 | 0.18 |
| PTFE/Kapton | 0.35 | 0.00 | 0.26 |

Note: All materials passed the VCM requirement. Only the partially fluorinated polyimide failed the weight loss requirement.

N96- 17087

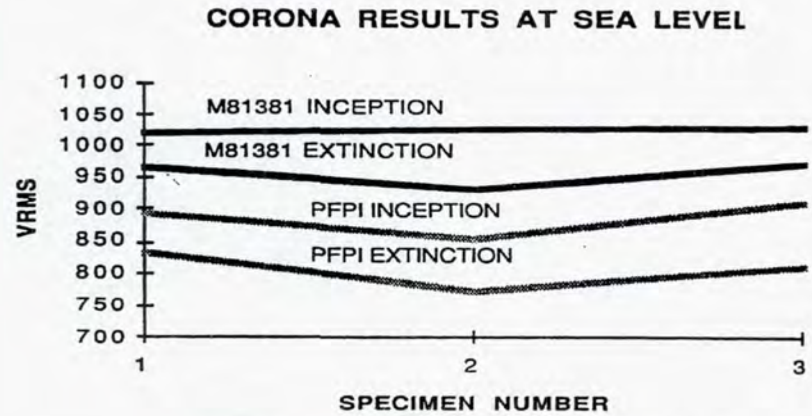
# NASA WIRING FOR SPACE APPLICATIONS PROGRAM TEST RESULTS

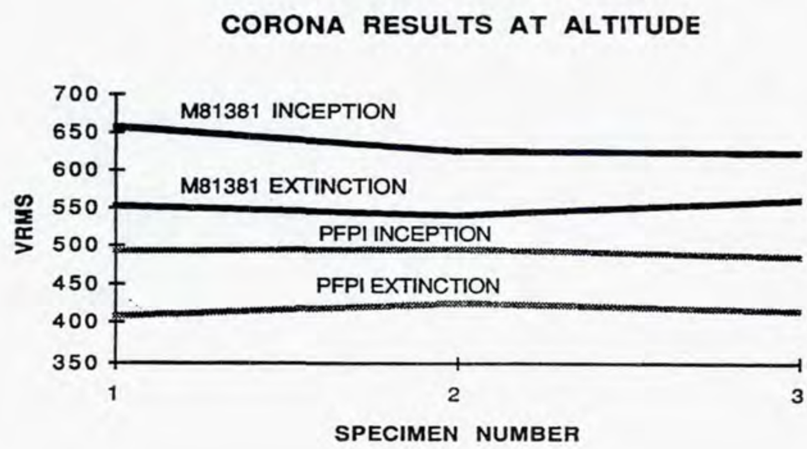
Jim Ide
McDonnell Douglas Aerospace–East
St. Louis, Missouri

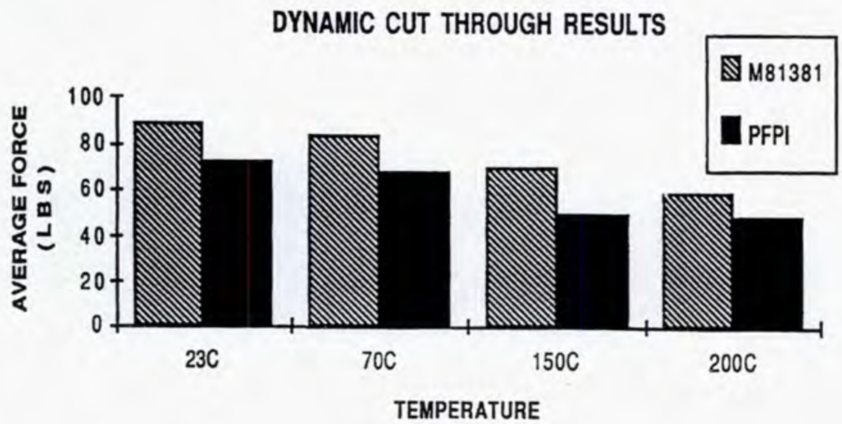
S10-33
6331
P_5

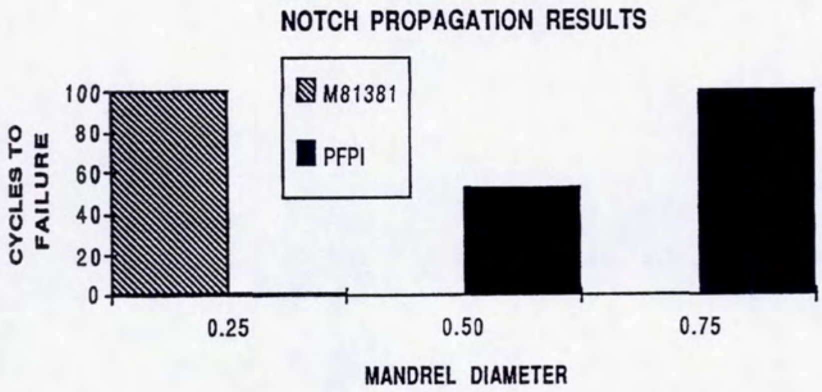
## FY '94 - '95 Testing Activities McDonnell Aerospace/TRW

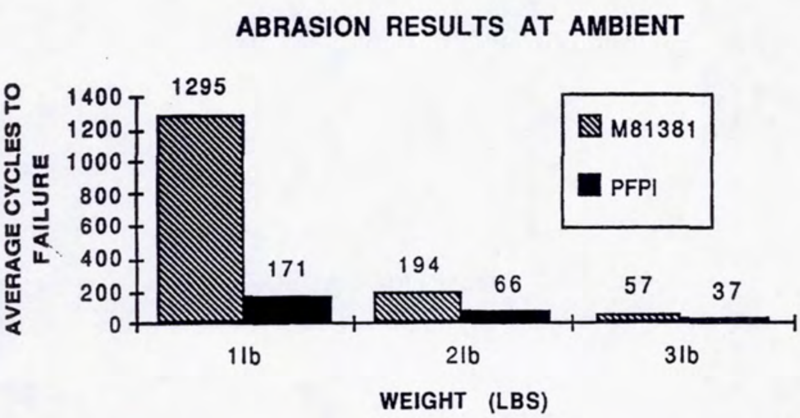
- ***Objective:*** To begin examination of mechanical and electrical properties of PFPI insulation.
- ***Tests:*** AC Corona: 400 Hz, sea level & 60,000 ft.
  Time/Current to Smoke
  Wire Fusing Time
  Abrasion Resistance: 25°C & 150°C
  Dynamic Cut Through
  Notch Propagation
  Weight Loss (Outgassing)
- ***Principal Investigator:*** Jim Ide
  McDonnell Douglas Aerospace - East
- ***Note:*** Immature manufacturing status of the PFPI material for wiring use resulted in degraded samples and must be considered when observing test results.

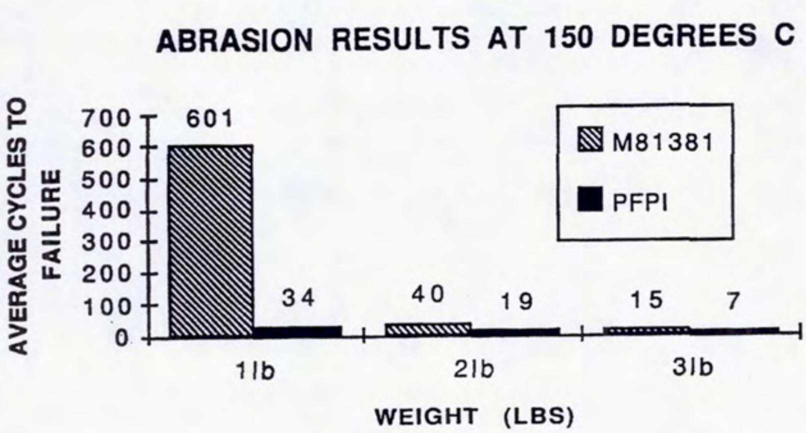

CORONA RESULTS AT SEA LEVEL
1100
1050
1000
950
900
850
800
750
700
VRMS
M81381 INCEPTION
M81381 EXTINCTION
PFPI INCEPTION
PFPI EXTINCTION
1
2
3
SPECIMEN NUMBER

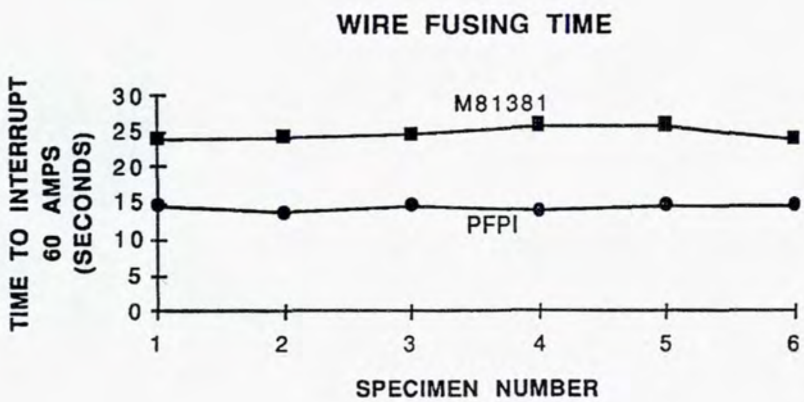

CORONA RESULTS AT ALTITUDE
700
650
600
550
500
450
400
350
VRMS
M81381 INCEPTION
M81381 EXTINCTION
PFPI INCEPTION
PFPI EXTINCTION
1
2
3
SPECIMEN NUMBER

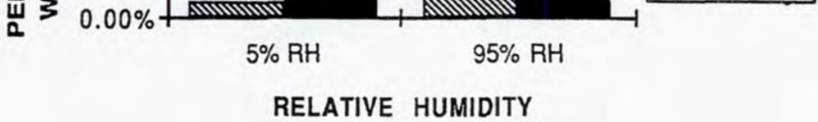

DYNAMIC CUT THROUGH RESULTS
M81381
PFPI
100
80
60
40
20
0
AVERAGE FORCE (LBS)
23C
70C
150C
200C
TEMPERATURE

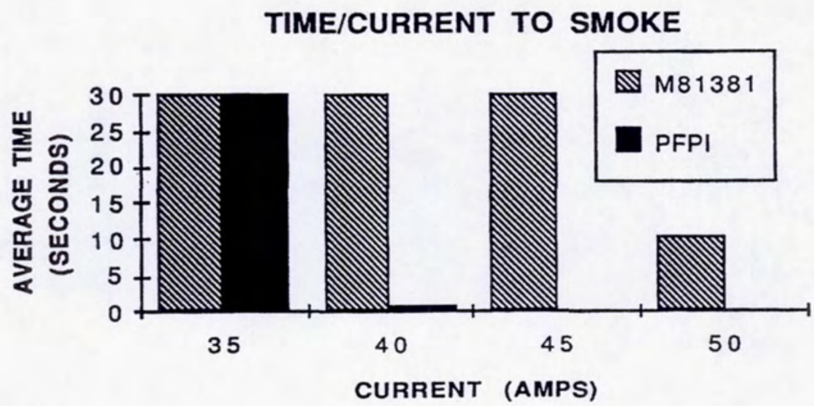

NOTCH PROPAGATION RESULTS
M81381
PFPI
CYCLES TO FAILURE
100
80
60
40
20
0
0.25
0.50
0.75
MANDREL DIAMETER


ABRASION RESULTS AT AMBIENT
M81381
PFPI
AVERAGE CYCLES TO FAILURE
1400
1200
1000
800
600
400
200
0
1295
171
194
66
57
37
1lb
2lb
3lb
WEIGHT (LBS)


ABRASION RESULTS AT 150 DEGREES C
M81381
PFPI
AVERAGE CYCLES TO FAILURE
700
600
500
400
300
200
100
0
601
34
40
19
15
7
1lb
2lb
3lb
WEIGHT (LBS)


WIRE FUSING TIME
TIME TO INTERRUPT 60 AMPS (SECONDS)
30
25
20
15
10
5
0
M81381
PFPI
1
2
3
4
5
6
SPECIMEN NUMBER


WEIGHT LOSS/OUTGASSING
PERCENTAGE OF WEIGHT LOSS
1.50%
1.00%
0.50%
0.00%
5% RH
95% RH
RELATIVE HUMIDITY
M81381
PFPI




## Conclusions

- PFPI & MIL-W-81381/7 similar for AC Corona and Dynamic Cut Through
- All other tests, PFPI did not perform well
- PFPI manufacturing process needs to be upgraded

# NASA WIRING FOR SPACE APPLICATIONS PROGRAM TEST RESULTS

Javaid Laghari and Jayant Suthar
State University of New York at Buffalo
Buffalo, New York

omit

## FY '94 - '95 Testing Activities
## University of Buffalo

- ***Objective:*** Investigate the electrical breakdown properties of the candidate wire insulation constructions.

- ***Tests:*** Dielectric Strength: 23°C, 200°C
  Time To Breakdown: 400 Hz, 200°C
  ASTM D-149

- ***Principal Investigators:*** Javaid Laghari and Jayant Suthar
  State University of New York at Buffalo

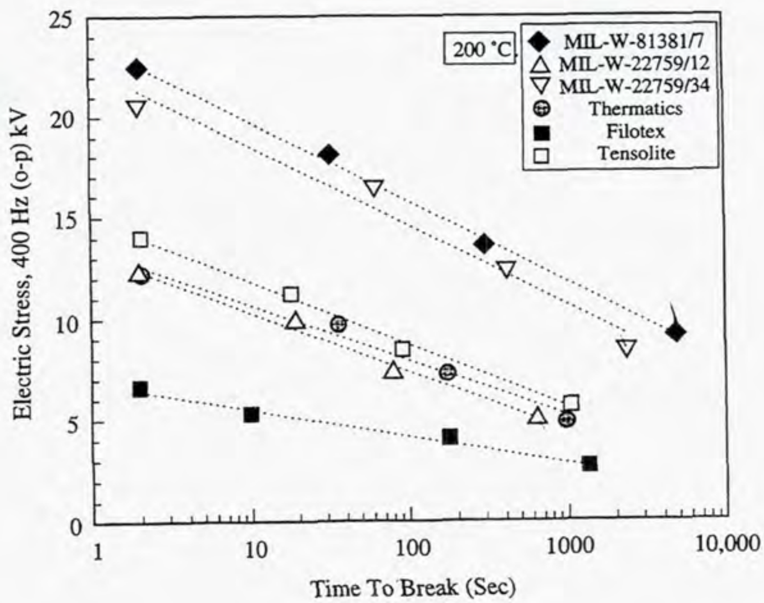
## NASA Wiring for Space Applications Program

### Dielectric Strength of Wiring Insulations

| Insulation System | 23°C $kV_{(o\text{-}p)}$ | 200°C $kV_{(o\text{-}p)}$ |
|---|---|---|
| MIL-W-81381/7 | 25.7 | 22.5 |
| MIL-W-22759/12 | 14.2 | 12.3 |
| MIL-W-22759/34 | 28.9 | 20.7 |
| Thermatics | 14.3 | 12.2 |
| Filotex | 10.2 | 6.7 |
| Tensolite | 14.2 | 14.0 |

# NASA Wiring for Space Applications Program

## Time-To-Breakdown Characteristics of Wiring Constructions at 200°C and Various Electrical Stresses




# NASA Wiring for Space Applications Program

## Final Conclusions

- In process of completing final in-house testing.
- Final results will be printed in program final report which is to be completed.

N96- 17088

# COMPARISON OF ARC TRACKING TESTS IN VARIOUS AEROSPACE ENVIRONMENTS

Thomas J. Stueber
NYMA, Inc.
NASA Lewis Research Center
Cleveland, Ohio

and

David McCall
Cleveland State University
Cleveland, Ohio

511-20
6332
P-7

I. LeRC Arc Tracking Test Parameters:

   A. Probability of Initiation
   B. Probability of Reinitiation*
   C. Extent of Arc Tracking Damage

II. Aparatus

   A. ACE Belljar (Vacuum and atmospheric pressure, 1g)
   B. Spacecraft Fire Safety Facility $(SF)^2$ (atmospheric, micro-gravity)

III. Sample Description

IV. Procedure

V. Arc Tracking Test Results:

   A. Barcell Wire & Cable Corp. M081381/7-20 28427

      1. Atmospheric Pressure, 1g
      2. Vacuum ($10^{-5}$ Torr), 1g
      3. Atmospheric Pressure μg

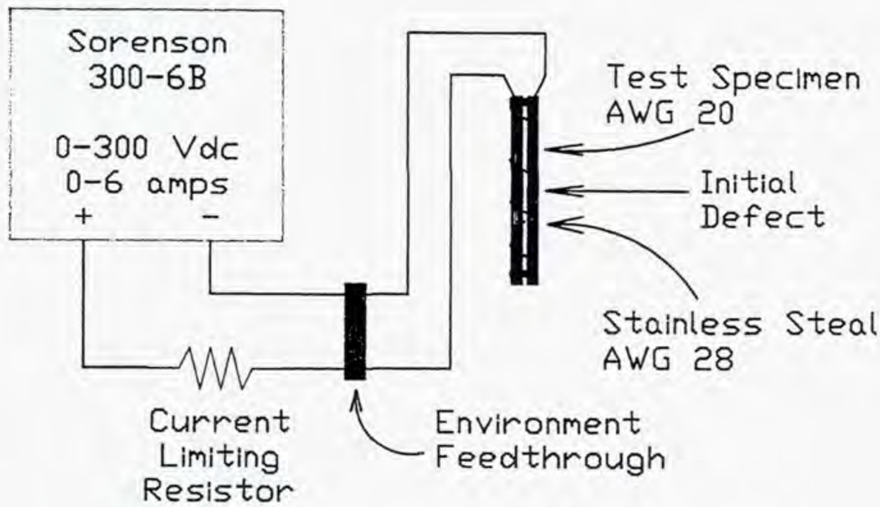
   B. Filotex Filartex* T8C1G20

      1. Atmospheric Pressure, 1g
      2. Vacuum ($10^{-5}$ Torr), 1g
      3. Atmospheric Pressure μg

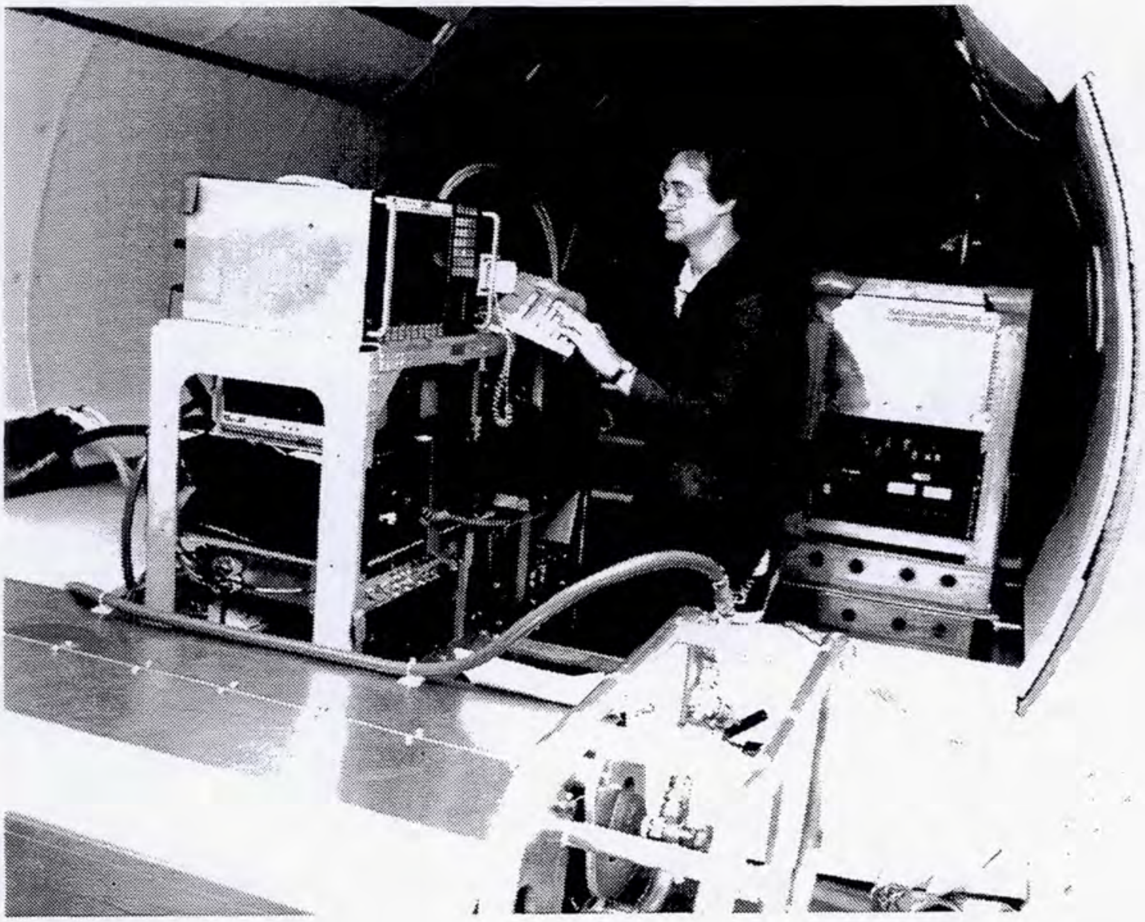
   C. Tensolite TLT-200-20S

      1. Atmospheric Pressure, 1g
      2. Vacuum ($10^{-5}$ Torr), 1g **
      3. Atmospheric Pressure μg

VI. Discussion

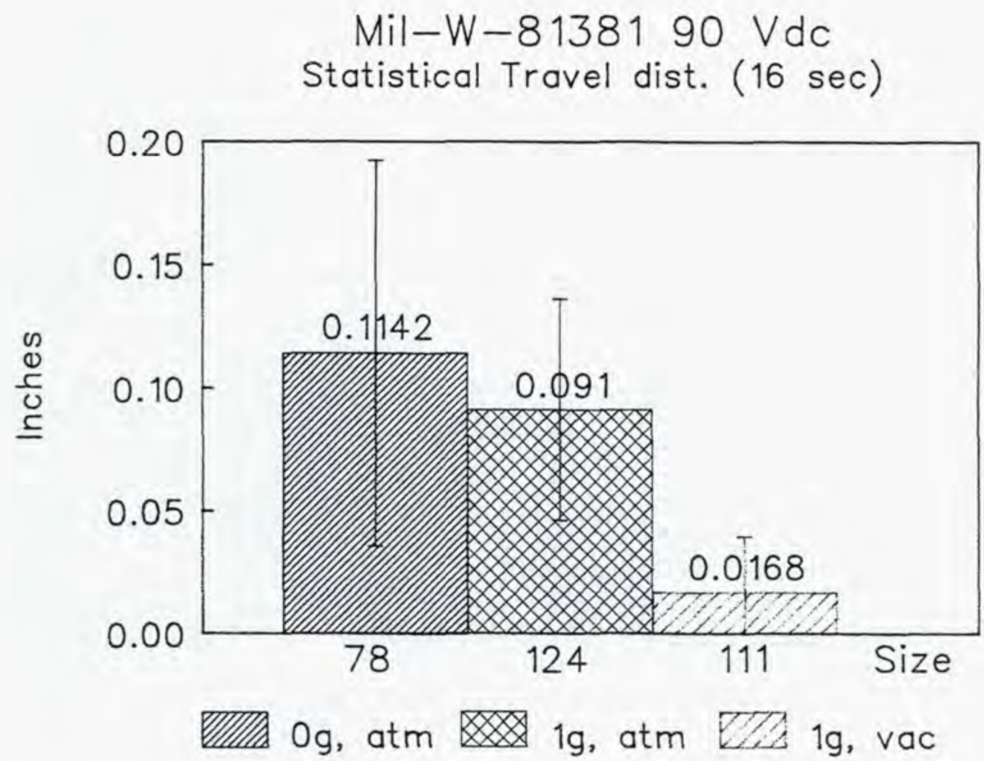

Sorenson
300-6B
0-300 Vdc
0-6 amps
+
-
Test Specimen
AWG 20
Initial
Defect
Stainless Steal
AWG 28
Current
Limiting
Resistor
Environment
Feedthrough

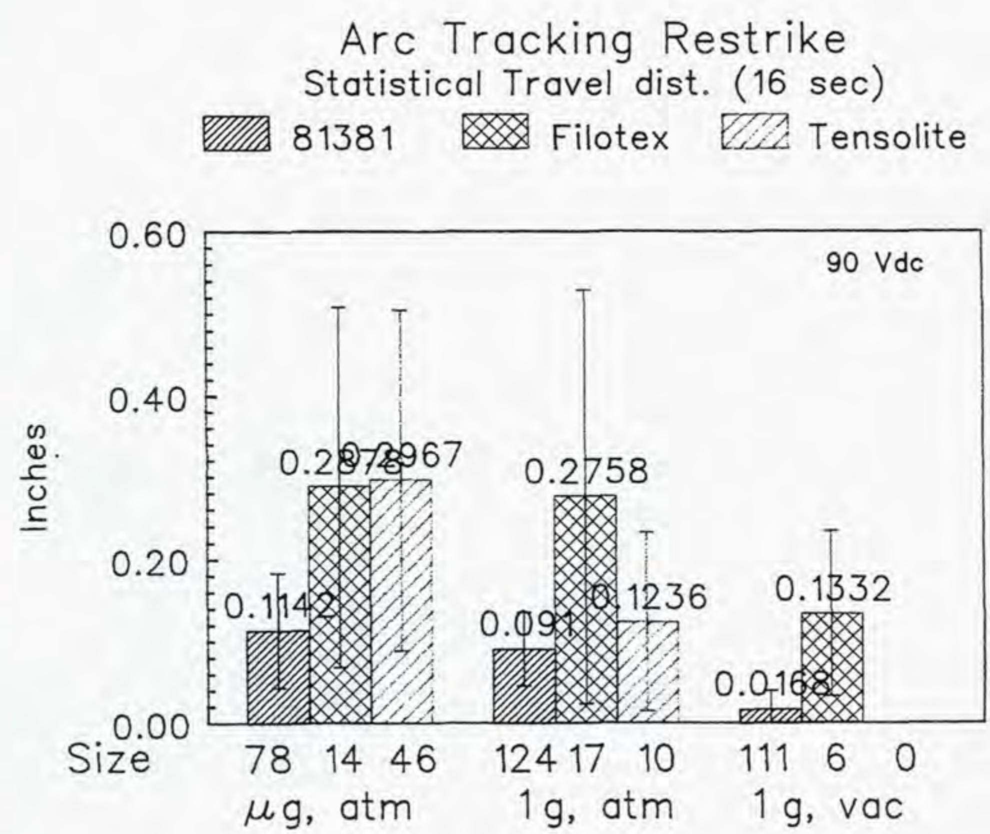

CAUTION
HIGH
VOLTAGE

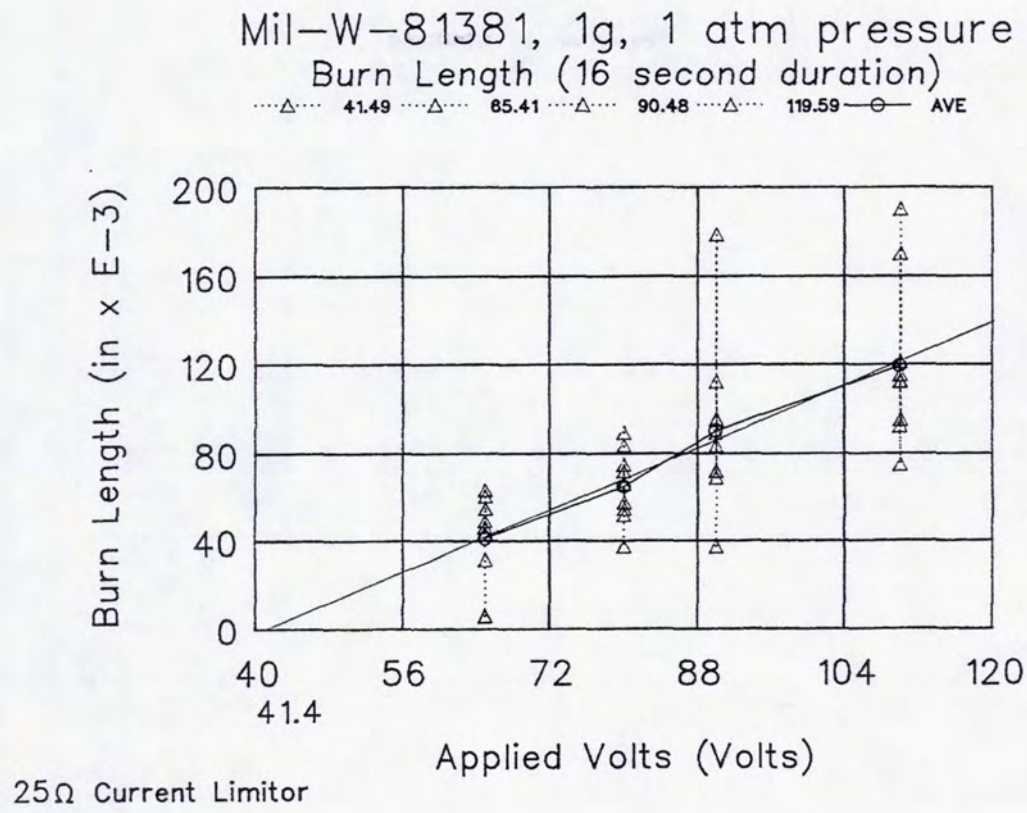


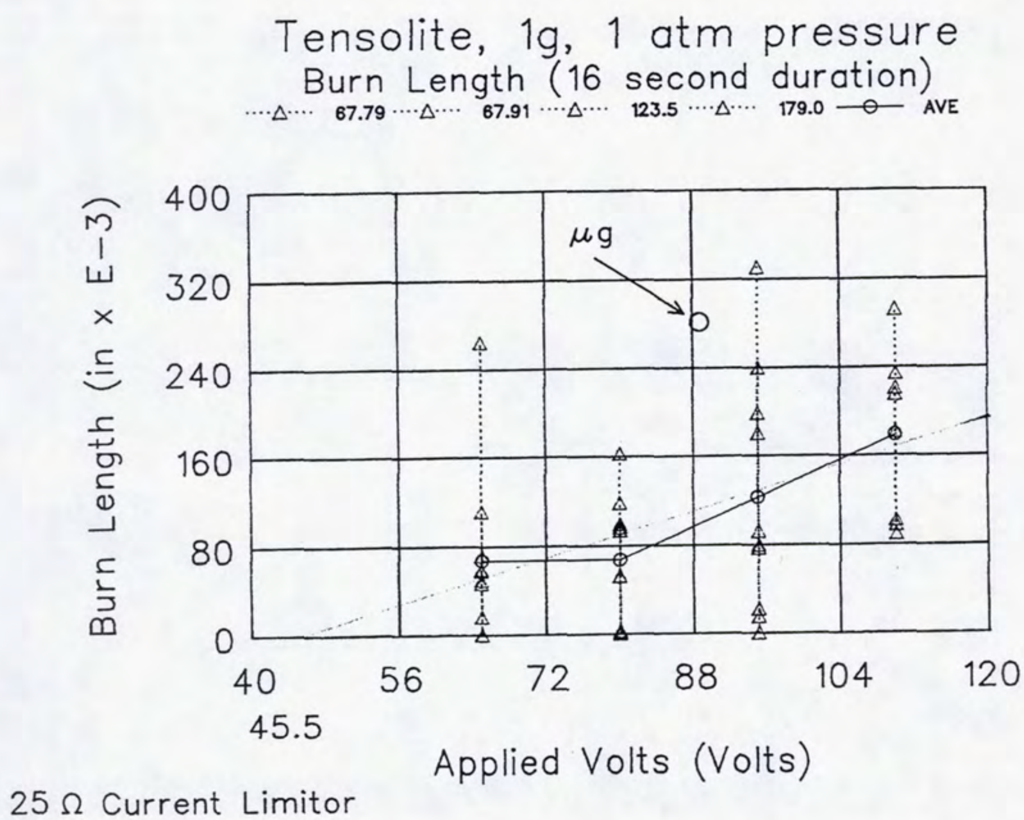
| | Mil-W-81381 | | | Filotex Filartex T8C1G20 | | | Tensolite TLT-200-20S | | |
|---|---|---|---|---|---|---|---|---|---|
| | μg, 1atm | 1g, 1atm | 1g, vac | μg, 1atm | 1g, 1atm | 1g, vac | μg, 1atm | 1g, 1atm | 1g, vac |
| Number Of Tests | 78 | 124 | 111 | 6 | 17 | 6 | 46 | 10 | 0 |
| Mean | 0.11424 | 0.09098 | 0.01678 | 0.35333 | 0.27583 | 0.13317 | 0.29674 | 0.12355 | ---- |
| Std Dev σ | 0.07834 | 0.04495 | 0.02302 | 0.25800 | 0.25312 | 0.10101 | 0.20804 | 0.10931 | ---- |
| Std Err | 0.00887 | 0.00404 | 0.00219 | 0.10533 | 0.06139 | 0.04124 | 0.03067 | 0.03457 | ---- |
| 95% Conf. | 0.01739 | 0.00791 | 0.00428 | 0.20644 | 0.12032 | 0.08083 | 0.06012 | 0.06775 | ---- |
| 99% Conf | 0.02289 | 0.01042 | 0.00564 | 0.27175 | 0.15839 | 0.10639 | 0.07914 | 0.08918 | ---- |

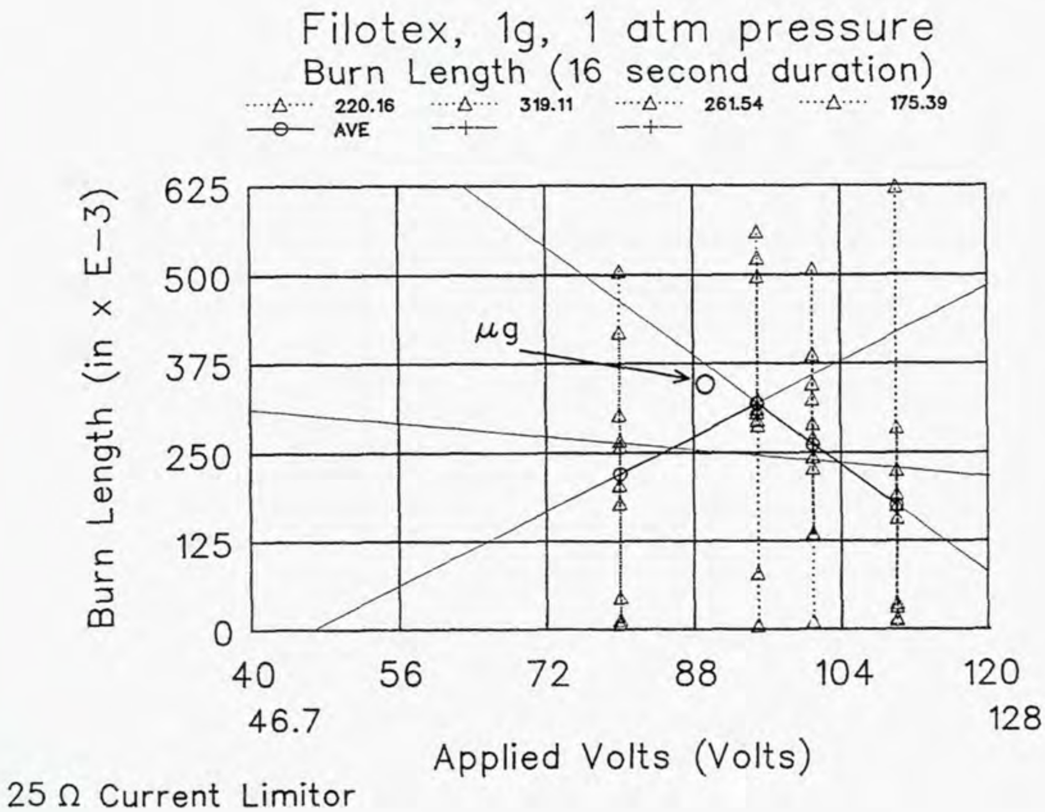
Table IV. Value units are inches. Duration of each test was 16 seconds.

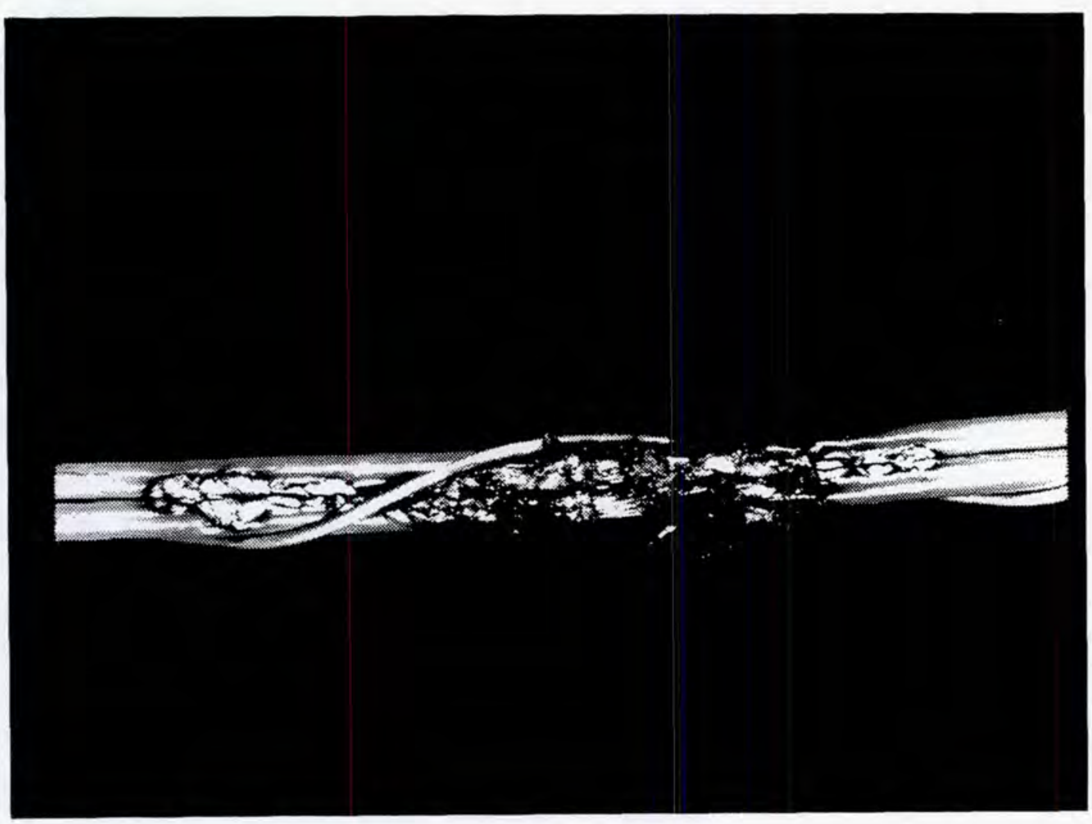

Mil-W-81381 90 Vdc
Statistical Travel dist. (16 sec)
0.20
0.15
0.10
0.05
0.00
Inches
0.1142
0.091
0.0168
78
124
111
Size
0g, atm
1g, atm
1g, vac

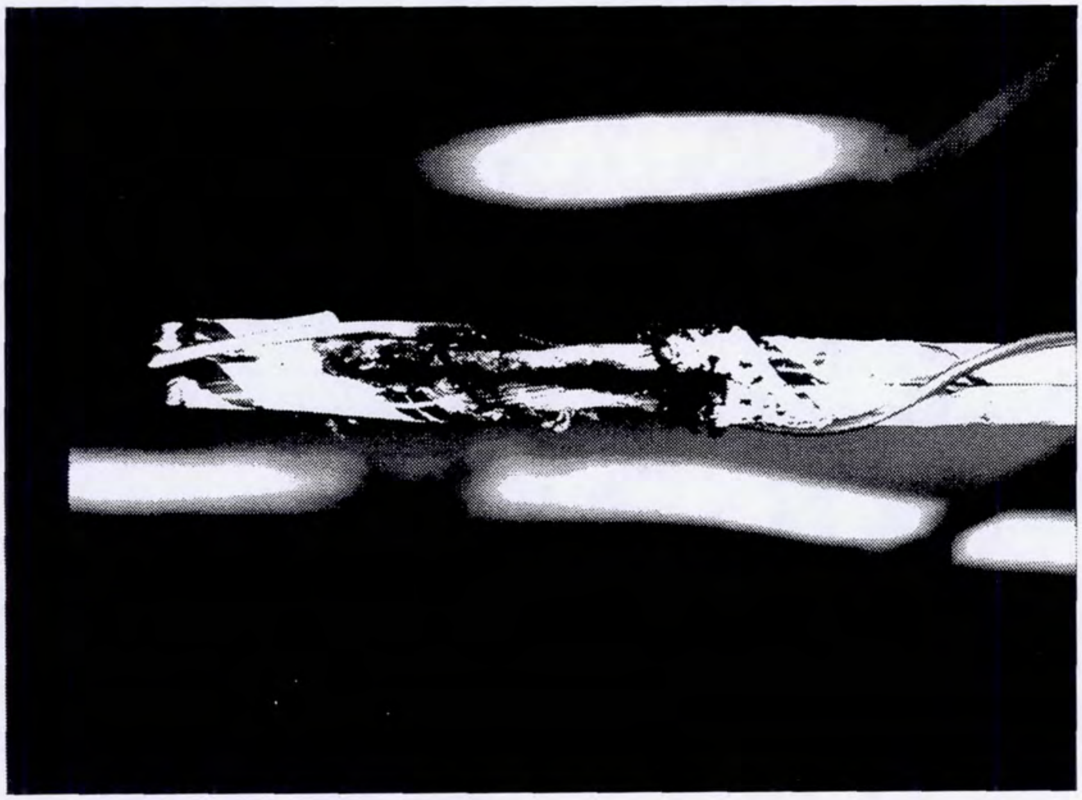

Arc Tracking Restrike
Statistical Travel dist. (16 sec)
81381
Filotex
Tensolite
90 Vdc
0.60
0.40
0.20
0.00
Inches
0.1142
0.2878
0.2967
0.091
0.2758
0.1236
0.0168
0.1332
Size
78 14 46
124 17 10
111 6 0
μg, atm
1 g, atm
1 g, vac

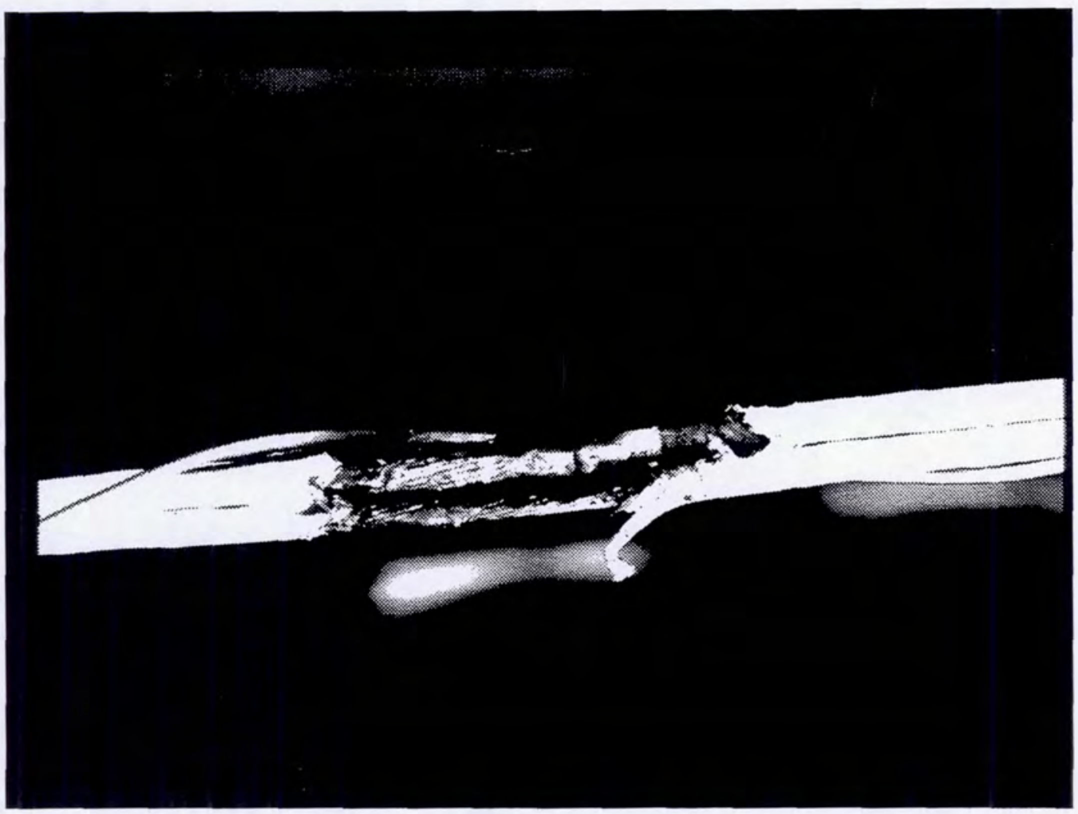

Mil–W–81381, 1g, 1 atm pressure
Burn Length (16 second duration)
41.49
65.41
90.48
119.59
AVE
Burn Length (in x E–3)
200
160
120
80
40
0
40
56
72
88
104
120
41.4
Applied Volts (Volts)
25Ω Current Limitor


Tensolite, 1g, 1 atm pressure
Burn Length (16 second duration)
67.79
67.91
123.5
179.0
AVE
μg
Burn Length (in x E–3)
400
320
240
160
80
0
40
56
72
88
104
120
45.5
Applied Volts (Volts)
25 Ω Current Limitor


Filotex, 1g, 1 atm pressure
Burn Length (16 second duration)
220.16
319.11
261.54
175.39
AVE
Burn Length (in x E−3)
625
500
375
250
125
0
μg
40
56
72
88
104
120
46.7
128
Applied Volts (Volts)
25 Ω Current Limitor







ARC TRACKING OF CABLES FOR SPACE APPLICATIONS



Test Results of Selected Cables

D. König, F.R. Frontzek, and J. Hanson
Technical University of Darmstadt
High Voltage Laboratory
Darmstadt, Germany

H.J. Reher
DASA
Bremen, Germany

and

M.D. Judd and D. Bryant
ESA/ESTEC
Noordwijk, The Netherlands



**Contents:**

## Introduction

### B a c k g r o u n d :

- Space Missions with Wiring System Failures
- Failure Modes:
  - ⇒ Pyrolysis
  - ⇒ Arc Tracking
  - ⇒ Fault Arc Propagation

### Comparison of existing methods and standards covering different aspects of arcing and arc tracking

⇒ No appropriate arc tracking test for space application available

### A i m :

Development of a new test method suitable for the assessment of the resistance of aerospace cables to arc tracking fore different specific environmental and network conditions of spacecrafts

## Test Concept

### TEST CONDITIONS

**Test Environments:**

⇒Normal Air at atmospheric pressure

⇒Dry gas mixture of 30 Vol.% $O_2$ and 70 Vol.% $N_2$ at a pressure of 700hPa (emergency conditions)

⇒Dry gas mixture of 24,5 Vol.% $O_2$ and 75,5 Vol.% $N_2$ at atmospheric pressure

⇒Vacuum ($p \leq 10^{-2}$Pa)

**Test Voltage:**

⇒according to that, expected to be applied in the Board Network

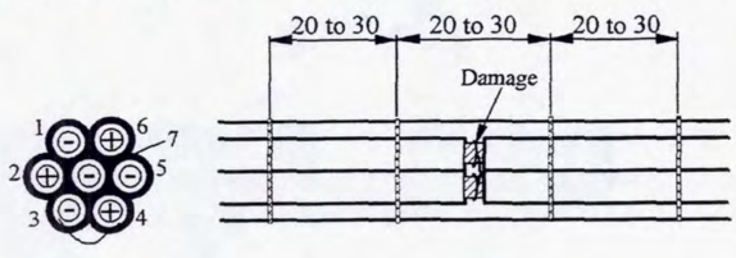
⇒quasi-constant in the range of 125V...132V, DC

**Test Current:**

⇒Adjustable, depend on rated current

### TEST SPECIMEN

- A bundle of seven 200 to 250mm long cables
- The predamage is induced at two cables and placed in the middle of the cable length and at the bottom of the horizontal positioned cable bundle
- Exploding wire igniter is connected to the two predamaged cables



## Test Concept

### TEST PROCEDURE

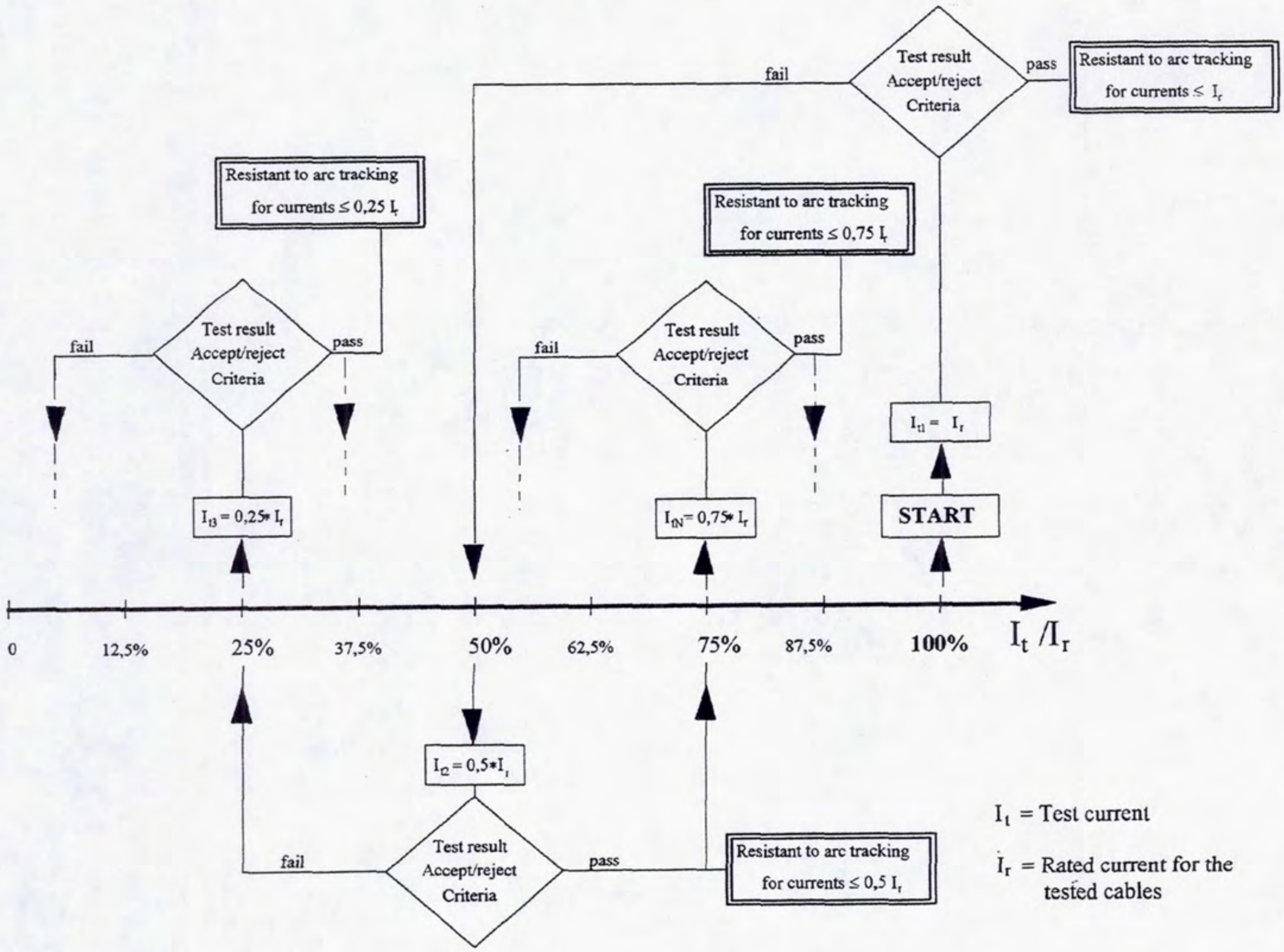
- Assembly of Test Specimen and Installation in the Test Chamber
- Generation of Test Atmosphere (Vacuum, Oxygen Enriched Atmosphere, Normal Air, etc.)
- Adjustment of Test Current
- Activation of Test Recording Devices (Video, Transient Recorder, etc.)
- Arc Initiation:
  - Start up in Switching Cycle: $t_s$- $t_p$- $t_s$
  - As a first approach: $t_s$= 10s, $t_s$= 3min
- Performance of Post Test Measurements

### TEST ACCEPTANCE CRITERIA

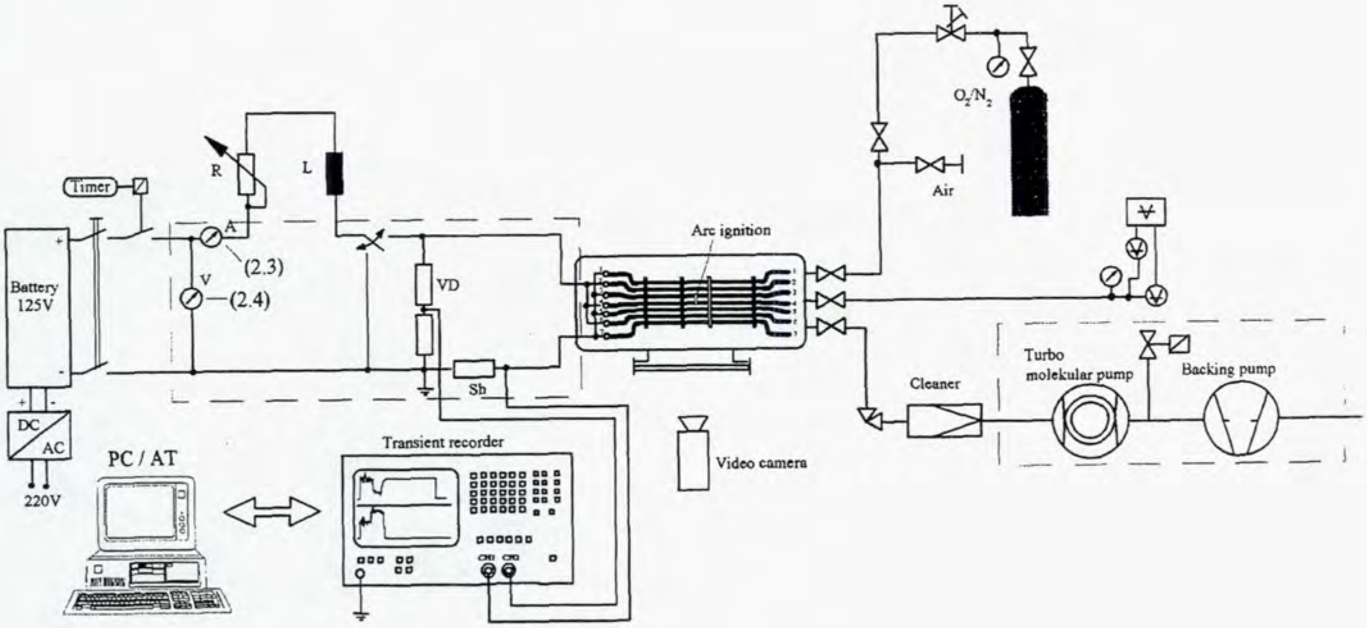
1. For a defined test voltage, test current and for a defined environment, all conductors of all five test specimens tested have to pass the continuity test
2. All cables of all five test specimens, tested without the predamaged cables, have to fulfill the requirement of insulation resistance test, i.e. the insulation resistance between the cable under test (all other cables of the test specimen are short-circuit) must be higher than 0,5MΩ
3. During the reapplication of the power for 10 seconds, following the three minutes pause, no visible arc or glow activity is acceptable
4. If only one of all tested specimens fail, additional three specimens have to be tested. If during these additional test series the accept criteria 1, 2 and 3 are fulfilled, the cable has passed the test successfully.

If these requirements have been met for the specified environmental conditions, then the cable tested shall be classified in different classes with respect to its **arc tracking resistance** for a given test voltage and currents below or equal to the rated current in consideration to the environmental condition.

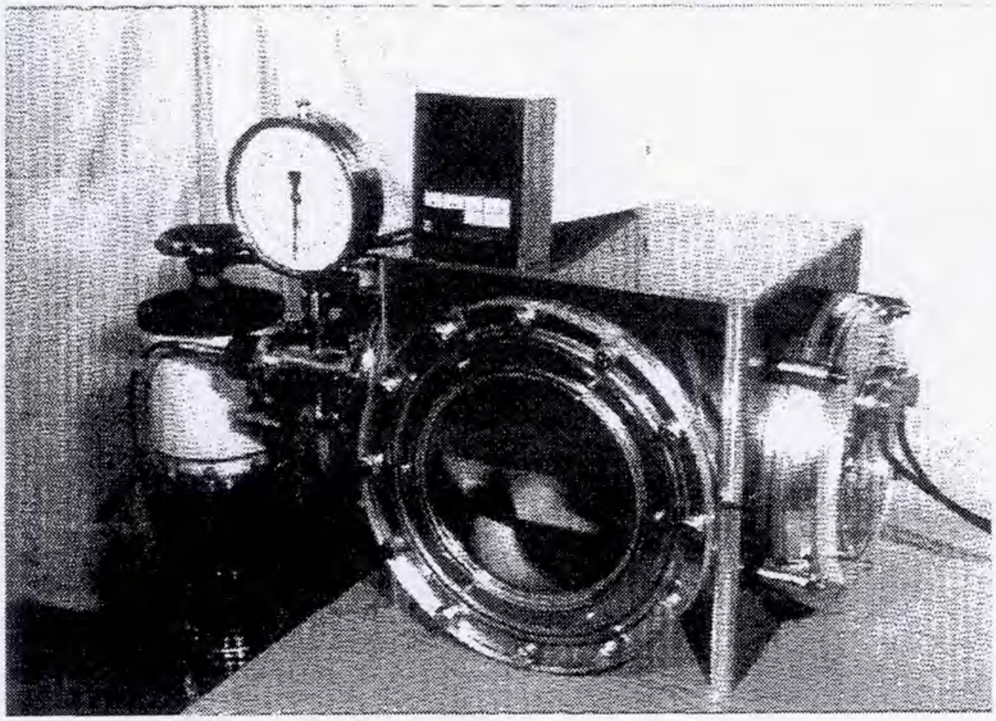
## Test Concept

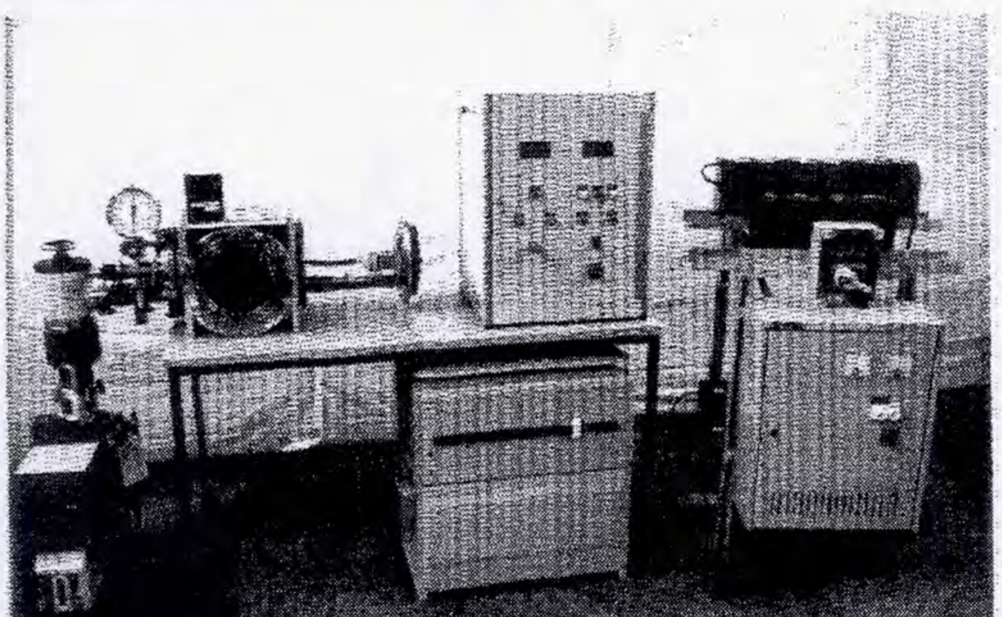


# Test Equipment

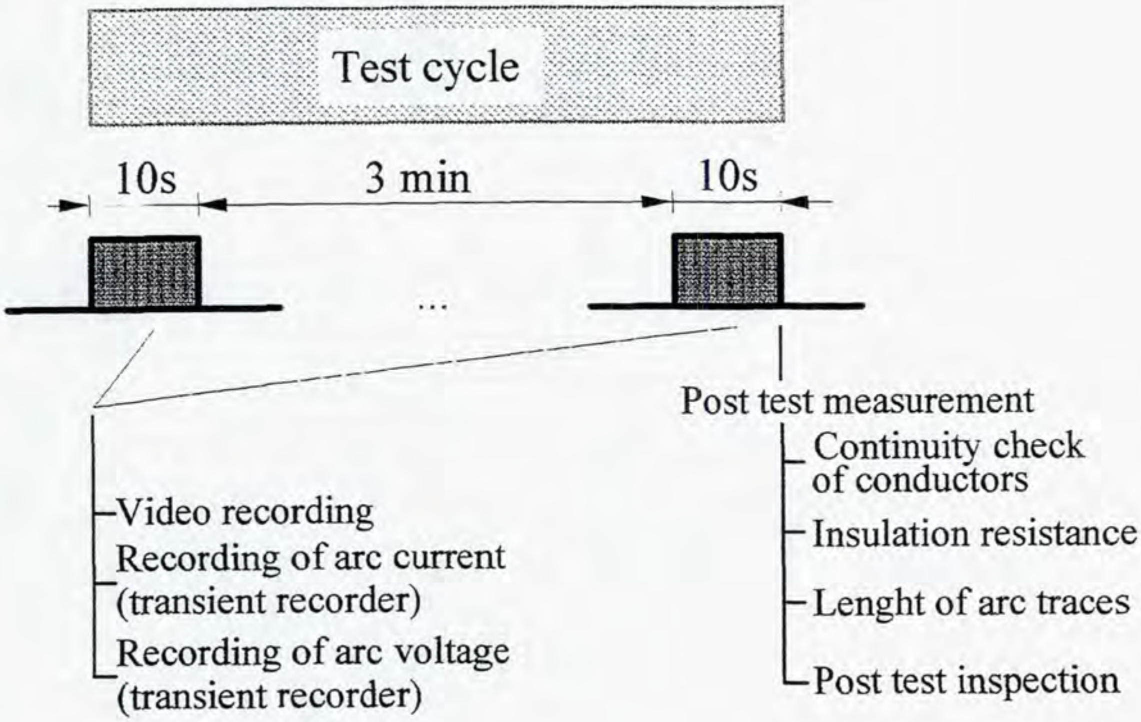


# Test Equipment developed and supplied to ESA and DASA





**Switching Cycle, Measurements and Evaluation Criteria**



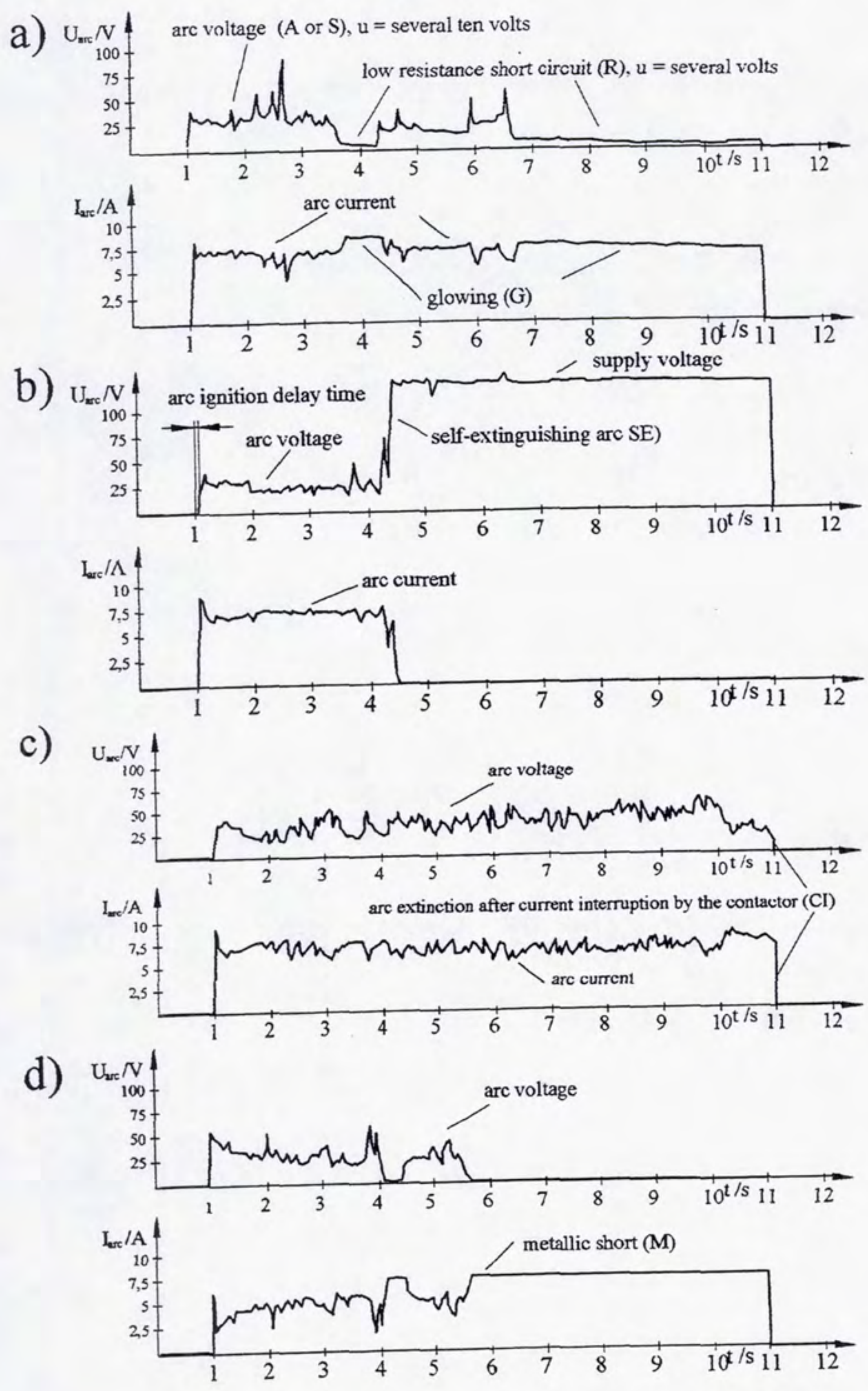

## Purpose of the test:

* Determination of the ability of wire insulation materials and cable constructions to resist arc tracking
* Measurement of the Arc Tracking Current Limit

## Advantages of the test method:

* Achievement of a distinction between, or a classification of different types of cables with respect to Arc Tracking from material point of view
* The determined "Arc Tracking Current Limit" is an important parameter needed for the design of the electrical supply system and relevant electrical protection measures

## Typical Transients of test current $I_{arc}$ and arc voltage $U_{arc}$



## Evaluation of the current and voltage transients

**a. Arc extinction caused by low resistance short circuit of conductors (R)**

(conductive material generated from molten insulating material and conductors bridging the conductors)

- propagation of glowing insulation down the wire bundle (continued pyrolization)
- arc reignition risks
- damages of adjacent cables, loss of the wire bundle

**b. Self-extinguishing arc without reignitions (SE)**

- very often no loss in wire bundle performance

**c. Arc extinction caused by clearing of the control circuit breaker (CI)**

(Under practical conditions a stable arc with a duration, exceeding the test duration time of 10s, has to be expected)

- propagation of a fault arc down the wire bundle
- damages of adjacent cables, loss of the wire bundle

**d. Arc extinction caused by metallic short circuit of conductors (M)**

- lost use of a wire pair within the bundle

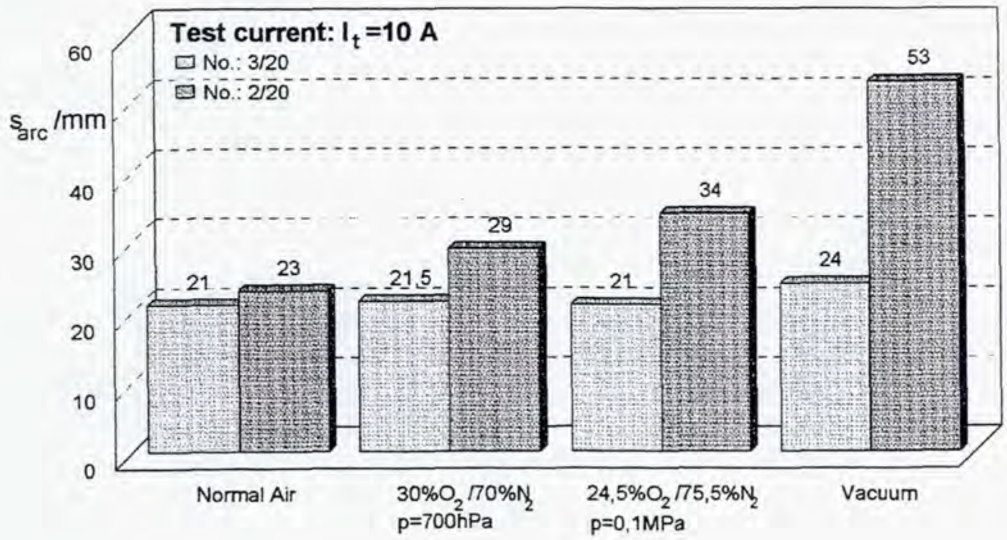
## Table of cable types tested

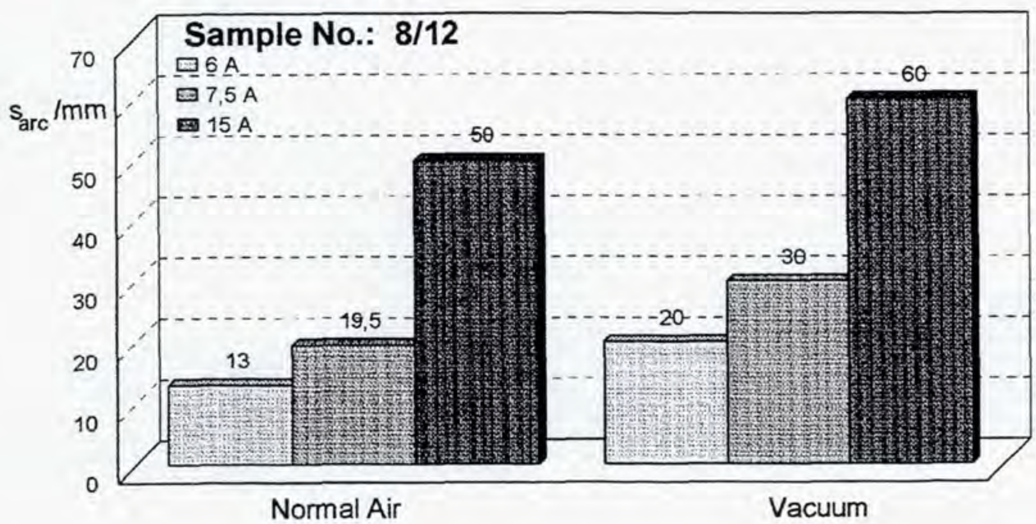
| Sample No. | ESA SCC-SPEC | Wire Size [AWG] | Insulation Layers | | |
|---|---|---|---|---|---|
| 1/20 | 3901 001 | 20 | PI | PI | PI |
| 1/12 | | 12 | PI | PI | PI |
| 1A/20 | 3901 002 | 20 | PI | PI | |
| 2/20 | 3901 007 | 20 | PI | PI | PTFE |
| 3/20 | 3901 009 | 20 | PTFE | PI | PI |
| 4/20 | 3901 012 | 20 | ETFE | | |
| 5/20 | - | 20 | Hybrid | | |
| 6/20 | - | 20 | PTFE | PI | PTFE |
| 7/20 | 3901 013 | 20 | PTFE | PI | |
| 8/12 | 3901 008 | 12 | PI | PI | PTFE |

AWG: American Wiring Gauge

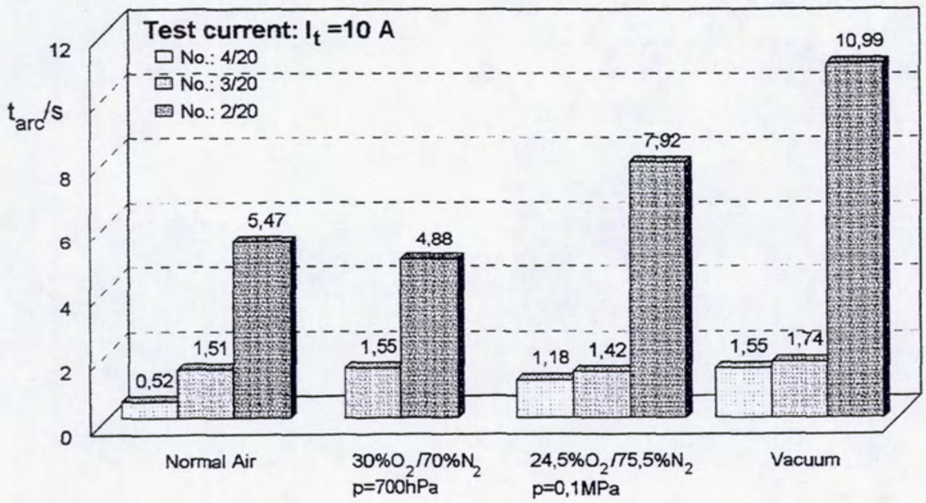
ETFE: Ethylene-Tetrafluoro-Ethylene
PTFE: Polytetrafluorethylene
PI: Polyimide
Conductor material: Copper/Silver

# Average values of arc path length $s_{arc}$

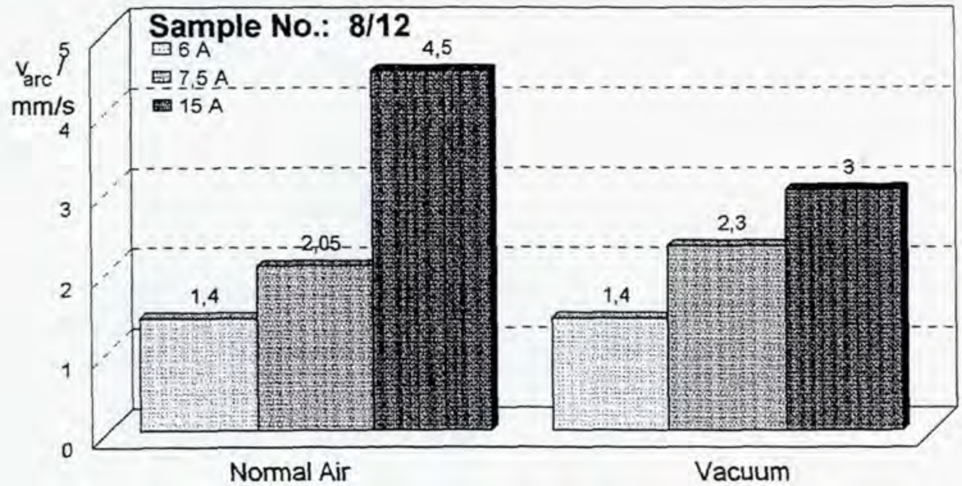


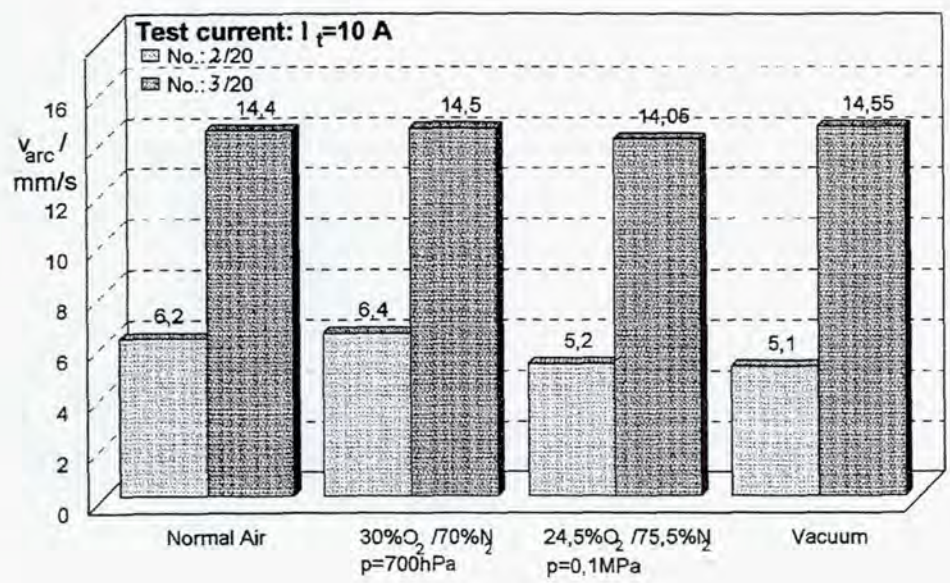



# Average values of arc duration $t_{arc}$

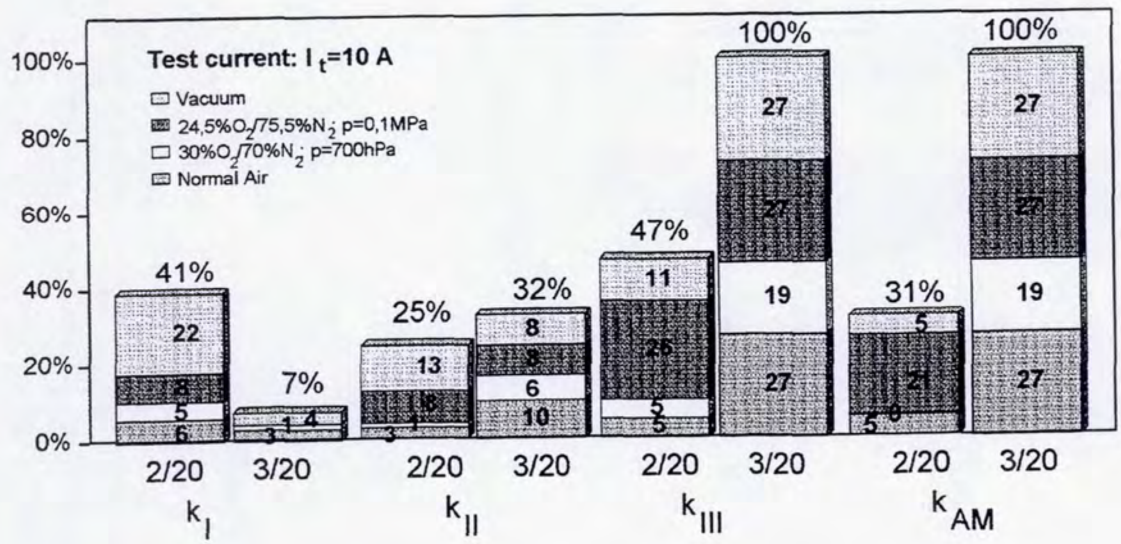


**Average values of arc propagation velocity $v_{arc}$**



# Values of coefficients $k_I$, $k_{II}$, $k_{III}$ and $k_{AM}$ for cables No. 2/20 and 3/20




$$k_I = \frac{\text{Number of cables with damaged conductors}}{\text{Number of cables tested}} \qquad k_{II} = \frac{\text{Number of cables with damaged insulation}}{\text{Number of cables tested}};$$

predamaged cables are not considered

$$k_{III} = \frac{\text{Number of tests, at which during time interval } T_2 \text{ glowing and / or arcing was observed}}{\text{Number of tests performed for a given test current}}$$

$$k_{AM} = \frac{\text{Number of tests, at which during time interval } T_2 \text{ the arc modes R / CI were observed}}{\text{Number of tests performed for a given test current}}$$

## Post-test measurement results:
## Continuity check of conductors

| Conductors without Continuity (Wire No.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No/wire AWG | Insulation Layers* | Test Current $I_{test}/A$ | Normal Atmosphere | | 24,5Vol.% $O_2$ 75,5Vol.% $N_2$ | | Vacuum | |
| | | | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 |
| 1/20 | PI,PI,PI | 10 | 4 | 3,4,6 | 2,3,4,7 | - | 2,3 | 4 |
| 1A/20 | PI,PI | 10 | 7 | - | - | 3 | 3 | 3 |
| 2/20 | PI,PI,PTFE | 10 | - | 3,4 | 3 | 3,4 | 3 | 3 |
| 3/20 | PTFE,PI,PI | 10 | - | 3,4 | - | - | 4 | 3 |
| 4/20 | ETFE | 10 | - | - | - | - | 3 | 3 |
| 5/20 | Hybrid | 10 | 2,3,4,7 | 3,4 | - | 3 | 2,3,4 | 3 |
| 6/20 | PTFE,PI,PTFE | 10 | 3,4 | 3 | 3,4 | 3,4,7 | 3,4,6 | 3 |
| 7/20 | PTFE,PI | 10 | 3 | 3,4 | 4 | 3,4 | 3 | 3 |
| 1/12 | PI,PI,PI | 30 | 4 | - | 3 | - ** | - | - |
| 4/20 | ETFE | 30 | 3,4 | 3,4 | NT | 3,4 | NT | NT |

* Material given from the conductor position

NT: not tested

** Test current: $I_t$= 10A

## Post-test measurement results:
## Insulation resistance check

| Insulation Resistance < 0,5 MΩ (Wire No.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No/wire AWG | Insulation Layers* | Test Current $I_{test}/A$ | Normal Atmosphere | | 24,5Vol.% $O_2$ 75,5Vol.% $N_2$ | | Vacuum | |
| | | | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 |
| 20/1 | PI,PI,PI | 10 | 1,2,7 | 2 | 2,5,6,7 | 5,7 | 2,7 | |
| 20/1A | PI,PI | 10 | 5 | 5,6,7 | 5,6,7 | 2,7 | 1,2,7 | |
| 20/2 | PI,PI,PTFE | 10 | - | - | - | - | 7 | |
| 20/3 | PTFE,PI,PI | 10 | 1,2,7 | 2,5,7 | 5,6,7 | 2,7 | 2,7 | |
| 20/4 | ETFE | 10 | - | - | 5 | - | - | |
| 20/5 | Hybrid | 10 | 1,2,7 | - | - | - | 1,2,5, 6,7 | 1,2,5, 6,7 |
| 20/6 | PTFE,PI, PTFE | 10 | 2,5,7 | - | - | 1,2,5, 7 | 1,2,5, 6,7 | 1,2,5, 6,7 |
| 20/7 | PTFE,PI | 10 | - | - | - | - | 1,2,5, 6,7 | 2,5,6, 7 |
| 12/1 | PI,PI,PI | 30 | 2,7 | 7 | 7 | NT | 1,2,5, 6,7 | 1,2,5, 6,7 |
| 20/4 | ETFE | 30 | - | - | NT | - | NT | NT |

NT: not tested

## Activities during the reapplication of the power

| Visible Arc and/or glow activity during the reapplication of the power (Wire No.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No/wire AWG | Insulation Layers* | Test Current $I_{test}/A$ | Normal Atmosphere | | 24,5Vol.% $O_2$ 75,5Vol.% $N_2$ | | Vacuum | |
| | | | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 |
| 20/1 | PI,PI,PI | 10 | S | NA | G | G | G | G |
| 20/1A | PI,PI | 10 | NA | NA | G | G | G | G |
| 20/2 | PI,PI,PTFE | 10 | NA | NA | NA | G | NA | NA |
| 20/3 | PTFE,PI,PI | 10 | G | G | G | G | G | G |
| 20/4 | ETFE | 10 | NA | NA | NA | NA | NA | NA |
| 20/5 | Hybrid | 10 | G | NA | NA | NA | NA | NA |
| 20/6 | PTFE,PI,PTFE | 10 | S | NA | NA | S,G | NA | G |
| 20/7 | PTFE,PI | 10 | NA | NA | NA | NA | NA | NA |
| 12/1 | PI,PI,PI | 30 | G | G | G | NA** | G | G |
| 20/4 | ETFE | 30 | NA | NA | NT | NA | NT | NT |

* Material given from the conductor position NT: not tested

** test current 10A

Abreviations:
- G : Glow
- A : Massive Arcing
- S : Short Arcing
- NA: No action

## Test specimen after test cycle
## Sample No.: 8/12; Normal Air

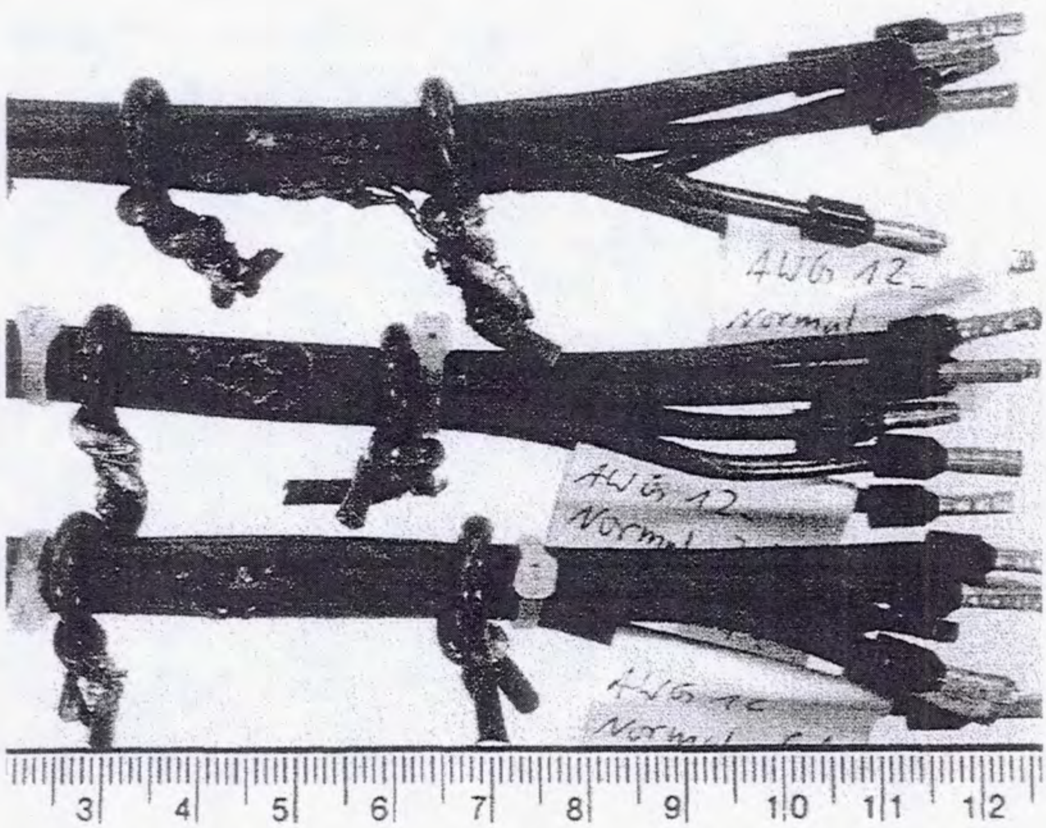
## Cable type : AWG 12

| | |
|---|---|
| ESA - Specification: | 3901 008 |
| Rated Current: | $I_r$ = 23 A |
| Insulation material: | PI/PI/PTFE |
| Conductor material: | Cu, Ag coated |
| Atmosphere: | Normal Air |
| Test Current: | $I_t$ : different |

$I_t$ = 15 A

$I_t$ = 7.5 A

$I_t$ = 6 A



**Test specimen after test cycle**
**Sample No.: 8/12; Vacuum**

**Cable type : AWG 12**

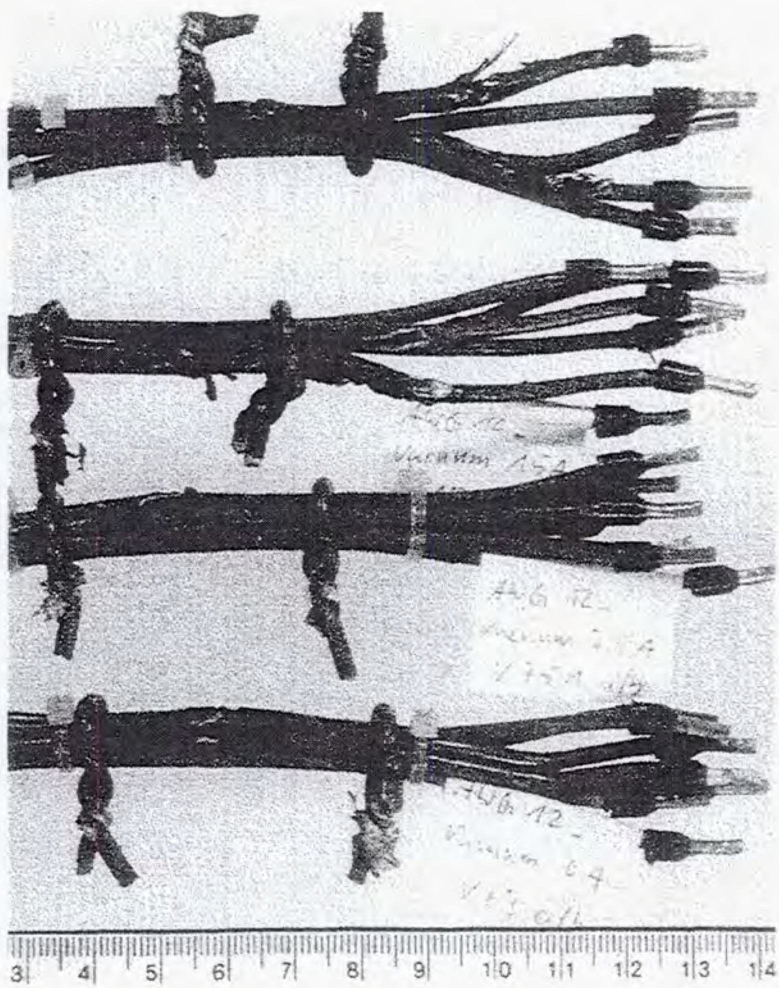
| | |
|---|---|
| ESA - Specification: | 3901 008 |
| Rated Current: | $I_r$ = 23 A |
| Insulation material: | PI/PI/PTFE |
| Atmosphere: | Cu, Ag coated |
| Conductor material: | Vacuum |
| Test Current: | $I_t$ : different |

$I_t$ = 30 A

$I_t$ = 15 A

$I_t$ = 7.5 A

$I_t$ = 6 A



## Test specimen after test cycle
## Sample No.: 2/20; $I_t$ = 10A

## Cable type : AWG 20

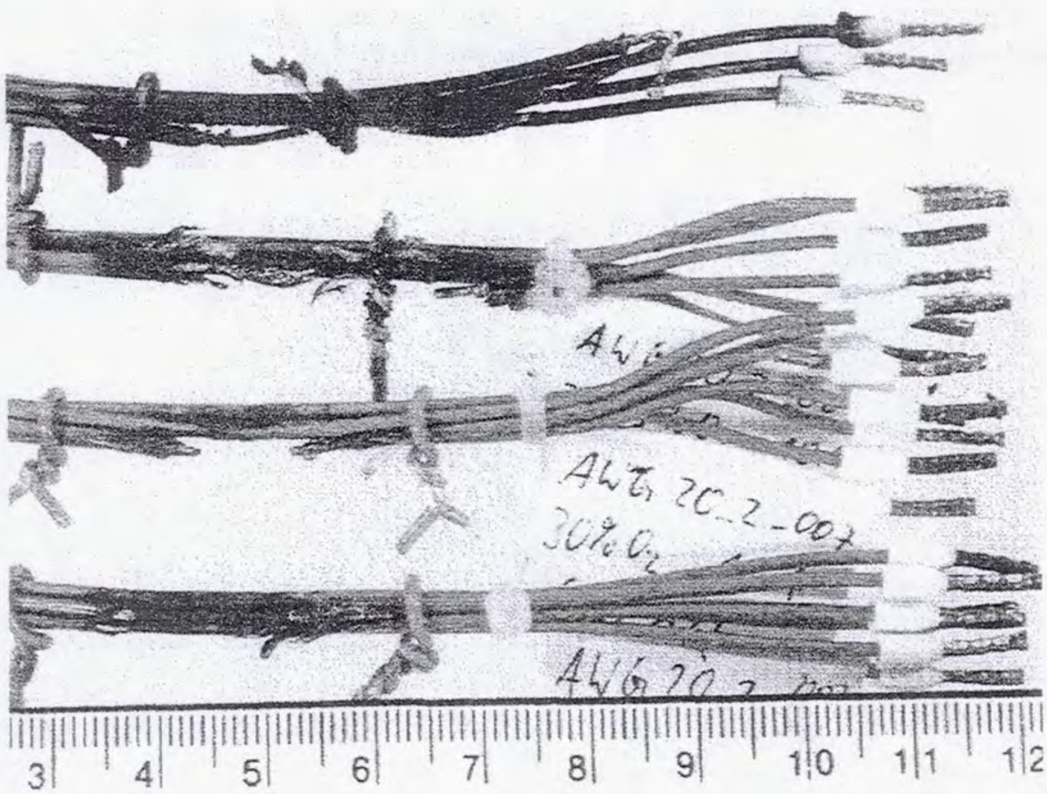
| | |
|---|---|
| ESA - Specification: | 3901 007 |
| Rated Current: | $I_r$ = 7.5 A |
| Insulation material: | PI/PI/PTFE |
| Conductor material: | Cu, Ag coated |
| Test Current: | $I_t$= 10 A |
| Atmosphere: | different |

Vacuum

24.5 Vol.% $O_2$
1000 mbar

30 Vol.% $O_2$
700 mbar

Normal Air



## Test specimen after test cycle
## Sample No.: 3/20; $I_t$ = 10A

## Cable type : AWG 20

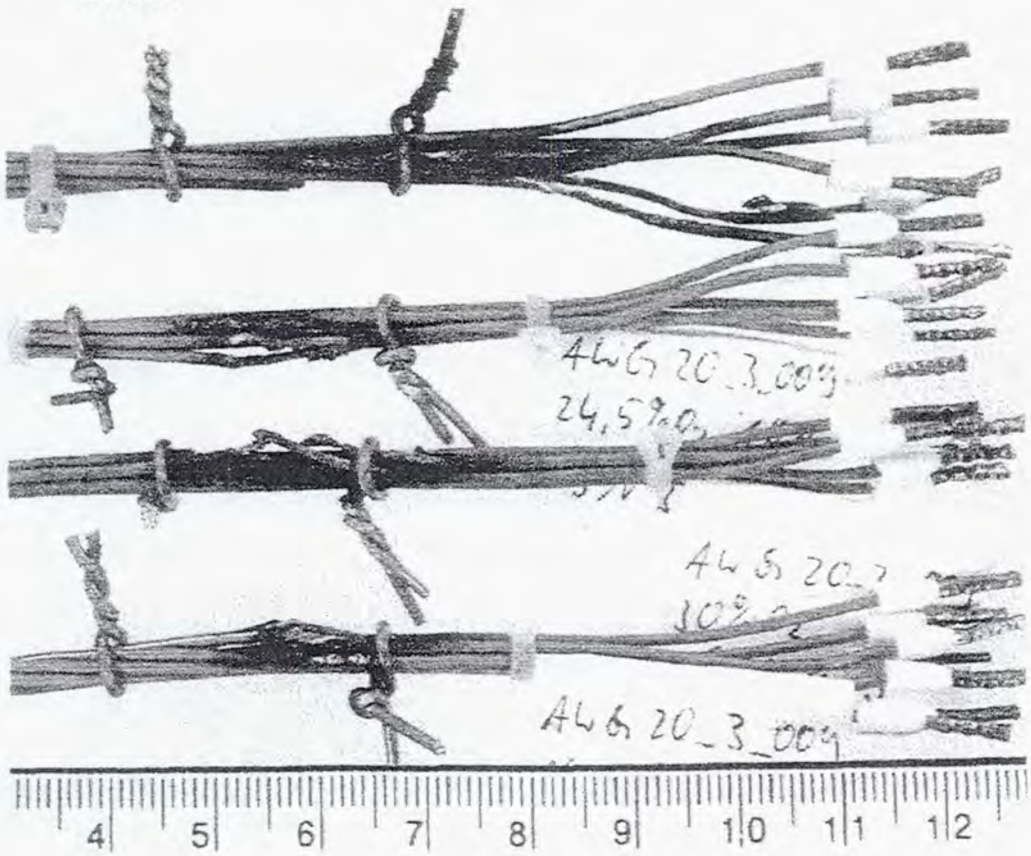
| | |
|---|---|
| ESA - Specification: | 3901 009 |
| Rated Current: | $I_r$ = 7.5 A |
| Insulation material: | PTFE/PI/PI |
| Conductor material: | Cu, Ag coated |
| Test Current: | $I_t$= 10 A |
| Atmosphere: | different |

Vacuum

24.5 Vol.% $O_2$
1000 mbar

30 Vol.% $O_2$
700 mbar

Normal Air



## Test parameters applied at arc tracking tests „On earth“ of cables AWG 20/2 and AWG 20/3

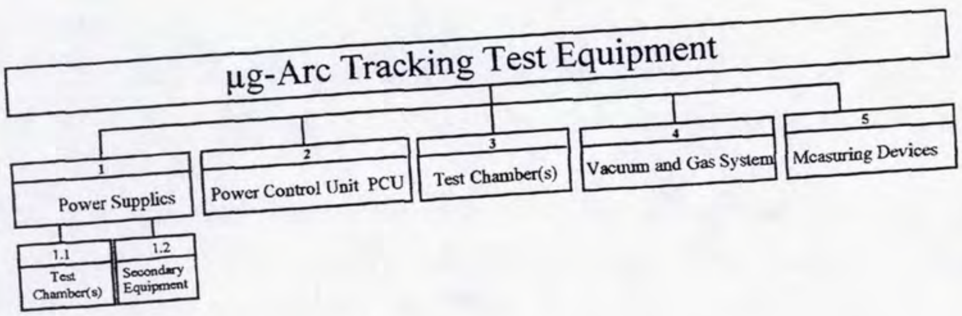
Environmental condition — Rated Voltage $U_r = 125$ V

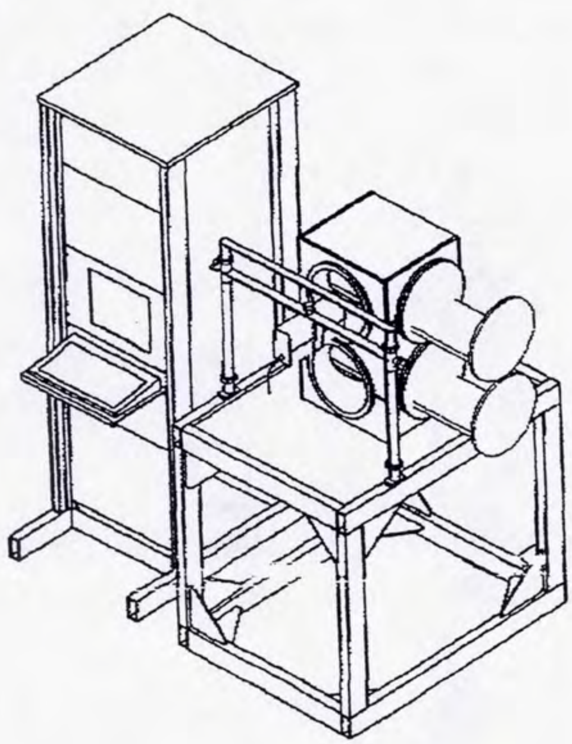
| Cable Type | | Vacuum | Normal air 1000mbar | Enriched oxygen 24,5Vol.%$O_2$ 1000mbar | Enriched oxygen 30Vol.%$O_2$ 700mbar | Fungal growth | | Moisture | | Dry | | Heating (T≈200°C) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Normal air | Vacuum | Normal air | Enr. 24,5% | Normal air | Enr. 24,5% | Normal air | Vacuum |
| AWG 20/2 | $I_{test}$=7.5A | III | III | III | | III | III | | | | | II | II |
| | $I_{test}$=10A | ~~IIII~~ II | ~~IIII~~ II | ~~IIII~~ II | ~~IIII~~ | | | | | | | | |
| AWG 20/3 | $I_{test}$=7.5A | III | III | III | | III | III | III | III | II | II | II | II |
| | $I_{test}$=10A | ~~IIII~~ II | ~~IIII~~ II | ~~IIII~~ II | ~~IIII~~ | | | | | | | | |

Environmental condition — Voltage Range

| Cable Type | | Vacuum 28V | Vacuum 60V | Vacuum 180V | Vacuum 220V | Vacuum 270V | Normal air 1000mbar 28V | Normal air 60V | Normal air 180V | Normal air 220V | Normal air 270V | Enriched oxygen 24,5Vol.%$O_2$ 1000mbar 28V | Enriched oxygen 60V | Enriched oxygen 180V | Enriched oxygen 220V | Enriched oxygen 270V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AWG 20/2 | $I_{test}$=7.5A | | II | II | II | II | II | II | II | II | II | | II | II | II | II |
| | $I_{test}$=10A | | | | | | | | | | | | | | | |
| AWG 20/3 | $I_{test}$=7.5A | I | II | II | II | II | II | II | II | II | II | | II | II | II | II |
| | $I_{test}$=10A | | | | | | | | | | | | | | | |

## Main units of the planned μg-Arc Tracking Test Equipment



## Conclusions

- The available test results indicate that the new test method appears to be valid and suitable for testing and screening the arc tracking characteristic of aerospace cables

- The results obtained provide information about consequences expected after reapplication of power and assess the ability of cable to further operate after arc tracking events

- The new test provides knowledge with respect to the behaviour of cables under arcing conditions for different environments including that of vacuum, which has not been taken into account in all test methods available up to now. In many cases vacuum has turned out to be an important worst-case parameter

- The test system works equally well whatever the chosen test atmosphere. The tests do not take much time compared to other known arc tracking tests. The new test method and the assembled test equipment allows one to achieve a distinction between or classification of different types of cables from a material point of view

- Further testing work needs to be done to investigate the important parameters having influence of arc tracking consequences on aerospace cables of different type and size

- A second test set up has been constructed for ESA/ESTEC and is presently located in the laboratories of DASA at Trauen

- A construction of a new equipment, based on the principles described above, to investigate the phenomenon under microgravity conditions (parabolic flight) is under work

## List of Publications

(1) König D.; Frontzek, F. R.; Dricot, F.; Reher H.-J.; Judd M.D.: Principles of a New Arc Tracking Test of Cables and Wires for Spacecraft. Proc. of the Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), October 18-21, 1992, Victoria, Canada, pp.363-369

(2) König, D.: A New Test Method for the Assessment of the Arc Tracking Properties of Wire Insulation in Air, Oxygen Enriched Atmospheres and Vacuum. Proc.of the Second NASA Workshop on Wiring for Space Applications, October 6-7, 1993, Cleveland, Ohio, USA, pp.173-188

(3) Dricot, F.; Reher, H.J.; Frontzek, F.R.; König, D.: Arc-Tracking Test of Wires. Final Report. Report No. ESA CR(P) 3734, 1994

(4) Frontzek, F.R.; König, D.; Judd, M.D.; Reher, H.J.: Phenomena of Fault Arc Propagation on Cables and Wires for Space Applications in Vacuum, Oxygen Enriched Atmosphere and Air. Proc. of the XVIth Intern. Symp. on Discharges and Electrical Insulation in Vacuum, May 23-30, 1994, Moscow-St.Petersburg, Russia, pp.452-458

(5) König D.; Frontzek, F. R.; Reher, H.-J.; Judd, M.D.: A new Test Method for the Assessment of the Arc Tracking Properties of Wire Bundles in Air, Oxygen Enriched Atmosphere and Vacuum. Proc. of the 1994 IEEE Intern. Symp. on Electical Insulation (ISEI), June 5-8, 1994, Pittsburgh, PA, USA, pp.145-150

(6) Dricot, F.; Reher, H.-J.: Survey of Arc-Tracking on Aerospace Cables and Wires. IEEE Trans. on Dielectrics and Electrical Insulation, Vol.1, No.5, October 1994, pp.896-903

(7) Frontzek, F. R.; König, D.; Judd, M. D.; Reher, H.-J.: Fault Arc Propagation on Cables and Wires for Space Applications in Vacuum, Oxygen Enriched Air and Air. IEEE Trans. on Dielectrics and Electrical Insulation, Vol.2, No.2, April 1995, pp.190-197

SESSION III

omit

# INSULATION AND SYSTEM TECHNOLOGIES

N96- 17090

# AN ADVANCED ARC TRACK RESISTANT AIRFRAME WIRE

J. Beatty
Tensolite Company
St. Augustine, Florida

5/3-33
6334
p-13

**HISTORICAL ANALYSIS:**

*TENSOLITE COMPANY*
*TUFFLITE* * *2000*

**TUFFLITE 2000**

*DETAILED PRODUCT ANALYSIS*

**INDEPENDENT TEST DATA:**

*BOEING BMS 13-60*
*US AIR FORCE/McAIR C.R.A.D. STUDY*

**BENEFITS OFFERED BY TUFFLITE 2000**

- **Tensolite is a custom cable manufacturer**
- **Specializing in high temperature materials as the dielectric medium.**
- **Expertise lies in:**
  - **Aerospace/Airframe**
  - **Specialty Electronics**
    - **Expanded PTFE**
    - **Foamed Thermoplastics**
  - **Mil-spec**
  - **Engineered Solutions**

* Tufflite 2000 is a tradename of a product manufactured by the Tensolite Company. Trade names or manufacturers' names are used in this report for identification only. This usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

**- In-house technical services that facilitate application specific cable designs for the following markets:**

- **Automated Test Equipment**
- **Telecommunications/Communications**
- **Surgical/Medical Instruments**
  - **Ultrasound Scanners**
  - **Minimally Invasive Surgical**
  - **High Resolution Video Camera**
  - **Patient Monitoring**
  - **Endoscopic (Powered Devices)**
- **Control/Instrumentation**
- **Oscilloscope**
- **Logic Analyzers**
- **Computer**
  - **Large System**
  - **Peripheral**
  - **Workstation**
  - **3D Graphics**
- **Aerospace**
  - **Airframe**
  - **GPI/TCAS**
  - **Satellite**
  - **Missiles**
  - **Military Avionics**

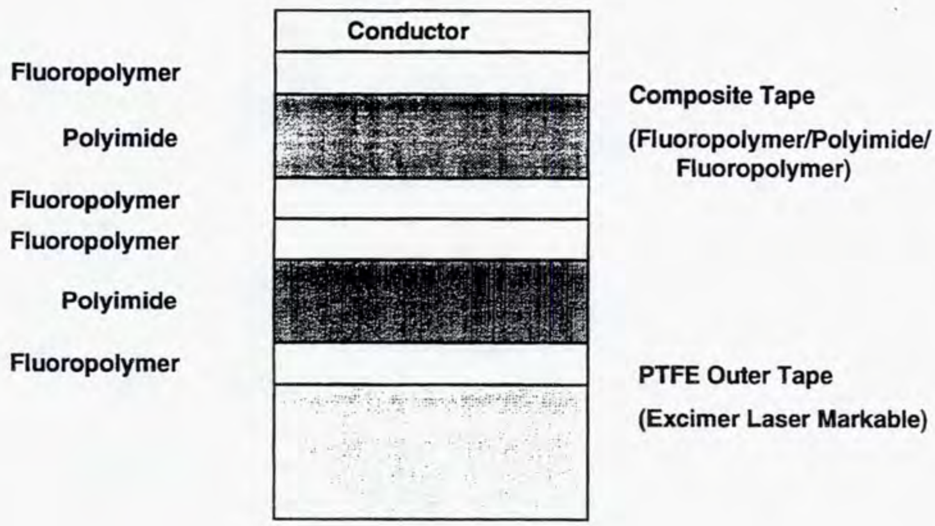
## *HISTORY OF THE TENSOLITE COMPANY*

| | |
|---|---|
| **1941** | Started Operations in Tarrytown, NY |
| **1951** | First to Use Teflon as Insulation |
| **1960** | Became a Subsidiary of Carlisle Corporation |
| **1962** | First to use Kapton as Insulation Material |
| **1978** | Moved to Buchanan, NY |
| **1979** | First to Introduce TPC Conductor with Kapton Insulation |
| **1985** | Patented the Process for Extruded, Expanded PTFE (Insulation used for high speed data transmission) |
| **1988** | Developed Tufflite 2000 Insulation System |
| **1989** | Moved to St. Augustine, FL |
| **1993** | Received Patent for Tufflite 2000 |

## ***AIRFRAME WIRE DEVELOPMENT***

| | |
|---|---|
| **1962** | Kapton insulation system introduced to airframe manufacturers. ***TENSOLITE:*** One of first to be approved for these constructions. |
| **1979** | Irradiated Tefzel insulation system introduced to airframe manufacturers. |
| **1980** | US Navy begins to report ARC TRACKING problems with Kapton Insulation. |
| **1982** | ***TENSOLITE:*** Begins design of multi-layered insulation system to reduce arc tracking. |
| **1986** | US Navy bans Kapton insulation from their aircraft. (US Air Force is undecided) |
| **1987** | US Air Force commissions McAir to determine: "New Insulation Systems for Aerospace Wiring Applications." C.R.A.D. Study (Customer Research And Development) |
| **1988** | ***TENSOLITE:*** Improves multi-layered constructions; making an insulation system to answer all issues with minimal compromise: ***TUFFLITE 2000*** |
| **1989** | Testing begins on US Air Force/McAir C.R.A.D. Studies. Boeing begins testing for New General Purpose, ARC RESISTANT, Airframe wire.<br><br>***TENSOLITE:*** Submits TUFFLITE 2000 samples to Boeing and Air Force tests. |
| **1991** | BMS 13-60 Document released concerning all purpose arc resistant wire. ***TENSOLITE:*** First approved source for BMS 13-60 Document. US Air Force C.R.A.D. Study completed.<br><br>***TENSOLITE:*** TUFFLITE 2000 found superior to all available airframe wires. |

## TUFFLITE DESIGN




## *US AIR FORCE/McAIR C.R.A.D. RESULTS*

| | | |
|---|---|---|
| 1. | FILOTEX* | 8.22 |
| 2. | *TENSOLITE* | 8.23 |
| 3. | MIL-W-81381 (KAPTON) | 9.21 |
| 4. | TELEDYNE THERMATICS | 9.39 |
| 5. | NEMA | 10.48 |
| 6. | MIL-W-22759 (XL ETFE) | 11.38 |

* This submission is not manufacturable on an industrial scale. It was processed in laboratory conditions, and Filotex does not have plans to develop it into a production construction."

As quoted from US Air Force/McAIR C.R.A.D. Document, section 12.0; Observations.

## Screening Tests

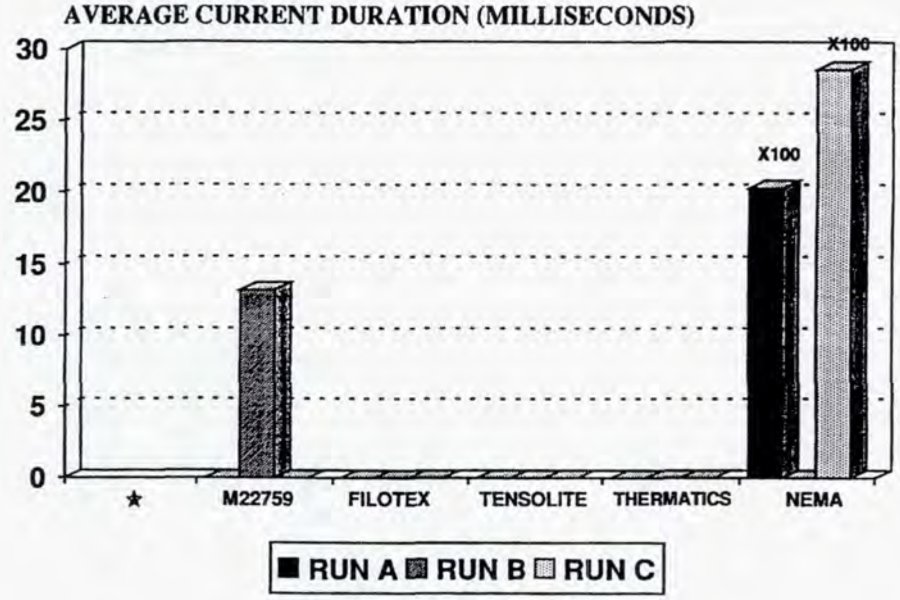
| Test | Document | Weight |
|---|---|---|
| • Finished Diameter | S-901 | 4.2 |
| • Finished Weight | S-902 | 4.2 |
| • Workmanship | S/M - 4.1.4 | 3.0 |
| • Stiffness and Springback | S-708 | 4.2 |
| • Dry Arc Resistance | S-301 | 5.5 |
| • Flammability | S-801 | 4.3 |
| • Toxicity | B0482 | 5.0 |
| • Fluid Immersion | S-601 | 4.5 |
| • Verification of Retained Properties: | | |
| - Heat Aging (1,000 hr @ 200°C) | | |
| - Abrasion | A-D09.16 | 5.5 |
| - Dynamic Cut Through | S-703 | 4.5 |
| - Flex Life | S/M - 3.9.6 | 5.5 |
| - Notch Propagation | S-707 | 5.0 |
| - Voltage Withstand | S-510 | 5.5 |
| - Insulation Resistance | S-504 | 4.5 |
| - Examine Product | S/M - 4.1.4 | 3.0 |
| | | Avg = 4.6 |

## Full Performance Tests

| Test | Document | Weight |
|---|---|---|
| Dielectric Constant | S-501 | 2.0 |
| Corona Inception and Extinction | S-502 | 3.3 |
| Surface Resistance | S-506 | 2.2 |
| Time/Current to Smoke | S-507 | 3.3 |
| Wet Arc Tracking | S-509 | 3.2 |
| Wire Fusing Time | S-511 | 3.2 |
| Forced Hydrolysis | S-602 | 3.5 |
| Humidity Resistance | S-603 | 4.5 |
| Weight Loss (Outgassing) | S-604 | 2.2 |
| Weathering Resistance | S-606 | 3.5 |
| Wicking | S-607 | 3.5 |
| Abrasion | A-D09.16 | 5.2 |
| Cold Bend | S-702 | 3.3 |
| Dynamic Cut Through | S-703 | 4.8 |
| Flex Life | S/M - 3.9.6 | 4.7 |
| Insulation Impact Resistance | S-705 | 3.1 |
| Insulation Tensile Strength | S-706 | 3.2 |
| Notch Propagation | S-707 | 5.0 |
| Smoke Quantity | S-803 | 4.3 |
| Thermal Index | S-804 | 4.0 |
| Thermal Shock | S-805 | 4.0 |
| Wire Surface Markability | DMS 2325 | 3.8 |
| Crush Resistance | A-D3032 | 3.0 |
| Aging Stability - SJ Cable | M-4.5.10 | 3.0 |
| Jacket Wall Thickness - SJ Cable | F-1018 | 3.3 |
| Wire-toWire Rub | DAC Procedure | TBD |
| Dry Arc Prop-Large Gauge, Thermal Age | BS1 No. 43 | TBD |
| 270VDC Dry Arc Prop.-No Protection | S-301 | TBD |
| 270VDC Dry Arc Prop.-With Protection | CuDust | TBD |
| 270DVC Dry Arc Prop.-Large Gauge, Inorganic | CuDust | TBD |

# BSI DRY ARC PROPAGATION TEST

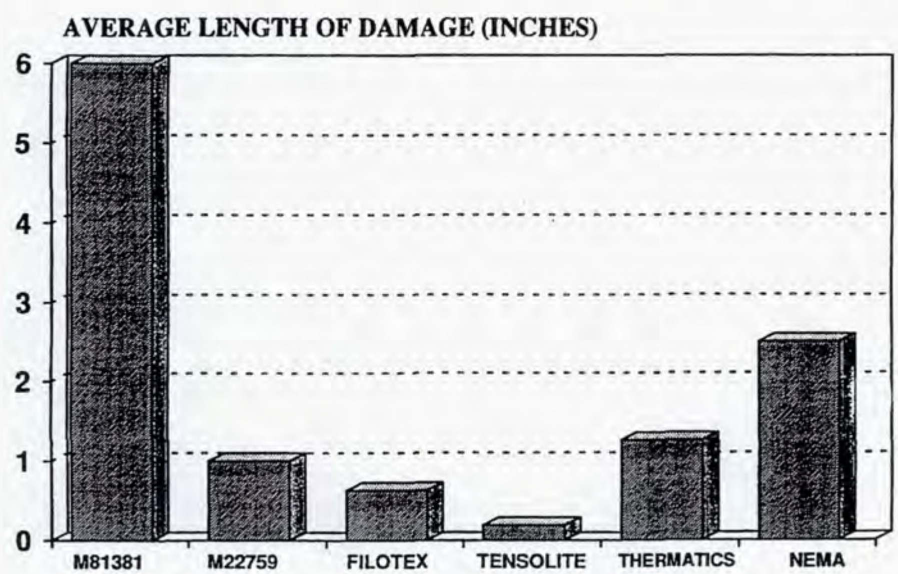
**RESTRIKE POWER APPLICATION TEST RESULTS**

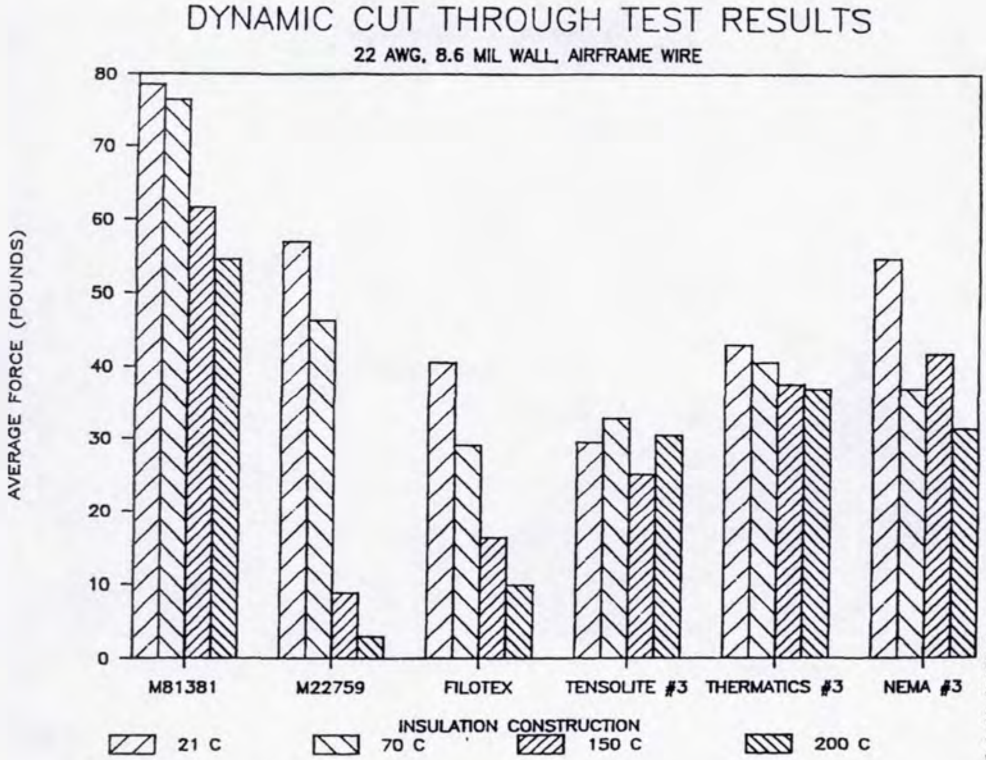



★ M81381 was not tested due to its propensity for Arc Tracking.

# WET ARC TRACKING HARNESS TEST RESULTS

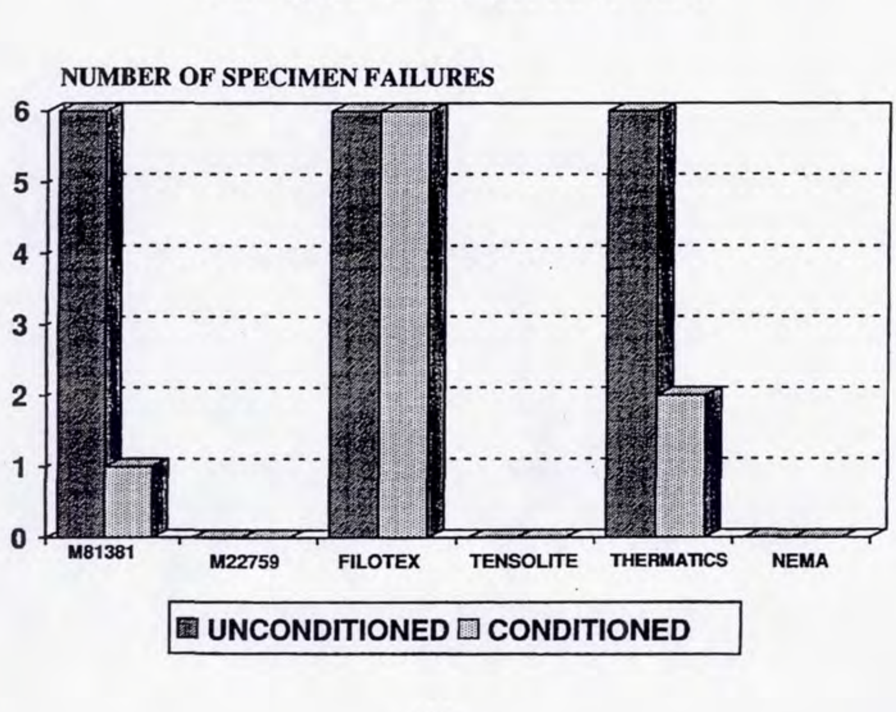
**22 AWG, 5.8 MIL WALL, HOOK UP WIRE**






F-33615-89-C-5605

FIGURE 5.64 - DYNAMIC CUT THROUGH TEST RESULTS, 22AWG, 8.6 MIL WALL, AIRFRAME WIRE



## *TUFFLITE 2000 PASSES ALL BMS 13-60 TESTS!*

- ❑ **ACCELERATED AGING**
- ❑ **ARC RESISTANCE (Wet and Dry)**
- ❑ **DYNAMIC CUT THROUGH**
- ❑ **HUMIDITY RESISTANCE**
- ❑ **WIRE-TO-WIRE ABRASION**
- ❑ **FLAMMABILITY**
- ❑ **SMOKE**
- ❑ **WEIGHT**
- ❑ **NOTCH SENSITIVITY**
- ❑ **FLEXIBILITY**
- ❑ **MARKABILITY**

**ONE WIRE CONCEPT**

**ONE INSULATION SYSTEM**

**(Tufflite 2000 can be used in both PRESSURIZED and UNPRESSURIZED zones)**

| | |
|---|---|
| TL | **Standard Construction**<br>Replacement for Mil Std 81381/11 |
| TLT | **Thin Wall Construction**<br>Replacement for Mil Std 81381/7 |
| TLS | **Increased Wall Construction**<br>Replacement for Mil Std 22759/6 |
| TLA | **TLS with Aluminum Conductor**<br>Power Feeder Cable |

*AVAILABLE IN THREE TEMPERATURE RATINGS: (150 C, 200 C, 260 C)*

**TENSOLITE TLS Weight Savings Analysis:**

**Boeing -Everett (Wide Body) and Renton (Narrow Body) Switched to TLS for Unpressurized applications.**

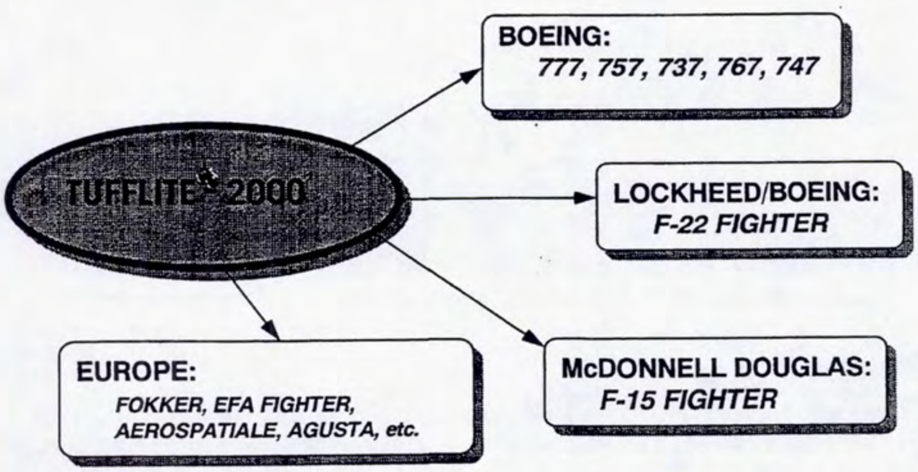
**Tensolite TLS (Boeing BMS 13-60 Types 7 through 12) replaced:**

- **BMS 13-31 - Mineral filled Teflon Cables (triax)**
- **BMS 13-58 - PTFE/Kapton/Braid**

**TLS is replacing these wires in the Engine, Wings and Landing Gear areas of the plane**

*** This switch to TLS from the older technology wiring saved Boeing *<u>150 lbs. per 747-400!</u>* This was the entire weight savings budget for the electrical engineering group for 1994.**

## *A LOOK AT THE AIRFRAME INDUSTRY*



**Tufflite 2000 Provides**

- **Flight proven performance on Boeing 737 and 757 airplanes**
- **Tufflite is the airframe wire chosen for the McDonnell Douglas F-15 fighter for Saudi Arabia and for the Lockheed F-22 ATF.**
- **Air Force/McAir C.R.A.D. independent tests show Tufflite superior to Mil-W-81381 Polyimide and Mil-W-22759 irradiated ETFE wire in a battery of forty-three (43) tests.**
- **Excellent Wet and Dry Arc Track resistance - far superior to Mil-W-81381 or Mil-W-22759 crosslinked ETFE.**
- **Lighter weight and smaller in diameter than traditional Mil-W-81381 Polyimide or Mil-W-22759 crosslinked ETFE.**
- **Superior dynamic Cut-Through performance even at elevated temperatures.**
- **True 260°C performance by utilizing Nickel plated copper conductors.**

# *BSI DRY ARC RESISTANCE TEST*

## SCOPE:

The Dry Arc Propagation Test patterned after the British Standards Institute procedure endeavors to simulate representative aircraft harness damage resulting from the creation of the arc.

## TEST SAMPLE:

Three, seven wire harnesses were fabricated for each of the five thermally aged insulation samples tested, for a total of 15 harness specimens. The length of the harness was 28 in. and consisted of four 12 AWG, 8.6 mil wall airframe wires and three 16 AWG 5.8 mil wall, hook-up wires that had been thermally aged in a forced draft oven at 210 C for 504 hours.

## TEST EQUIPMENT:

Generating system: Constant speed drive system rated at 75,000 volt-amperes, 115 V, three phase, 400 Hz, mounted to a 200 horsepower GE motor. DC power was supplied by two transformer rectifier units rated at 28 V DC with a current rating of 150 amps which provided a total rated DC current output of 300 amps.

# BSI DRY ARC RESISTANCE TEST (continued)

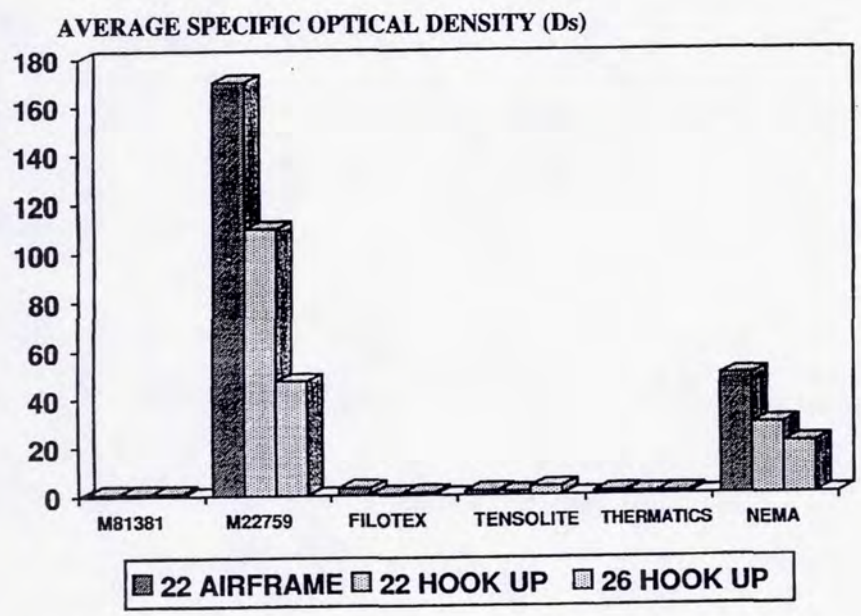
## TEST PROCEDURE:

An aluminum blade was set in a guillotine type device attached to a reciprocating arm set to oscillate at 10 Hz. The wire harness was positioned so that the two notched wires were on top of the harness. The aluminum blade was then brought in contact with the exposed conductors with a force of 52 grams. The test was initiated by oscillating the arm to 10 Hz and energizing the AC and DC contactors to apply power simultaneously to the harness and observing arc conditions, a video camera was used for recording visual data. Power was maintained to the harness for 10 seconds after a circuit breaker opened. The blade was removed from the harness, the generator was brought off line, and the DC motor was turned off and data recorded. A restrike attempt was performed on the specimen 15 to 20 minutes after the initial strike. The blade was not included in the restrike attempt.

## TEST RESULTS:

Current duration of the arc for the initial power application as well as the restrike were recorded. In addition, the visual harness damage was recorded for physical phenomenon, such as length of disintegration as a result of the arc, length of insulation charring, and the amount of exposed or recessed conductor.

## SMOKE QUANTITY TEST RESULTS



# BSI WET ARC TRACKING

## SCOPE:

The Wet Arc Tracking Test was used to evaluate the performance of an unconditioned insulated wire sample under wet are tracking conditions. This test became a BSI standard as of March 1989.

## TEST SAMPLE:

One seven wire harness was fabricated from each of the following: (1) 22 AWG, 8.6 mil wall airframe samples, (2) 20 AWG 5.8 mil wall, airframe wire samples. Each of the seven wires were cut to a length of 400 mm. Two of the seven wires were notched. The notches were placed at 200 mm and 210 mm from one end. The harness was fabricated with wires positioned in a six around one configuration.

## TEST EQUIPMENT:

Generating Equipment: Three phase, 115 V, 400 Hz, 100 amps per phase, laboratory power. A 100 mL pipette capable of delivering a drop sized to 20 mm at a rate of two drops/min was positioned 2 to 4 mm over the harness. The harness was attached to a Teflon plate with the solution positioned to flow over the first notch in the harness, then over the second notch, and out through a hole connected to a drain. The fluid consisted of 1% ammonium chloride and 0.02% iso-octylphenoxypolyethanol, a non-ionic wetting agent, diluted undistilled water.

## TEST PROCEDURE:

The test was performed at room (ambient) temperature in a vented chamber. Electrolyte flow was initiated and power was applied to the harness. Care was taken to ensure that the electrolyte solution was flowing over the damaged sections and into the wire harnesses and not rolling off the sides. The test ran continuously on each harness for eight hours unless an active failure occurred. The test was observed for one of the following:
ACTIVE FAILURE: Either (1) Disruptive arc such that an open circuit occurred. (2) Tripping of the circuit breaker. (3) Arc propagation resulted. Following an active failure the electrolyte flow was stopped and power was maintained to the harness for 30 minutes. The circuit breakers were reset and power was reapplied for 15 minutes. There was no additional reset of the circuit breakers.
PASSIVE FAILURE: A passive failure will not trip circuit breakers, but will usually involve the progressive erosion of the conductors until an open circuit occurs on one or both of the damaged wires. A passive failure was detected by monitoring the indicating lights on each powered line.

## TEST RESULTS:

The test results recorded the time for circuit interruption (active or passive failure), circuit breakers which tripped initially and after being reset, insulation resistance test, and description of the damage to the insulation including the length of charring.

## *TENSOLITE DATABUS CABLE:*

***Fly -By-Wire***

**BOEING 777**

Tensolite developed the new databus cable for the Boeing 777. The proposed designs were subjected to extensive tests by Tensolite and Boeing engineers in order to develop a cable that would meet the stringent requirements.

**DESIGN CRITERIA**

The databus chosen for the Boeing 777 is ARINC 629 using digital autonomous terminal access control (DATAC). The design criteria for the cable was: lightweight, high speed capability, signal integrity, and signal isolation (very little leakage).

**EXPANDED PTFE**

The Tensolite design utilizing expanded PTFE insulation was chosen as the one and only design for the DATAC or "stub" cable.

N96- 17091

# DRY AND WET ARC TRACK PROPOGATION RESISTANCE TESTING

Rex Beach
Naval Air Warfare Center
Aircraft Division
Indianapolis, Indiana

514-33
6335
p. 16

### Presentation Overview:

- History of NAVAIR interest and involvement in Insulation Arc Track Propagation Resistance testing
- Recent developments in NAVAIR's involvement with Insulation Arc Track Propagation Resistance testing
- Parameters common to both Wet and Dry Arc Tests of MIL-STD-2223
- Wet Arc Track Propagation Resistance Test MIL-STD-2223 method 3006
- Dry Arc Track Propagation Resistance Test MIL-STD-2223 method 3007
- Video of NAWC AD Indianapolis Wet and Dry Arc Resistance Test Equipment
- Tensolite Co. slow motion video of arc initiation in the Dry Arc Test
- NAWC AD Indianapolis Wet and Dry Arc Track test capabilities

### Early History of NAVAIR's Involvement with Wire Arc Track Testing

- Informal testing of energized wire bundles with small arms by Navy personnel
- Ballistics testing of Polyimide and XLETFE insulated wires at NAWC AD Pax River, MD (NATC)
- Testing of various wire insulations at the Naval Research Labs (NRL) Washington, DC
-
- Major factor in NAVAIR's decision to no longer use MIL-W-81381 Polyimide insulated wires and to replace MIL-W-81381 wire in installed aircraft with MIL-W-22759 crosslinked ETFE insulated wires during aircraft maintenance

### Recent Events in NAVAIR's Involvement with Wire Arc Track Testing

• Monitoring industry and government activity with Insulation Arc Track Propagation Resistance testing

• Industry development of hybrid insulation systems with Polyimide (arc propagating insulation) *in combination with fluoro-polymer insulations (arc propagation resistant* insulation) made development of laboratory arc track propagation resistance tests critical to evaluate the new insulation systems

• Government-industry task group chaired by NAVAIR formed to write MIL-W-22759/80-92 specification sheets for PTFE/Polyimide hybrid insulation wires and develop standardized and repeatable Wet and Dry Arc Propagation Resistance Tests for MIL-STD-2223 capable of reference in the new wire specification sheets

### Parameters common to Wet and Dry Arc tests of MIL-STD-2223

Bundle with 7 wires, the top 5 wires energized using 20 KVA , 400 Hz, 208 Volt, 3 phase power and lower two not energized

Arc is initiated between the top two wires of bundle (phase A1 & B1) and allowed to propagate until a thermal CB trips, continuity is lost in both of these wires, or the test runs to a defined endpoint with no arc event occurring

If breakers on the damaged wires trip, breakers are reset one time to restrike the arc

Pass/fail criteria is determined by measuring the length of wire damage due to arc propagation and the ability of the 5 middle and bottom wires in the bundle that are <u>not</u> intentionally damaged to pass a post test dielectric withstanding voltage test

3 wire bundles are tested with 0, 0.5, 1, 1.5, and 2 ohms resistance in the circuit. This provides 15 wire bundles to be tested. The dielectric withstanding pass/fail criteria counts the number of the 75 wires (15 bundles x 5 wires) that are not intentionally damaged that pass the dielectric test. MIL-W-22759/80-/92 requires at least 70 wires to pass for the normal weight wire and at least 67 to pass for the light weight wire

### Wet Arc Track Test Method 3006 of MIL-STD-2223

Mil-STD-2223 test is based on similar tests required by Boeing specification BMS 13-60, and ASTM D3032 section 27, and BSI test methods

This test methodology is now widely accepted in US and Europe

Arc initiated by cutting a .75- 1.0 mm window 360 degrees around the two top wires of the 7 wire bundle (A1 and B1) and arranging the wires with the stripped windows 6.25 mm apart then dripping 3 % NaCl solution on the energized bundle at 8-10 drops/minute

A nonarc event test is declared and the test stopped if the two top conductors erode away (no continuity) and no breakers trip after 8 hours.

## Dry Arc Track Test Method 3007 of MIL-STD-2223:

This test methodology is not as standardized as the Wet Arc Track test yet

- All dry arc methods use an electrical short being induced across energized wires of a bundle initiated by one of the following means:
- Wires shorted by ballistic projectile
- Wire strand used to short between exposed conductors
- Exposed ends of the wire bundle shorted using graphite powder or copper dust
- Reciprocating abrader blade "sawing" through insulation used to induce a short

Many different methods have been used until recently

The reciprocating blade method is rapidly becoming the standard test method:
  Military - MIL-STD-2223 method 3007
  McDonnell Douglas St. Louis specifications 5M2071 through 5M2074
  Boeing Commercial Aircraft Specification BMS 13-60 and BSS 7324 test standard
  ASTM D3032 section 29

## Dry Arc Track Test Method 3007 of MIL-STD-2223:

Arc is initiated by a reciprocating blade connected to the neutral of the 3 phase power "sawing through" the A1 and B1 phase wires on the top of the 7 wire bundle

A nonarc event is declared and the test stopped if the blade contacts a mechanical stop set to stop the blade before it can damage wires other than the top 2 wires used to initiate the arc

There are many more variable to be controlled compared to the wet test due to the mechanical contact between the abrader blade and the wire bundle

## NAWC AD Indianapolis Test Capabilities:

NAWC AD Indianapolis has Wet and Dry Arc Arc Track Propagation Resistance test capabilities at this time

NAWC AD Indianapolis is the designated qualification test lab for wet and dry track propagation resistance testing for the MIL-W-22759/80-/92 PTFE/Polyimide hybrid insulation wires

NAWC AD Indianapolis is NAVAIR's lab for arc track evaluation of new wire insulation sytems and hopes to work with other military, government, and commercial activities to perform arc track evaluations of new insulation systems and to advance the state of the art in insulation arc track testing

NAWC AD Indianapolis is promoting the Mil-STD-2223 test methods to other activities for arc track testing so test results taken at different activities can be correlated and compared

# METHOD 3006

## WET ARC-PROPAGATION RESISTANCE

1. PURPOSE. The wet arc-propagation resistance test for wire insulation provides an assessment of the ability of an insulation to prevent damage in an electrical environment. In service, electrical arcs may originate from a variety of factors including insulation deterioration, faulty installation, and chafing, and may be further induced by water or other fluids which create conductive paths. It has been documented that results of an arc-propagation test may vary slightly due to the method of arc initiation; therefore a standard test method must be selected to evaluate the general arc-propagation resistance characteristics of an insulation. This test method initiates an arc by dripping salt water over pre-damaged wires which creates a conductive path between the wires. The arc propagation resistance is defined by the length of arc-propagation damage along the pre-damaged wires and by the extent of damage to all adjacent wires which are initially undamaged. The test also evaluates the ability of the insulation to prevent further arc-propagation when the electrical arc is re-energized. The power supply, test current, circuit resistances, and other variables are optimized for testing 20 gauge wires. The use of other wire sizes may require modifications to the test variables.

2. TEST EQUIPMENT

a. A transparent screen to protect laboratory personnel from molten metals, UV radiation, and other debris that may be ejected from the test specimen.

b. A variable speed, peristaltic pump or suitable other device and a hypodermic needle or burette. The apparatus should be able to deliver the electrolyte solution at a rate of 100 ± 10 mg (0.0035 ± 0.00035 ounces) per minute (8 to 10 drops of 3 percent sodium chloride solution) to the test specimen. An alternative means of delivery is acceptable.

c. A mechanical device for supporting the test bundle in free air in a horizontal position.

d. An electrolyte solution made by dissolving 3 ± 0.5 percent by weight of sodium chloride (NaCl) in distilled water.

e. A three phase wye connector power supply, grounded at wye, derived from a rotary machine or solid state power source of not less than 20 KVA rating, delivering 208 volts line-to-line at 400 Hz.

f. MS3320-7.5 (7.5 Amp) and MS25244-50 (50 Amp) protective circuit breakers.

g. Variable load and fixed load resistors.

h. MIL-T-43435 (Type V) lacing tape.

3. TEST SAMPLES. A test sample shall consist of 15 bundles of wire. Each bundle is composed of seven wires approximately 20.3 - 40.6 cm (8 - 16 inches) in length. A minimum of 21.3 meters (70 feet) is required. It is recommended that 20 gauge wire be use for the test.

4. TEST PROCEDURE

4.1 Preparation of bundles. Conduct a 2500 volt Wet Dielectric test on 100 percent of the wire in accordance with the Wet Dielectric test procedure described in MIL-STD-2223 method 3005 before the arc-propagation resistance test is performed. Discard any failed sections of wire. Cut seven wire segments 20.3 - 40.6 cm (8 - 16 inches) in length for each of the 15 bundles. Clean the cut wires using a cloth saturated with isopropyl alcohol. Strip both ends of five of the seven wire segments. Use these stripped ends for making electrical connections. These five wire segments will be called "Active Wires". The two unstripped wire segments will be called "Passive Wires". Using a sharp blade, cut a square groove completely around (360 degrees) the insulation of two of the active wires at their midpoints to expose the conductor. The width of the exposed conductor should be between 0.5 mm and 1.0 mm (0.0197 and 0.03941 inch). Form the bundle by laying the seven wire segments straight and geometrically parallel. Assemble the wires to form the six-around-one configuration shown in Figure 1. The two pre-damaged wires should be placed in the A1 and B1 positions and care should be taken to ensure that there is a longitudinal distance of 6.0 mm to 6.5 mm (0.2362 to 0.2560 inch) as measured between the stripped window of the two exposed conductors. The two passive wires correspond to the D1 and D2 components shown in Figure 1. Use MIL-T-43435 lacing tapes to hold the test bundle together. Clean the assembled bundle using a cloth saturated with isopropyl alcohol prior to installation in the fixture.

4.2 Electrical connection. Connect the test bundle to the power supply and circuit resistance using the schematic circuit shown in Figure 2. Connect one end of each active wire to the appropriate phase of the power supply as shown in Table I. Use an MS3320-7.5 (7.5 Amp) circuit breaker and a circuit resistance in series with each of the active wires. Use the circuit resistance values shown in Table II. Connect the other end of the five active wires under test to variable resistive loads. Adjust the resistance to limit the current flowing through each wire to 1 ± 0.2 Ampere. Protect the test circuits with MS25244-50 (50 Amp) circuit breakers connected on the supply side of the test set up.

TABLE I. Electrical connection.

| Wire Identification | Power Supply | Layer |
|---|---|---|
| A1 | Phase A | Top |
| B1 | Phase B | Top |
| C1 | Phase C | Middle |
| A2 | Phase A | Middle |
| B2 | Phase B | Middle |
| D1 | None | Lowest |
| D2 | None | Lowest |

TABLE II. Circuit resistance.

| Test Number | Circuit Resistance (ohm) |
|---|---|
| 1 | 0.0 |
| 2 | 0.5 |
| 3 | 1.0 |
| 4 | 1.5 |
| 5 | 2.0 |

4.3 Initiation of test. Test three bundles for each of the five circuit resistances. Using the mechanical supports, mount the test bundle in a draft-free location so that the wires with the exposed conductors are upper most. Adjust the flow of the electrolyte to 8-10 drops per minute. Position the hypodermic needle to drop the electrolyte into the groove between the wires with the exposed conductor. Position the tip of the needle so that the vertical distance of the tip is 150 mm (5.91 inch) above the specimen. Position the protective screen to shield the operator from ejecting objects or UV radiation. Close all circuit breakers. Allow the electrolyte to flow. Apply three phase 400 Hz power.

5. RESULTS. Use one of the following conditions to conduct and complete the test.

5.1 If circuit breakers in any of the phases A2, B2, or C1 trips at any time during the test, wait 3 minutes and disconnect power. Conduct a 1000 volt Wet Dielectric test on wires A2, B2, C1, D1 and D2 in accordance with the Wet Dielectric procedure of MIL-STD-2223 method 3005. Record the number of wires which fail. Measure and record the total length of physical damage to each wire (including phase A1 and B1 wires) in inches.

5.2 If either phase A1 or phase B1 circuit breaker trips at any time during the test, disconnect the power and identify the phase of the tripped circuit breaker. Wait 3 minutes. Reset the circuit breaker, apply power and continue the test. Continue the test for eight hours or until either phase A1 or phase B1 circuit breaker has tripped twice. CAUTION: DO NOT RESET A CIRCUIT BREAKER THAT TRIPS TWICE. Conduct a 1000 volt, Wet Dielectric test on wires A2, B2, C1, D1 and D2 in accordance with the Wet Dielectric test of MIL-STD-2223 method 3005. Record the number of wires which fail. Measure and record the total length of physical damage to each wire (including phase A1 and B1 wires) in inches.

5.3 If the conductor(s) of phases A1 and B1 wires erode without tripping phase A1 or phase B1 circuit breakers (as may be indicated by an open circuit indicator), continue the test for a total of 8 hours or until the test endpoints of 5.1 or 5.2 occur. Conduct a 1000 volt Wet Dielectric test on wires A2, B2, C1, D1 and D2 in accordance with the Wet dielectric procedure of MIL-STD-2223 method 3005. Record the number of wires which fail. Measure and record the total length of physical damage to each wire (including phase A1 and B1 wires) in inches.

5.4 Circuit breakers should be periodically tested to assure they still meet the overload trip requirements of the applicable military specification (MS) sheet. Circuit breakers outside their overload trip limits should be replaced.

6. INFORMATION REQUIRED IN THE INDIVIDUAL SPECIFICATION. Specifications shall list minimum number of wires which must pass the dielectric test after the bundle has been energized, and also the maximum allowable length of physical damage to the individual wires in the bundle.

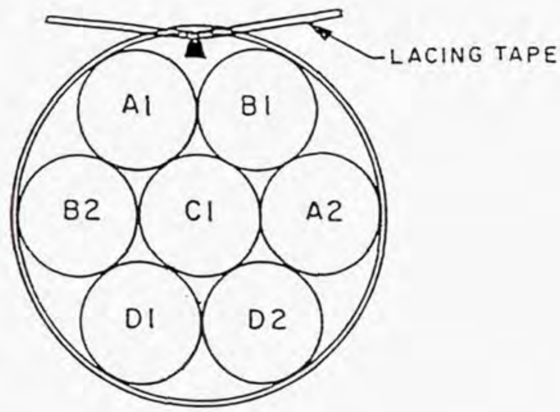



FIGURE 1. Bundle Configuration.

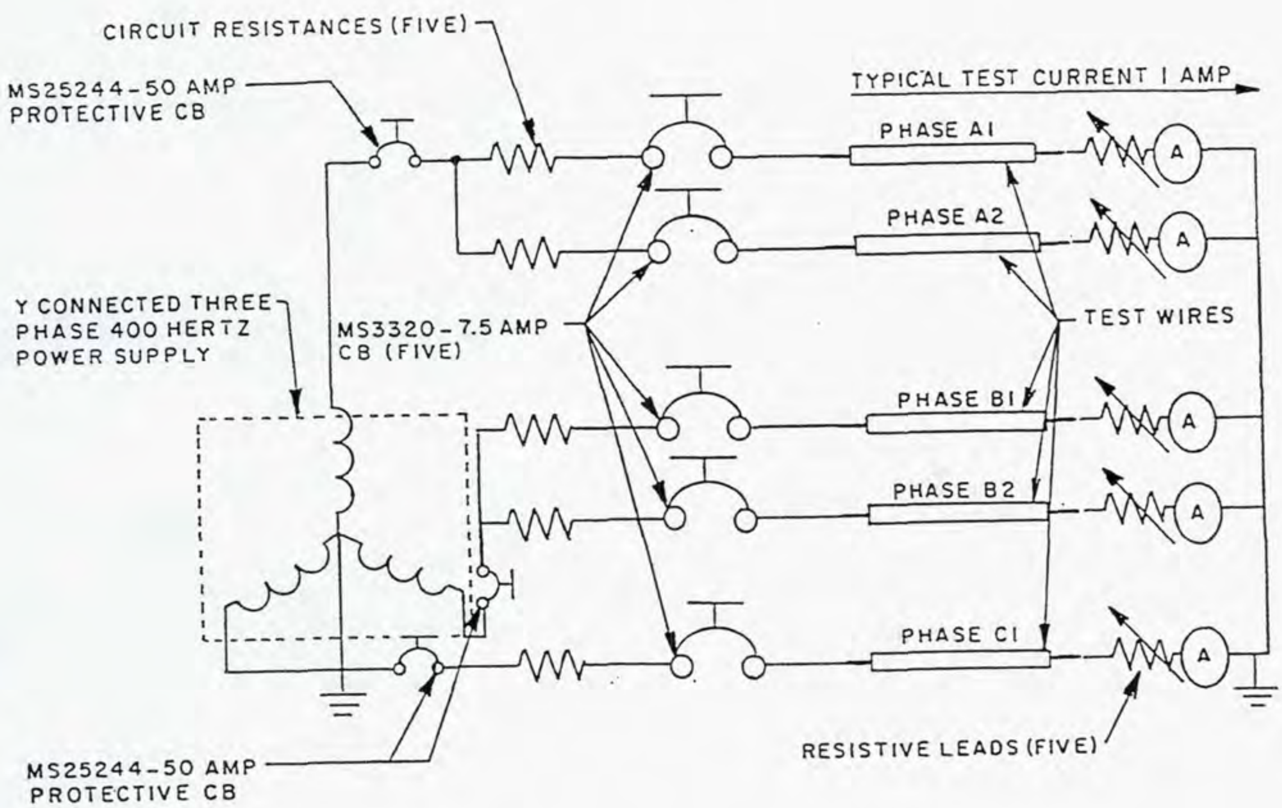



FIGURE 2. Electrical Connection

# METHOD 3007

## DRY ARC-PROPAGATION RESISTANCE

1. PURPOSE. The dry arc-propagation resistance test for wire insulation provides an assessment of the ability of an insulation to prevent damage in an electrical arc environment. In service, electrical arcs may originate from a variety of factors including insulation deterioration, faulty installation, and chafing. It has been documented that results of an arc-propagation test may vary slightly due to the method of arc initiation. Therefore a standard test method must be selected to evaluate the general arc-propagation resistance characteristics of an insulation. This test method initiates an arc with a vibrating blade. The arc-propagation resistance is defined by the length of arc-propagation damage along the wires in contact with the blade and by the extent of damage to all adjacent wires undamaged by the vibrating blade. The test also evaluates the ability of the insulation to prevent further arc-propagation when the electrical arc is re-energized. The power supply, test current, circuit resistances and other variables are optimized for testing 20 gauge wires. The use of other wire sizes may require modification of other test variables.

2. TEST EQUIPMENT

a. An abrader blade made from 6061-T6 aluminum material. Use a grit size 60 grinding wheel or 60 grit sanding belt to sharpen the blade. A typical abrader blade is shown in Figure 1. Use the blade sharpening fixture shown in fixture shown in Figure 2.

b. A transparent screen to protect laboratory personnel from molten metals, UV radiation, and other debris that may be ejected from the test specimen.

c. An oscillating mechanism to which the abrader blade is connected. The oscillating mechanism shall provide a stroke of 3.81 cm (1.50 inches) at a frequency of 0.5 ± 0.05 cycles per second.

d. A test fixture which includes a test block to hold the wire at right angles to the abrading blade. The block is made from 6061-T6 aluminum.

e. A three phase wye connected power supply, grounded at wye, derived from a rotary machine or solid state power supply of not less than 20 KVA rating, delivering 208 volts line-to-line at 400 Hz.

f. A mechanical stop constructed of stainless steel.

g. MS3320-7.5 (7.5 Amp) and MS25244-50 (50 Amp) protective circuit breakers.

h. Variable load and fixed load resistors.

i. MIL-T-43435 (Type V) lacing tape.

j. MS25281 plastic clamps.

3. TEST SAMPLES. A test sample shall consist of 15 bundles of wire. Each bundle is composed of seven wires and shall be of sufficient length, 35.6 cm (14 inches) minimum, to allow the bundle to be installed in the test fixture. A minimum of 37.3 meters (122.5 feet) of wire is required. It is recommended that 20 gauge wire be used for the test.

4. TEST PROCEDURE

4.1 Preparation of bundles. Conduct a 2500 volt Wet Dielectric test on 100 percent of the wire in accordance with the Wet Dielectric test procedure described in MIL-STD-2223 method 3005 before the arc propagation resistance test is performed. Discard any failed sections of wire. Cut seven wire segments at least 35.6 cm (14 inches) in length for each of the 15 bundles. Clean the cut wires using a cloth saturated with isopropyl alcohol. Strip both ends of five of the seven wire segments. Use these stripped ends for making electrical connections. These five wire segments will be called "Active Wires". The two unstripped wire segments will be called "Passive Wires". Form the bundle by laying the seven segments straight and geometrically parallel. Assemble the wires to form the six-around-one configuration shown in Figure 3. Use MIL-T-43435 lacing tapes to hold the test bundle together. Clean the assembled bundle using a cloth saturated with Isopropyl alcohol prior to installation in the test fixture.

4.2 Bundle installation. A test fixture shall be used to hold the wire bundle in place perpendicular to the abrader blade. Details of a suggested test fixture are shown in Figure 4. Before installation, the wire bundle shall be tied with MIL-T-43435 lacing tape at .635 cm (.25 inch) on each side of where the abrader blade is to be applied; then secured to the test fixture. The wire bundle is clamped with MS25281 plastic clamps at two points on the fixture at a minimum distance of 15.24 cm (6.0 inches). The clamp points are equidistant from the point of application of the abrader. The slide bolt allows the adjusting screw to move the holding plates snugly against the bundle. Ensure that the active wires A1 and B1 are parallel with the top plane of the test fixture, and that the passive wires D1 and D2 are in complete contact with the base of the test fixture. The bundle must not be allowed to move while the abrader blade is cutting wires A1 and B1. The test fixture shall contain an adjustable mechanical stop, which may be set to allow for various penetration depths of the vibrating blade.

4.3 Electrical connection. Connect the test bundle to the power supply and circuit resistance using the schematic circuit shown in Figure 5. Connect one end of each active wire to the appropriate phase of the power supply as shown in Table I. Use an MS3320-7.5 (7.5 Amp) circuit breaker and a circuit resistance in series with each of the active wires. Use the circuit resistance values shown in Table II. Connect the other end of the five active wires under test to variable resistive loads. Adjust the resistance to limit the current flowing through each wire to 1.0 ± 0.2 Ampere. Protect the test circuits with MS25244-50 (50 Amp) circuit breakers connected on the supply side of the test set up. Connect the abrader blade to the neutral of the generator. Connect the generator neutral to ground.

TABLE I. Electrical connection.

| Wire Identification | Power Supply | Layer |
|---|---|---|
| A1 | Phase A | Top |
| B1 | Phase B | Top |
| C1 | Phase C | Middle |
| A2 | Phase A | Middle |
| B2 | Phase B | Middle |
| D1 | None | Lowest |
| D2 | None | Lowest |

TABLE II. Circuit resistance.

| Test Number | Circuit Resistance (ohm) |
|---|---|
| 1 | 0.0 |
| 2 | 0.5 |
| 3 | 1.0 |
| 4 | 1.5 |
| 5 | 2.0 |

4.4 Initiation of test. Test three bundles for each of the five circuit resistances. Install the oscillating mechanism which may use a reciprocating arm, or vertical and horizontal precision linear ball slides (a suggested ball slide apparatus is shown in Figure 6). Adjust the mechanical stop to ensure that the abrader blade penetrates into the A1 and B1 wires a distance of 0.87 times the radius of the seven wire bundles. Close all circuit breakers. Apply a nominal load of 250 grams (0.551 pounds) to the abrader at the point of contact with one wire. Adjust the blade to ensure that the major plane of the blade lies perpendicular to the longitudinal axis of the bundle. Apply the abrader blade on the test bundle. Position the protective screen to shield the operator from ejecting objects and UV radiation. Apply three phase 400 Hz power. Actuate the abrader. Allow the abrader blade movement to continue.

5. RESULTS. Use one of the following conditions to conduct and complete the test.

5.1 If the abrader cuts through A1 and B1 wires without tripping phase A1 or phase B1 circuit breakers, stop the abrader movement. Disconnect the power.

5.2 Conduct the 1000 volt Wet Dielectric test on wires A2, B2, C1, D1 and D2 in accordance with the Wet Dielectric procedure of MIL-STD-2223 method 3005. Record the number of wires which fail. Measure and record the total length of physical damage to each wire (including phase A1 and B1 wires) in inches.

5.3 If a circuit breaker in any of the phases A2, B2 or C1 trips at any time during the test, stop the abrader and disconnect the power. Perform tests as listed in 5.2.

5.4 If either phase A1 or phase B1 circuit breaker trips at any time during the test, stop the abrader. Disconnect the power and determine if the conductor of wires A1 or B1 are open. If both wires are open, conclude the test by performing tests as listed in 5.2. If wire A1 or wire B1 are not open, wait 3-4 minutes, reset the circuit breaker and restart the abrader and then immediately re-apply the power. Continue the test until either phase A1 or phase B1 circuit breaker has tripped a second time, phases A1 and B1 are open, or the blade movement is stopped by the mechanical stop. CAUTION: DO NOT RESET A CIRCUIT BREAKER THAT TRIPS TWICE. Perform the tests as listed in 5.2. Use a new abrader blade edge for each test bundle, if any blade damage is present, or if circuit breakers A1 or B1 trip during the test.

5.5 Circuit breakers should be periodically tested to assure they still meet the overload requirements of the applicable military specification (MS) sheet. Circuit breakers outside their overload trip requirements should be replaced.

6. INFORMATION REQUIRED IN THE INDIVIDUAL SPECIFICATION. Specifications shall list minimum number of wires which must pass the dielectric test after the bundle has been energized, and also the maximum allowable length of physical damage to the individual wires in the bundle.

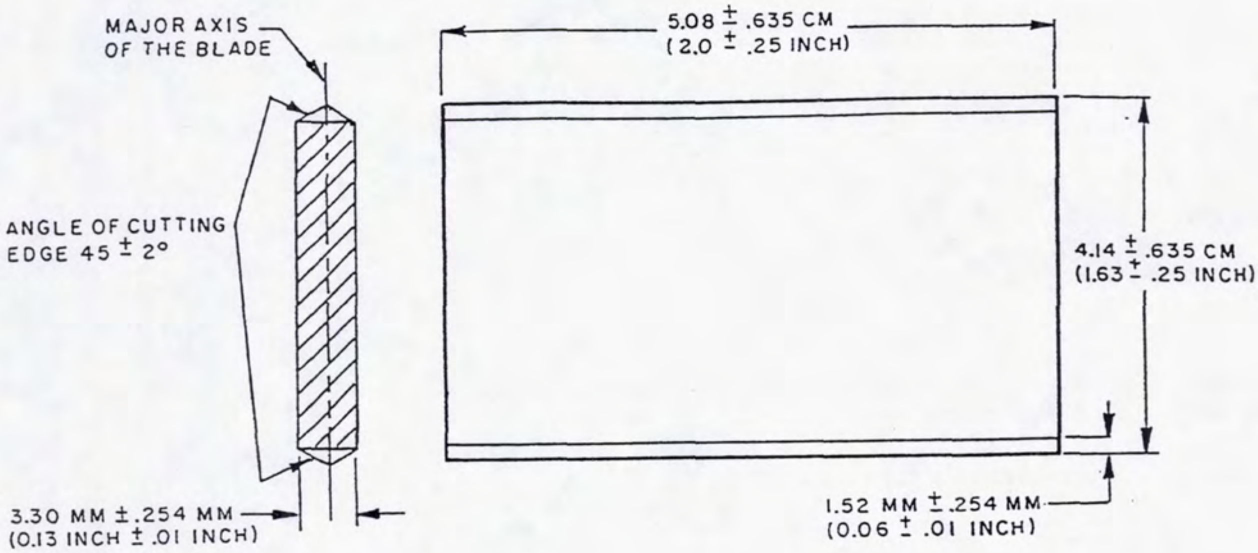



FIGURE 1. Blade.

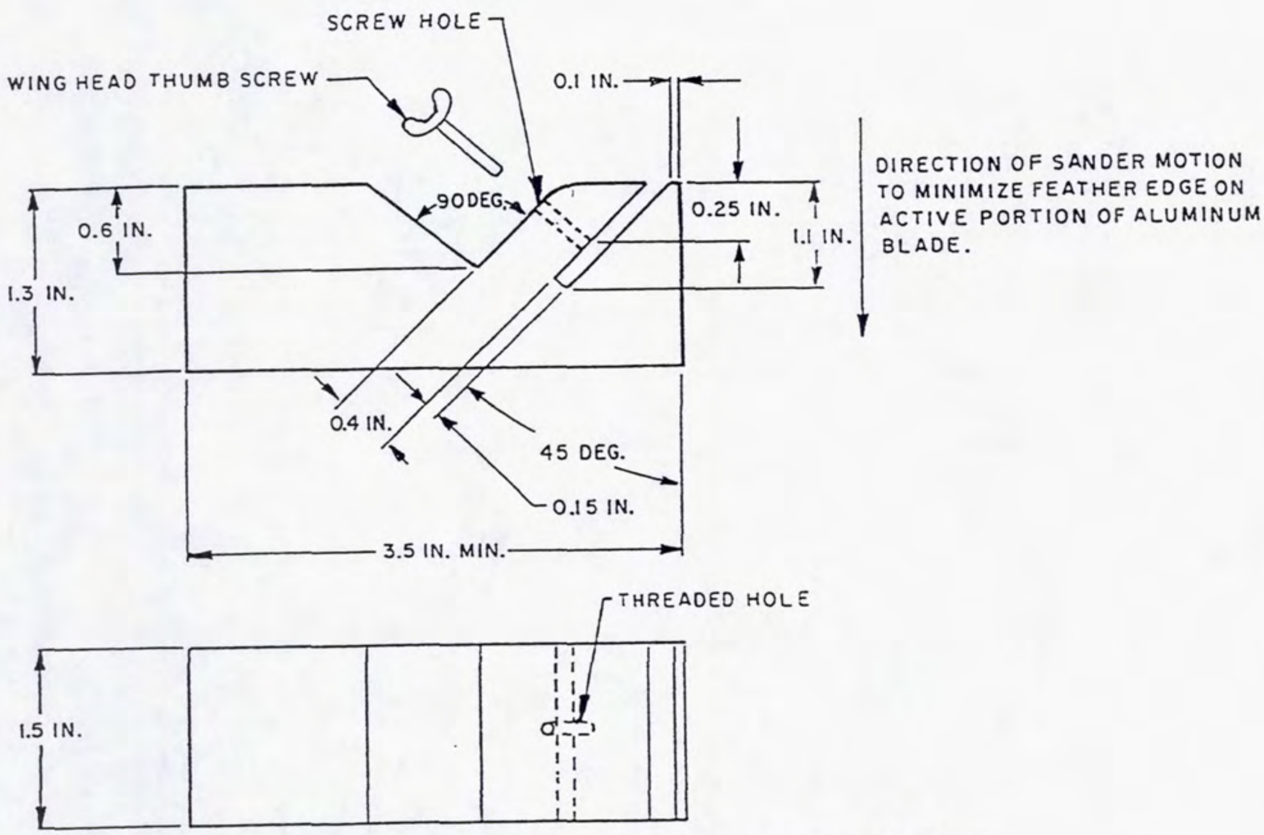



FIGURE 2. Aluminum blade sharpening fixture.

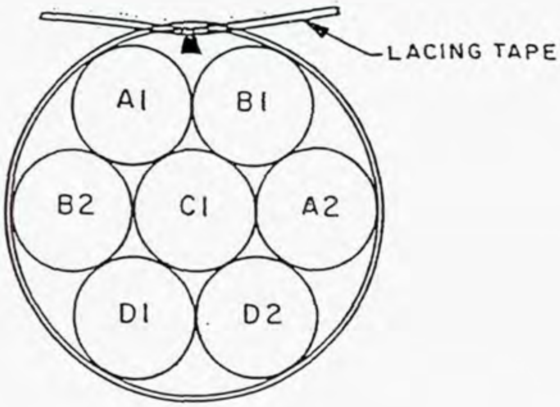



FIGURE 3. Bundle configuration.

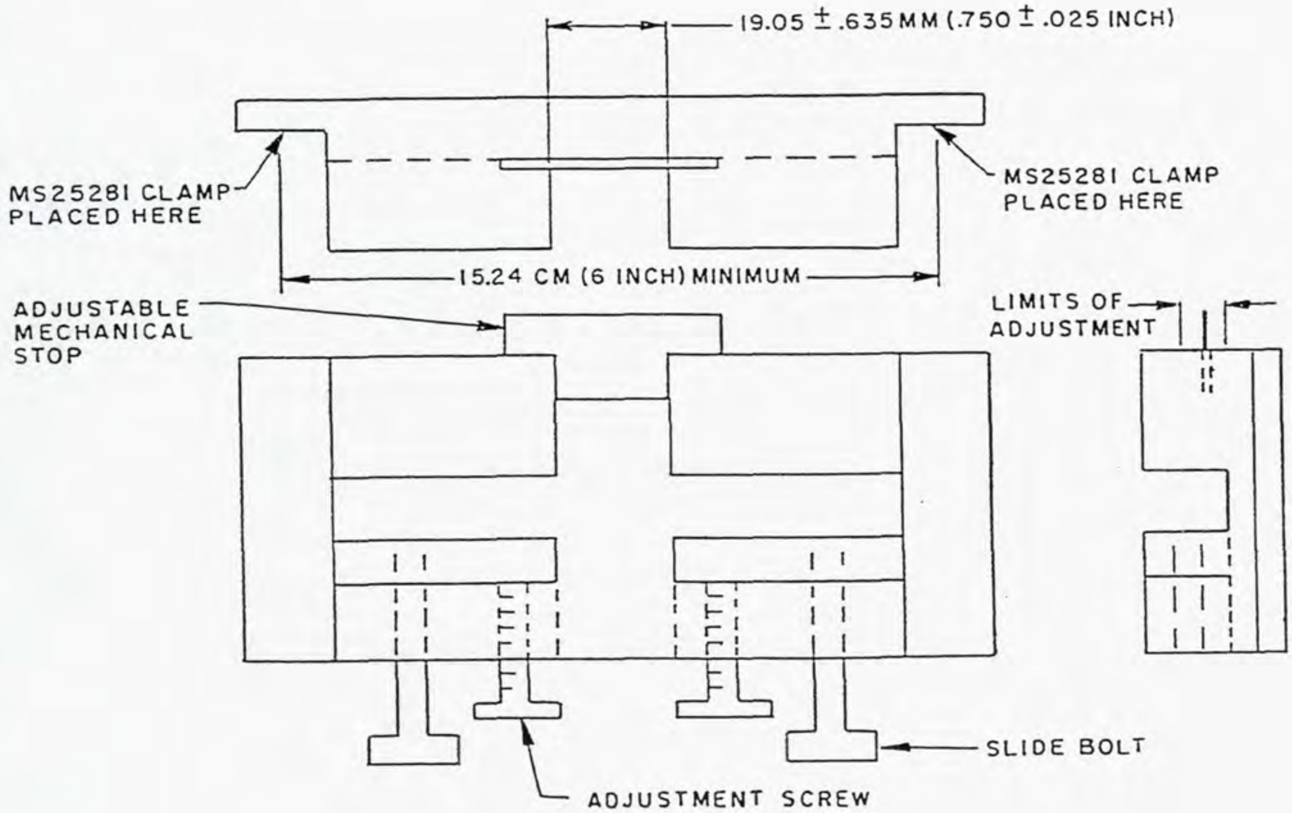



FIGURE 4. Test fixture.

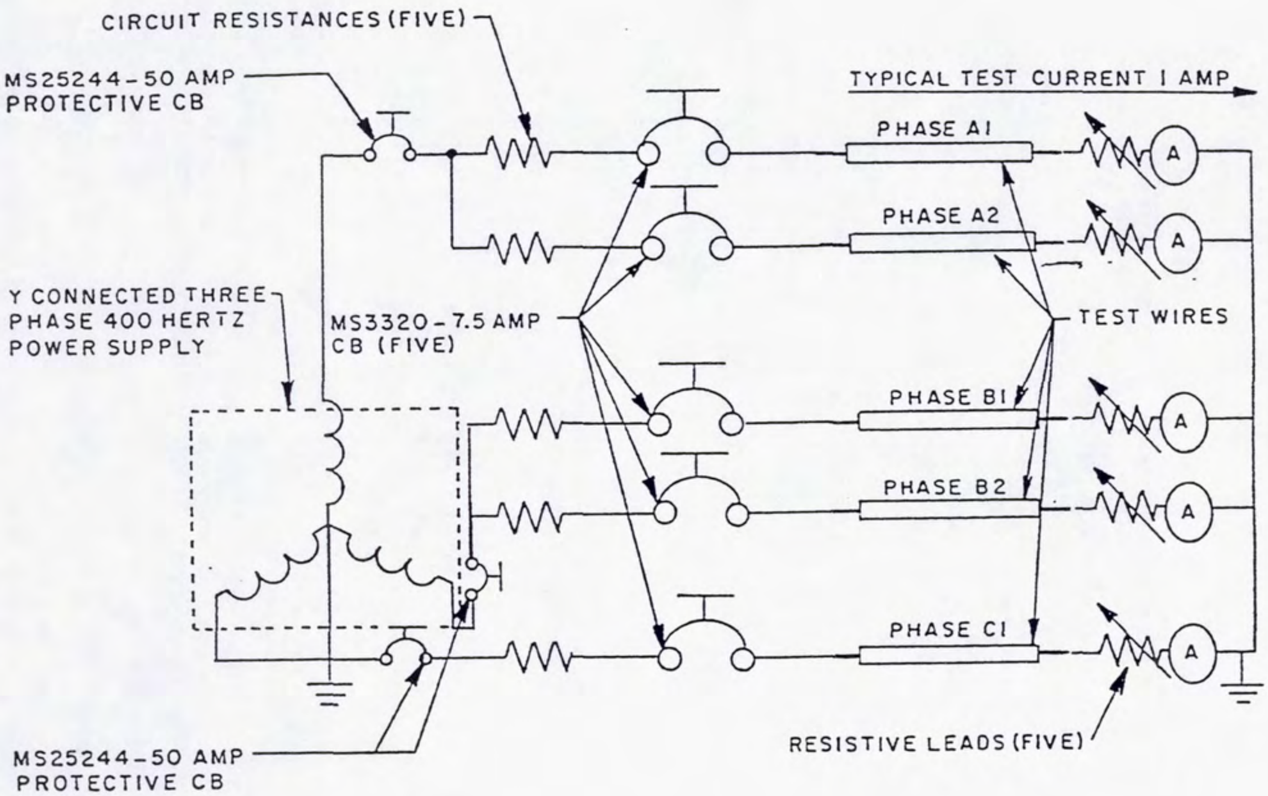



FIGURE 5. Electrical connection.

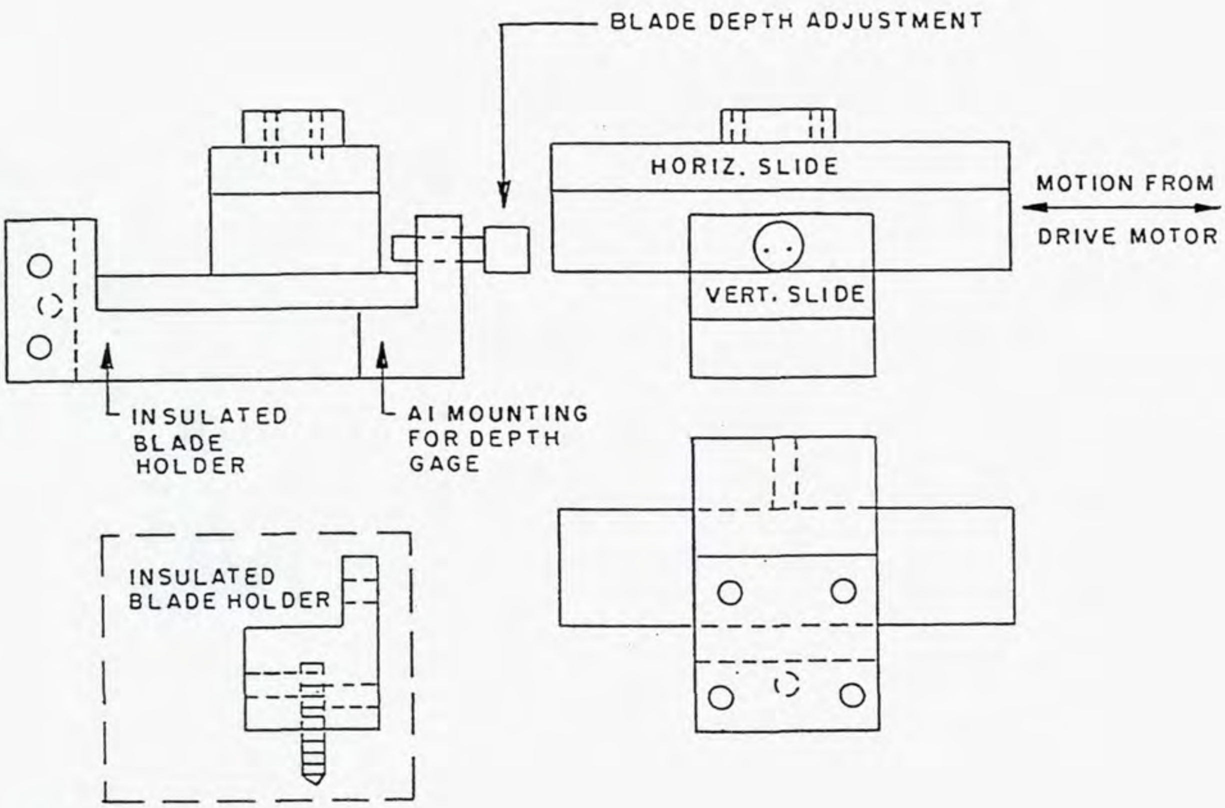



FIGURE 6. Ball slide blade fixture.

N96- 17092

# FEATURE EXTRACTION OF ARC TRACKING PHENOMENON

John Okyere Attia
Department of Electrical Engineering
Prairie View A&M University
Prairie View, Texas

515-33
6336
p-9

## ARC TRACKING

ELECTRIC ARC BETWEEN CONDUCTING WIRES DUE TO INSULATION BREAKDOWN

KAPTON INSULATOR

PROBLEM FOR AEROSPACE INDUSTRY

- NASA (SPACELAB)
- US NAVY

## OBJECTIVE

TO OBTAIN THE SALIENT FEATURES OF ARC TRACKING PHENOMENON

## DATA ACQUISITION

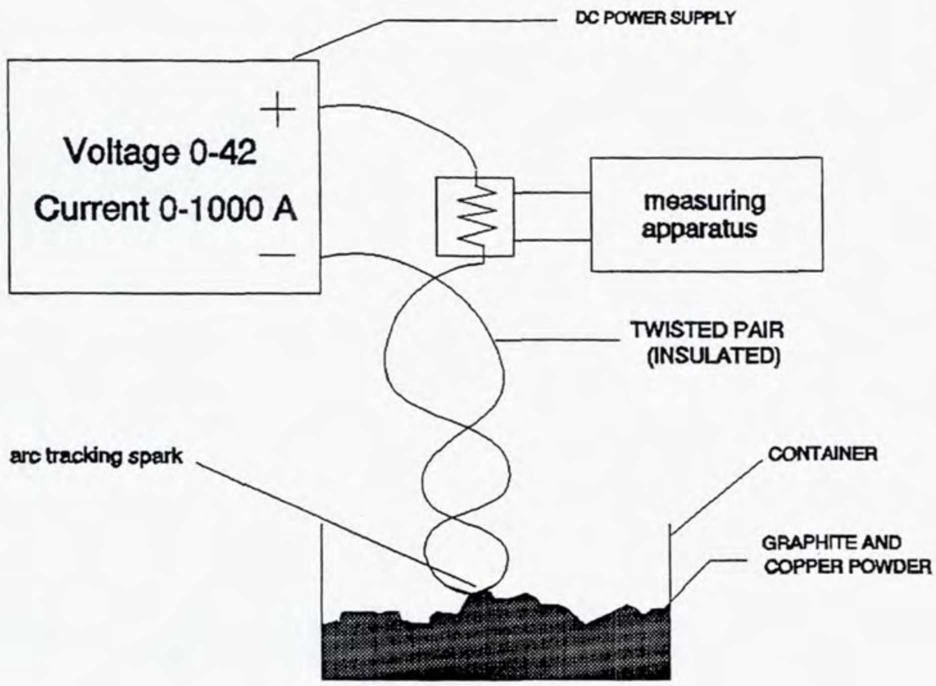
CABLES
- GAGES 20, 22, 24 (WITH KAPTON INSULATION)
- TKV (WITH KAPTON AND TEFLON INSULATION)

DC POWER SUPPLY
- CAPABLE OF SUPPLYING UP TO 1000 A
- DC VOLTAGE OF THE SUPPLY - 10 V, 30 V AND 42 V

RECORD TIME - 2 SECONDS

SAMPLING RATE - 2000 Hz

DATA ACQUISITION SYSTEM




The lockheed experimental setup

## SIGNAL PROCESSING

WELCH METHOD FOR COMPUTATION OF POWER SPECTRAL DENSITY

- 2 - SECOND DATA DIVIDED INTO 4 SECTIONS
- HAMMING WINDOW
- FFT PERFORMED AND ACCUMULATED

MATLAB

- WELCH METHOD WAS IMPLEMENTED USING MATLAB
- ALL OTHER COMPUTATIONS ALSO DONE USING MATLAB

PARAMETERS OBTAINED FROM DATA

- STANDARD DEVIATION OF TIME DOMAIN DATA
- PEAK VALUE OF POWER SPECTRAL DENSITY
- MEAN VALUE OF POWER SPECTRAL DENSITY
- STANDARD DEVIATION OF POWER SPECTRAL DENSITY
- MEAN FREQUENCY CONTENT
- PERCENTAGE OF TIME ARC TRACKING OCCURRED
- PERCENTAGE OF TIME FOR CURRENT BUILD-UP

$$f_m = \frac{\sum_{i=1}^{N} P_i f_i}{\sum_{i=1}^{N} P_i}$$

where:

$P_i$ is the power spectral density at frequency $f_i$

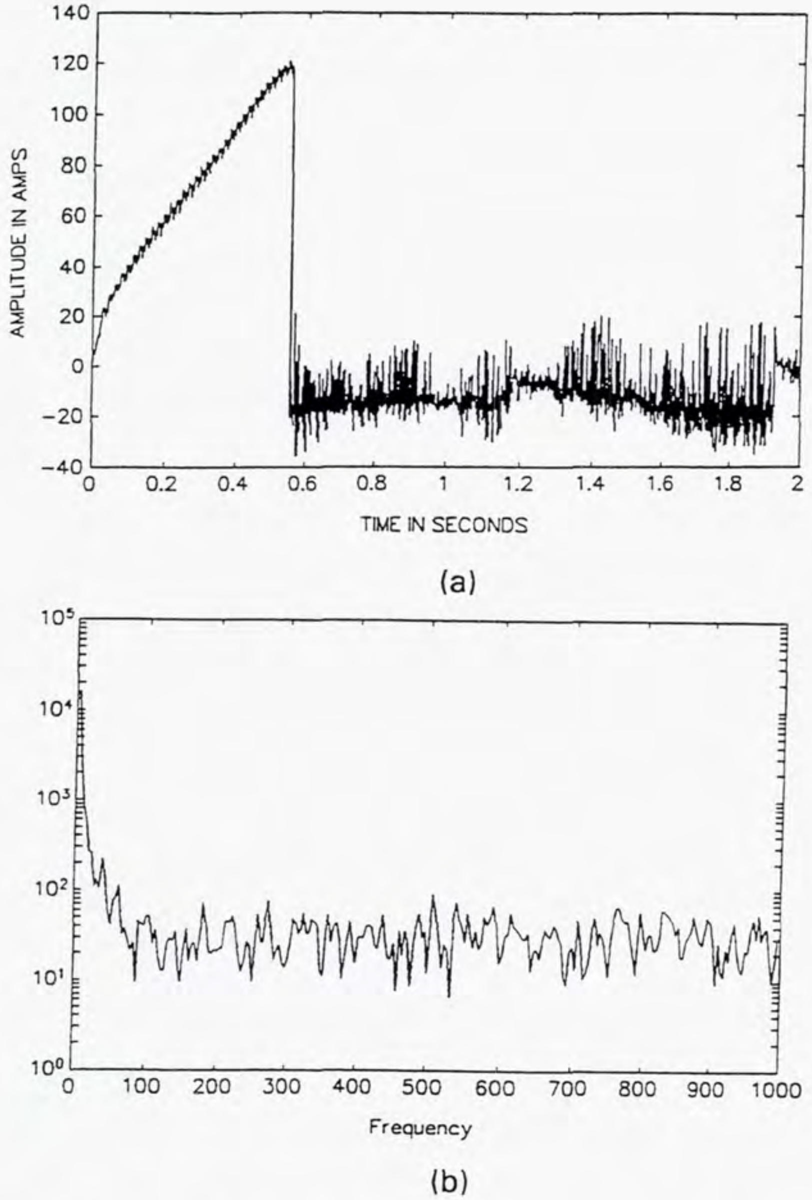
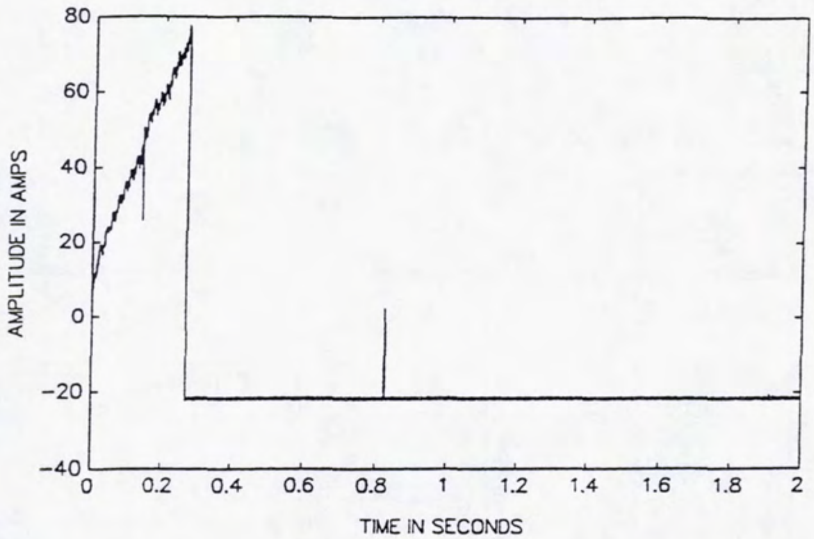
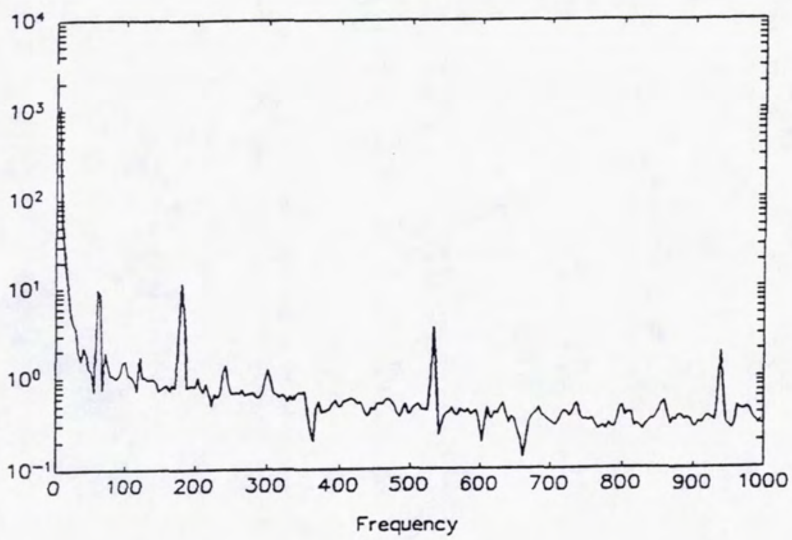



Figure 1 (a) Arc Tracking Signal in the time domain and (b) its power spectral density




(a)




(b)

Figure 2 (a) Non-Arc Tracking Signal in the time domain and (b) its power spectral density

Table 1

Categorization of data into arc tracking and no arc tracking.

| CABLE AND VOLTAGE | DATA | REMARKS |
|---|---|---|
| G24V20E3 | A1 | STRONG ARC TRACKING |
| G24V20E4 | A2 | " |
| G22V20E2 | A3 | " |
| G22V20E1 | A4 | " |
| G22V30E3 | A5 | " |
| G20V30E2 | A6 | " |
| G22V30E1 | A7 | " |
| G20V42E4 | A8 | " |
| G20V42E3 | A9 | " |
| G22V30E4 | A10 | " |
| G20V30E5 | A11 | " |
| G20V42E5 | A12 | " |
| G20V42E2 | A13 | " |
| G22V42E3 | A14 | |
| G22V10E3 | B1 | " |
| G22V42E5 | B2 | " |
| G22V42E2 | B3 | " |
| G20V30E1 | B4 | " |
| G20V42E1 | B5 | " |
| G22V42E4 | B6 | " |
| G22V30E2 | C1 | NO ARC TRACKING |
| G22V30E5 | C2 | " |
| TKV42E1 | C3 | " |

TABLE 2

Parameters Obtained from Arc Tracking Data

SD - standard deviation of time domain arc tracking data
MP - peak value of power spectral density
MVP - mean value of power spectral density
SDP - standard deviation of power spectral density
MFRQ - Mean frequency content

| DATA | SD | MP $X10^4$ | MVP | SDP $X10^3$ | MFREQ |
|---|---|---|---|---|---|
| A1 | 31.9 | 1.6 | 238 | 1.51 | 102.12 |
| A2 | 30.5 | 1.47 | 272 | 1.5 | 106.77 |
| A3 | 41.7 | 1.59 | 176.2 | 1.4 | 96.6 |
| A4 | 41.7 | 1.59 | 176 | 1.4 | 324.8 |
| A5 | 15.23 | 1.7 | 231 | .23 | 86.6 |
| A6 | 38.8 | 2.7 | 476 | 2.7 | 136.9 |
| A7 | 11.47 | .27 | 141 | 0.358 | 31.28 |
| A8 | 25.67 | 1.90 | 599 | 2.25 | 45.59 |
| A9 | 32 | 1.9 | 1326 | 2.9 | 45.39 |
| A10 | 1.45 | 20.21 | 4.9 | .0052 | 236 |
| A11 | 10.3 | 7.47 | 1292.5 | 8.04 | 35 |
| A12 | 25.5 | 1.99 | 484 | 1.7 | 315 |
| A13 | 60.3 | 3.2 | 319 | 2.9 | 36.28 |
| A14 | 14 | 0.31 | 153 | .375 | 23.26 |
| B1 | 43.4 | 0.472 | 42.2 | .417 | 14.4 |
| B2 | 17.5 | 0.48 | 217 | .665 | 90.6 |
| B3 | 6.7 | 0.15 | 56.8 | .0159 | 30.6 |
| B4 | 10.6 | 0.12 | 35.8 | .134 | 29.46 |
| B5 | 9.5 | 0.71 | 229 | .85 | 136.9 |
| B6 | 7.6 | 505 | 37.5 | .085 | 83.4 |
| C1 | 45.4 | 0.16 | 14.2 | .15 | 36.28 |
| C2 | 23.7 | 0.116 | 10.19 | .002 | 70.8 |
| C3 | 5.5 | .423 | 28.8 | .078 | 115.7 |

TABLE 3

Other Parameters of Arc Tracking Data

TARC - Percentage of Time Arc Tracking occurred
BUPT - Percentage of Time for the Current to Build-Up

| DATA | TARC | BUPT |
|---|---|---|
| A1 | 67.5 | 32.5 |
| A2 | 75 | 25 |
| A3 | 72.5 | 27.5 |
| A4 | 71 | 29 |
| A5 | 69 | 0 |
| A6 | 77 | 78 |
| A7 | 100 | 0 |
| A8 | 90 | 0 |
| A9 | 100 | 0 |
| A10 | 27.5 | 0 |
| A11 | 19 | 48 |
| A12 | 92.5 | 0 |
| A13 | 76 | 24 |
| A14 | 22.5 | 0 |
| B1 | 10 | 75 |
| B2 | 40 | 0 |
| B3 | 16 | 0 |
| B4 | 60 | 0 |
| B5 | 35 | 0 |
| B6 | 7 | 0 |
| C1 | 0 | 25 |
| C2 | 0 | 14 |
| C3 | 0 | 0 |

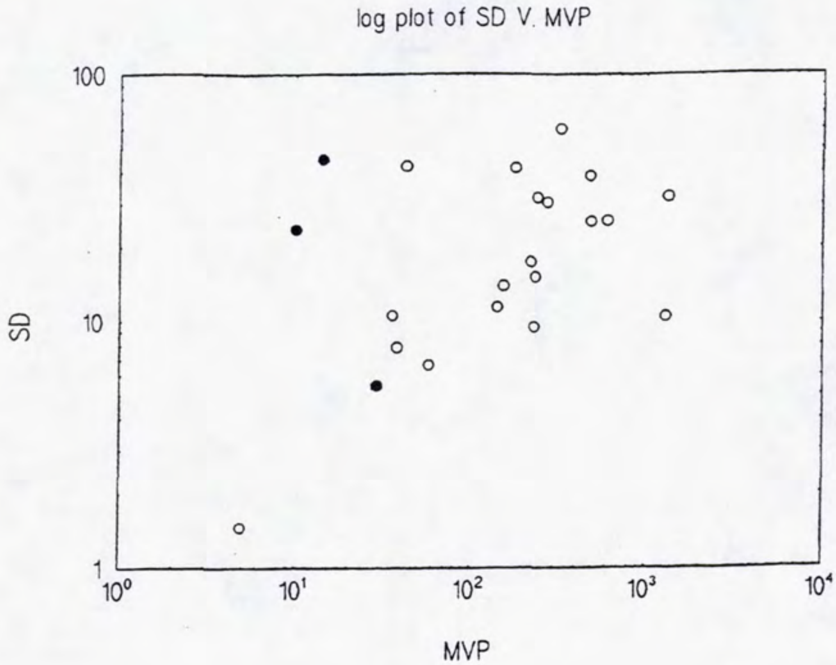



Figure 3 Standard deviation (SD) versus mean value of power spectral density (MVP)
o - *arc tracking* data
● - non-arc tracking data

**CONCLUSIONS AND FUTURE WORK**

USEFUL PARAMETERS FOR DETECTING ARC TRACKING

MEAN VALUE OF POWER SPECTRAL DENSITY
STANDARD DEVIATION OF TIME DOMAIN DATA
PERCENTAGE OF TIME ARC TRACKING OCCURRED

FEATURES OF ARC TRACKING SIGNAL

MEAN VALUE OF POWER SPECTRAL DENSITY IS GREATER THAN 30

OR

MEAN VALUE OF POWER SPECTRAL DENSITY IS LESS THAN 5
AND STANDARD DEVIATION OF TIME DOMAIN DATA IS LESS THAN 2

DESIGN OF "SMART" CIRCUIT FOR PROTECTION OF EQUIPMENT AGAINST ARC TRACKING

FAST FLOATING POINT DIGITAL SIGNAL PROCESSOR
INCORPORATE THE FEATURES OBTAINED IN THIS WORK

ACCELERATED AGING TEST RESULTS FOR AEROSPACE WIRE INSULATION CONSTRUCTIONS



William G. Dunbar
Consultant
Bellevue, Washington



## ABSTRACT

Several wire insulation constructions were evaluated with and without continuous glow discharges at low pressure and high temperature to determine the aging characteristics of acceptable wire insulation constructions. It was known at the beginning of the test program that insulation aging takes several years when operated at normal ambient temperature and pressure of 20°C and 760 torr. Likewise, it was known that the accelerated aging process decreases insulation life by approximately 50% for each 10°C temperature rise. Therefore, the first phases of the program, not reported in these test results, were to select wire insulation constructions that could operate at high temperature and low pressure for over 10,000 hours with negligible shrinkage and little materials deterioration. The final phase of the program was to determine accelerated aging characteristics.

When an insulation construction is subjected to partial discharges the insulation is locally heated by the bombardment of the discharges, the insulation is also subjected to ozone and other deteriorating gas particles that may significantly increase the aging process. Several insulation systems using either a single material or combinations of teflon, kapton, and glass insulation constructions were tested. All constructions were rated to be partial discharge and/or corona-free at 240 volts, 400 Hz and 260°C (500°F) for 50,000 hours at altitudes equivalent to the Paschen law minimum partial discharge aging tests were preceded by screening tests lasting 20 hours at 260°C. The aging process was accelerated by subjecting the test articles to temperatures up to 370°C (700°F) with and without partial discharges. After one month operation with continuous glow discharges surrounding the test articles, most insulation systems were either destroyed or became brittle, cracked, and unsafe for use. Time with space radiation as with partial discharges is accumulative.

## INSULATED CONDUCTOR LIFE

Conductor life will last decades of years when operated at normal ambient temperature ±20°C. When operated with partial discharges the insulation is heated by the discharges, the insulation oxidized and life shortened to 10 to 500 hours depending upon the partial discharge intensity and applied voltage. Several tests were performed at Boeing using aircraft teflon insulated conductors at 23±10°C, 400 Hz, and 240±5 Vrms. After one month the insulation was brittle, cracked, and unsafe for further use. Time with partial discharges is accumulative. The time may be continuous as in an experiment or in short bursts over several years.

# AEROSPACE WIRE INSULATION CONSTRUCTIONS SELECTED FOR TEST

## TEST ARTICLES

8---Manufacturers Supplied Test Articles
25--Wire Insulation Constructions
12--Test Articles Per Wire Construction Were Evaluated

## INITIAL SCREEN TESTS

Visual Inspection
Dielectric Strength
Insulation Resistance
Fluid Resistance
Wrap
Shrinkage after 20 hours at 260C
Abrasion Resistance
Weight loss after 20 hours at 260C

All test articles passed the initial screening test

# ACCELERATED AGING TESTS AND RESULTS

TEMPERATURE ALTITUDE TEST PARAMETERS

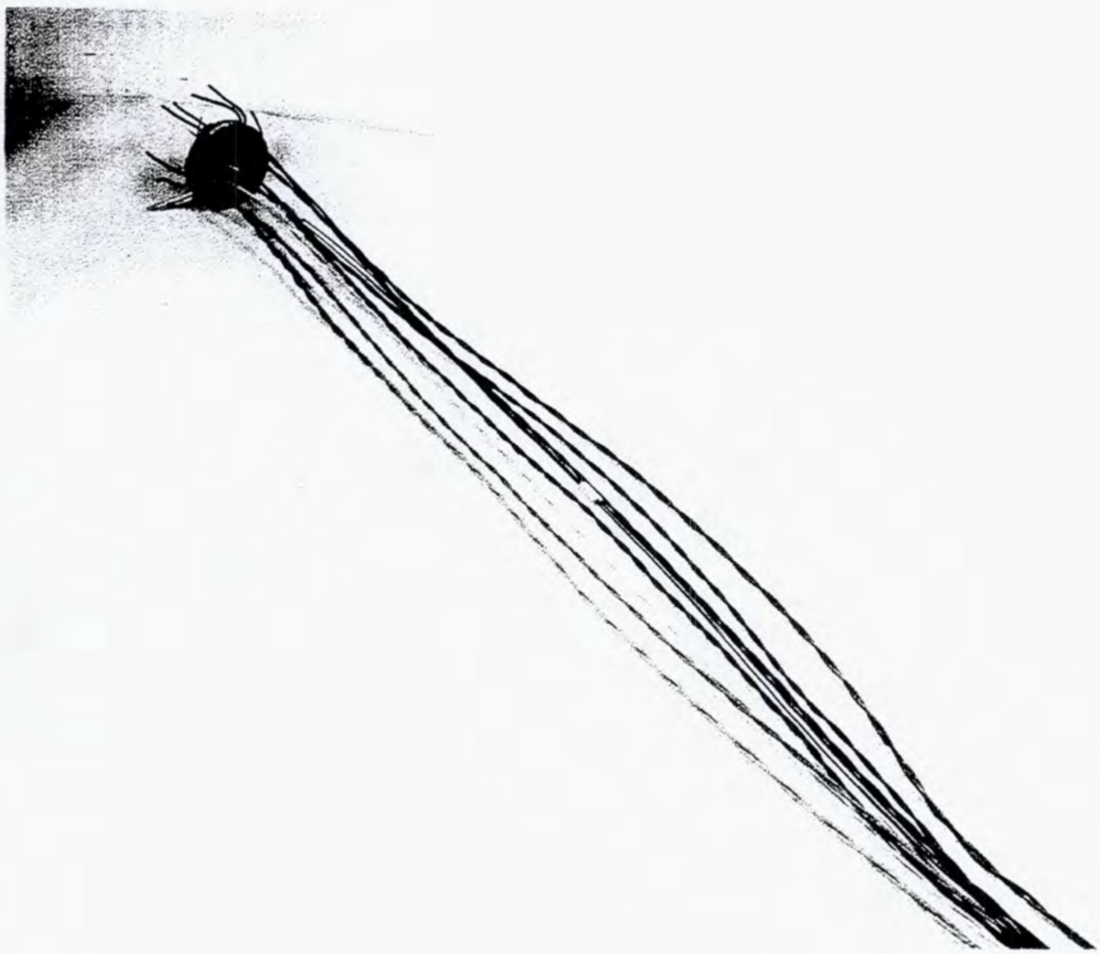
| TEMPERATURE C | TIME Hours |
|---|---|
| 371 | 336 |
| 357 | 504 |
| 343 | 1,440 |
| 321 | 3,888 |
| 312 | 8,760 |
| 304 | 13,200 |

| | |
|---|---|
| Total test time | 28,128 hours |
| Time at maximum temperatures | 15,000 hours |
| Time at 21 torr | 15,000 hours |
| Time at 760 torr and 30C | 11,250 hours |
| Transition time (temperature, pressure) | 1,878 hour |

Thermal Aging Test Results

20 Wire Insulation Constructions Failed
5 Wire Insulation Constructions Passed *

* Most wire constructions had some shrinkage, minimal weight loss, and on some, the teflon oozed through glass braids.



# AGING TEST RESULTS

## Partial Discharges

The lower the insulation system dielectric constant the higher the partial discharge initiation voltage for equal thickness insulation systems tested with ac

Increasing the insulation system increases the initiation voltage somewhat.

Outgassing insulation systems tends to generate EMI that must be considered when taking initiation voltage measurements.

## Aging

Teflon insulation tended to roughen(polymerize) and crack with continued aging with and without glow discharges.

The binders for wraped Kapton insulation systems tended to outgas and evaporate allowing the kapton to unwind. With glow discharges the Kapton darkened and the insulation resistivity dropped significantly.

Kapton-Teflon insulation systems had many punctures between the Kapton wraps.

Glass braid over Teflon had color leaching and some of the teflon tended to ooze through the glass braid. All samples survived the 2,000 hours testing with and without glow discharges-but some samples appeared visually poor.

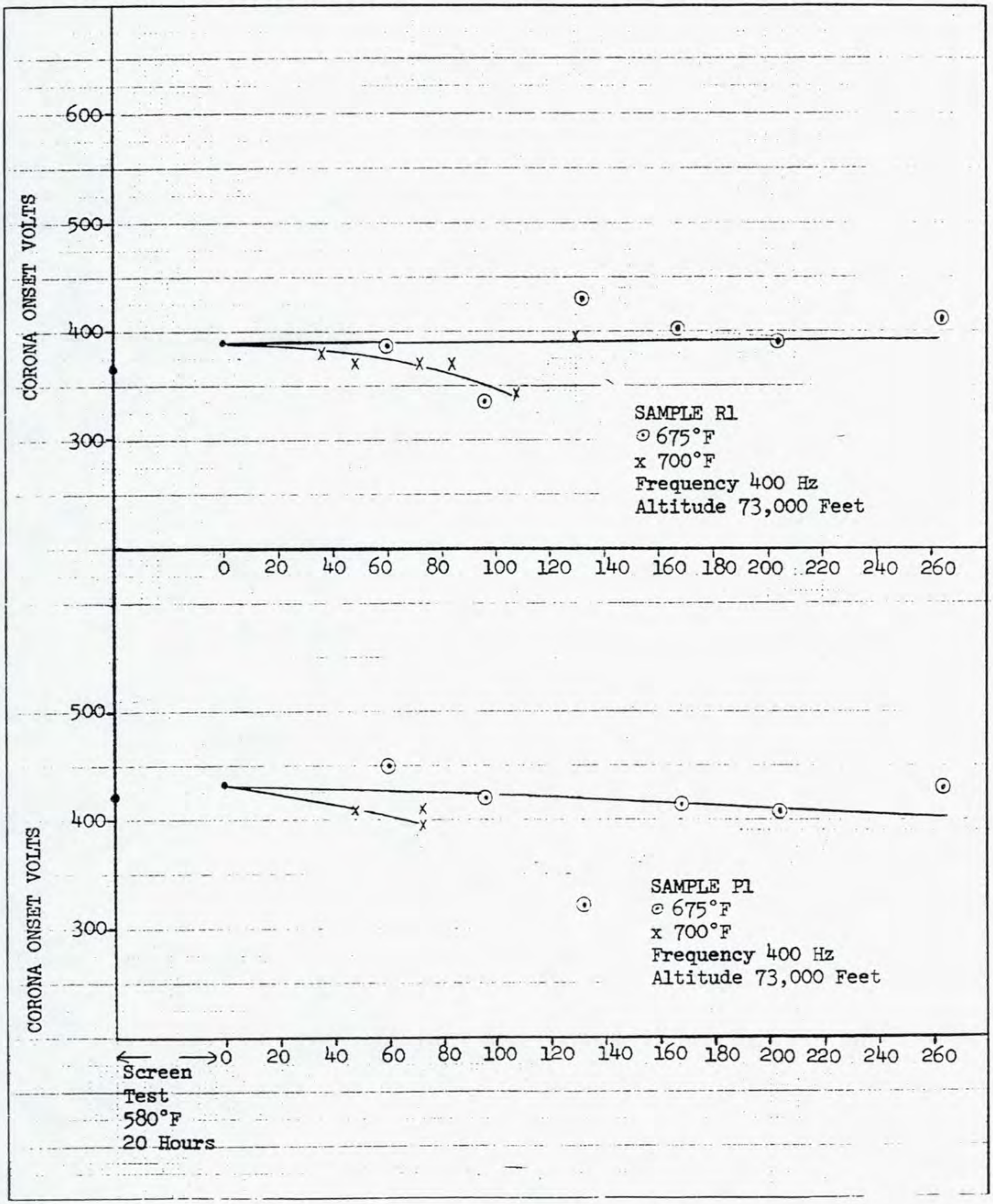



FIGURE 6.5-36 COV AS A FUNCTION OF THERMAL AGING

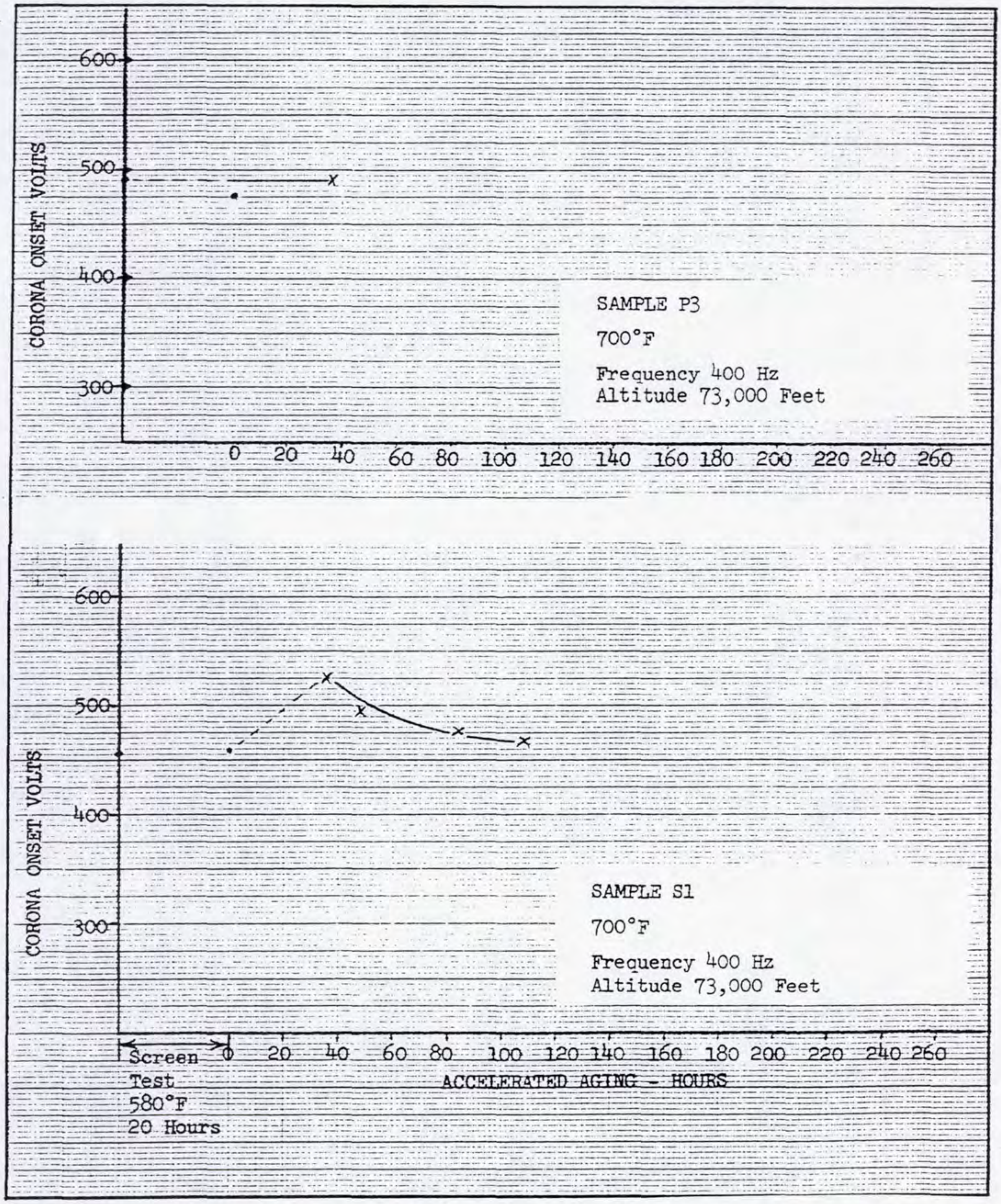



FIGURE 6.5- COV AS A FUNCTIONING OF THERMAL AGING

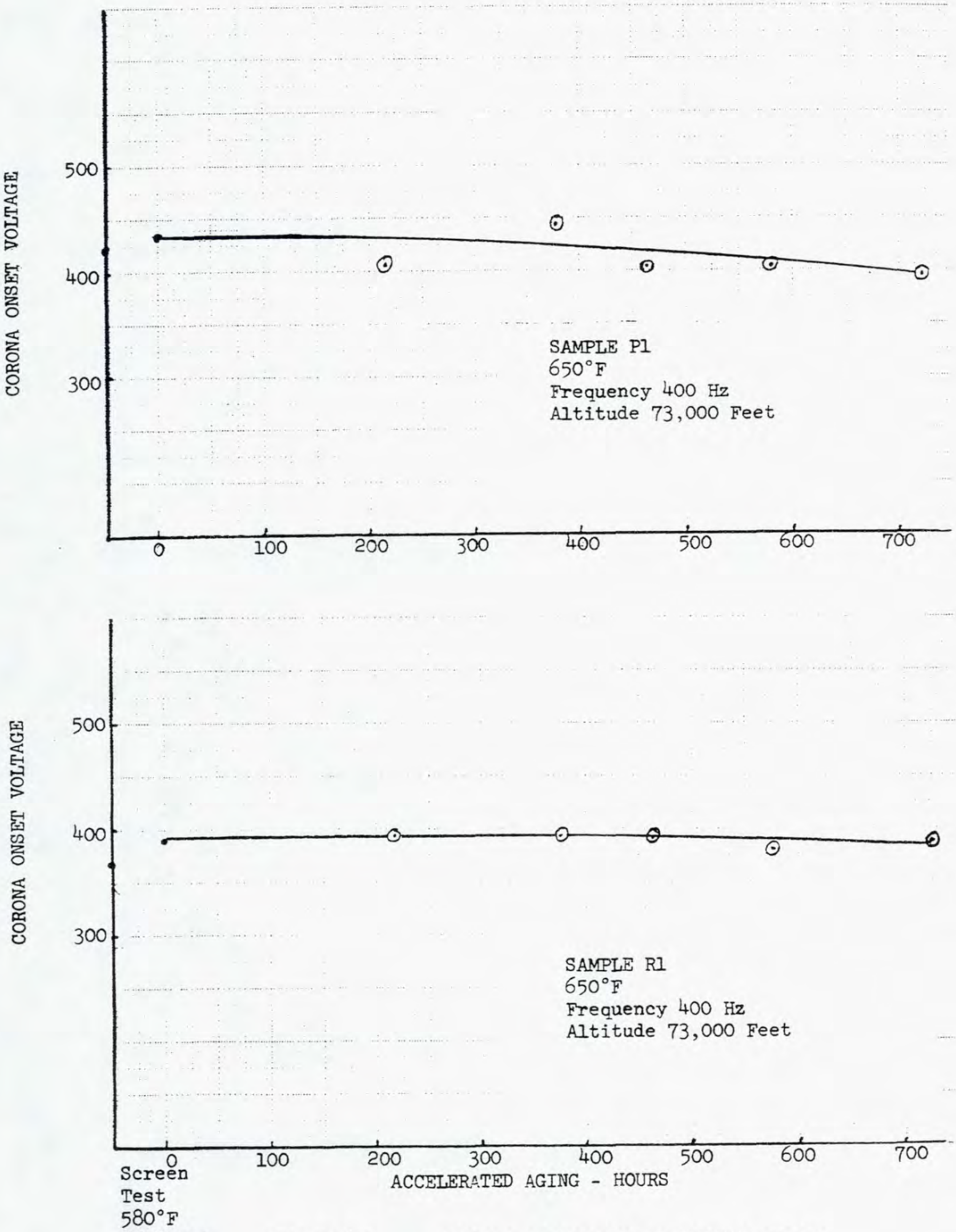



FIGURE 6.5 COV AS A FUNCTION OF THERMAL AGING

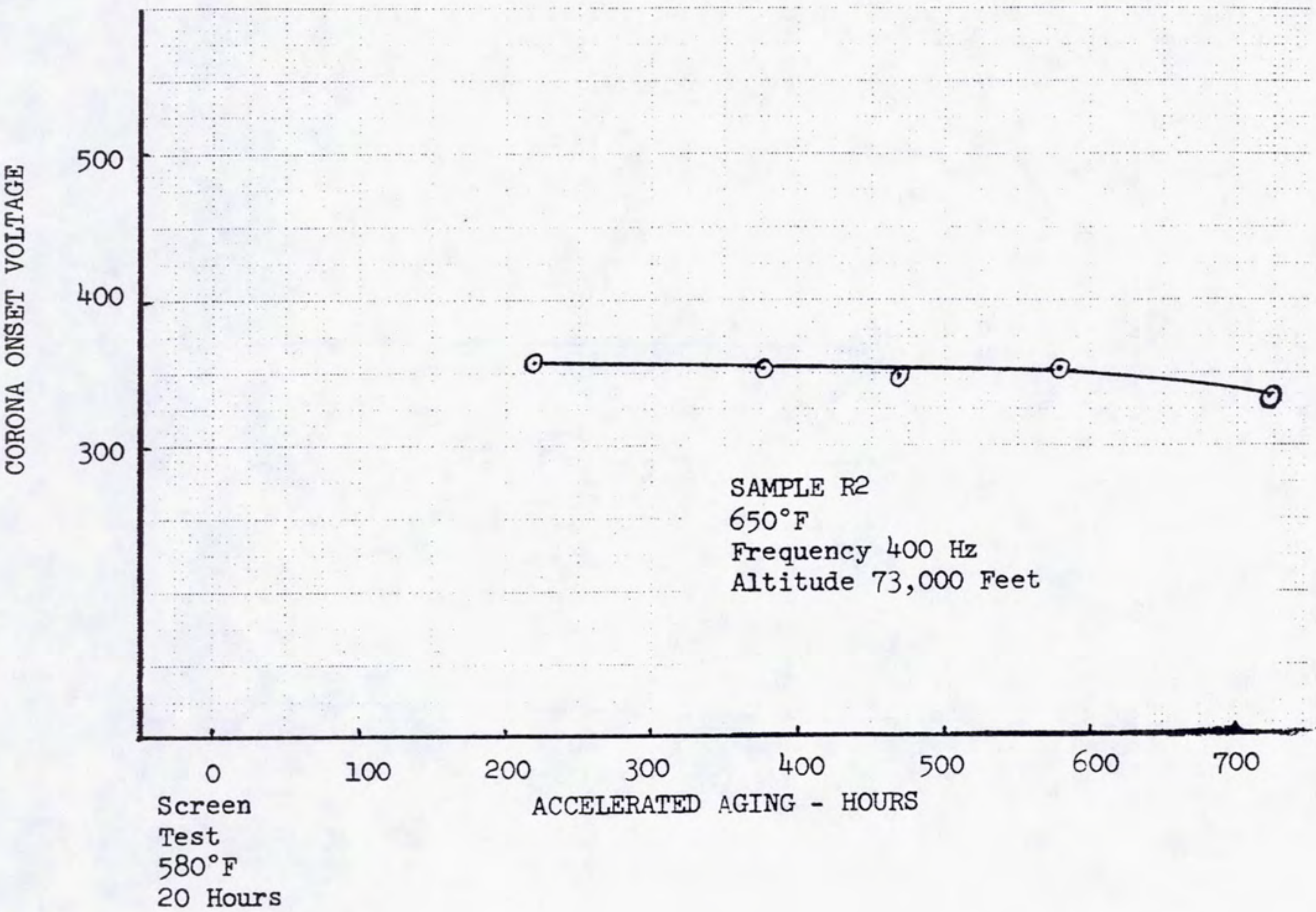



FIGURE 6.5 COV AS A FUNCTION OF THERMAL AGING

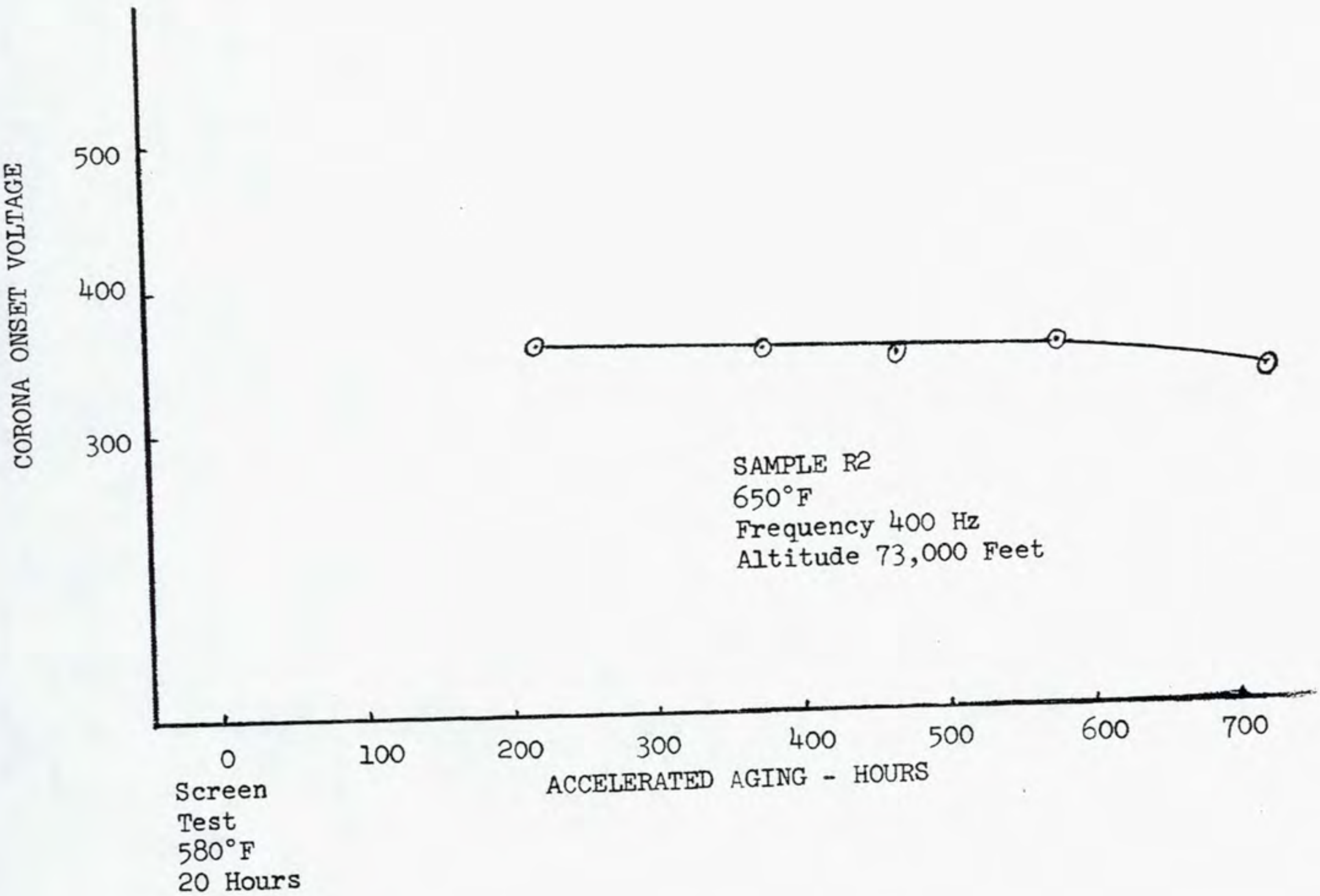
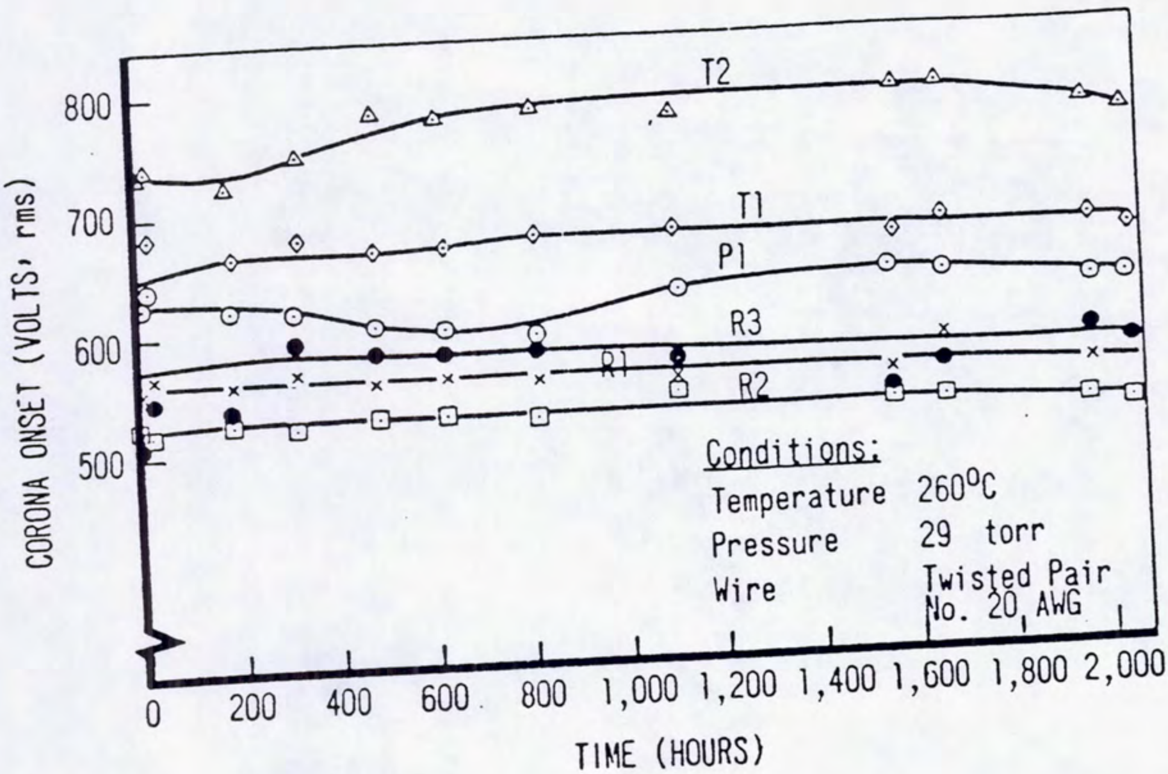


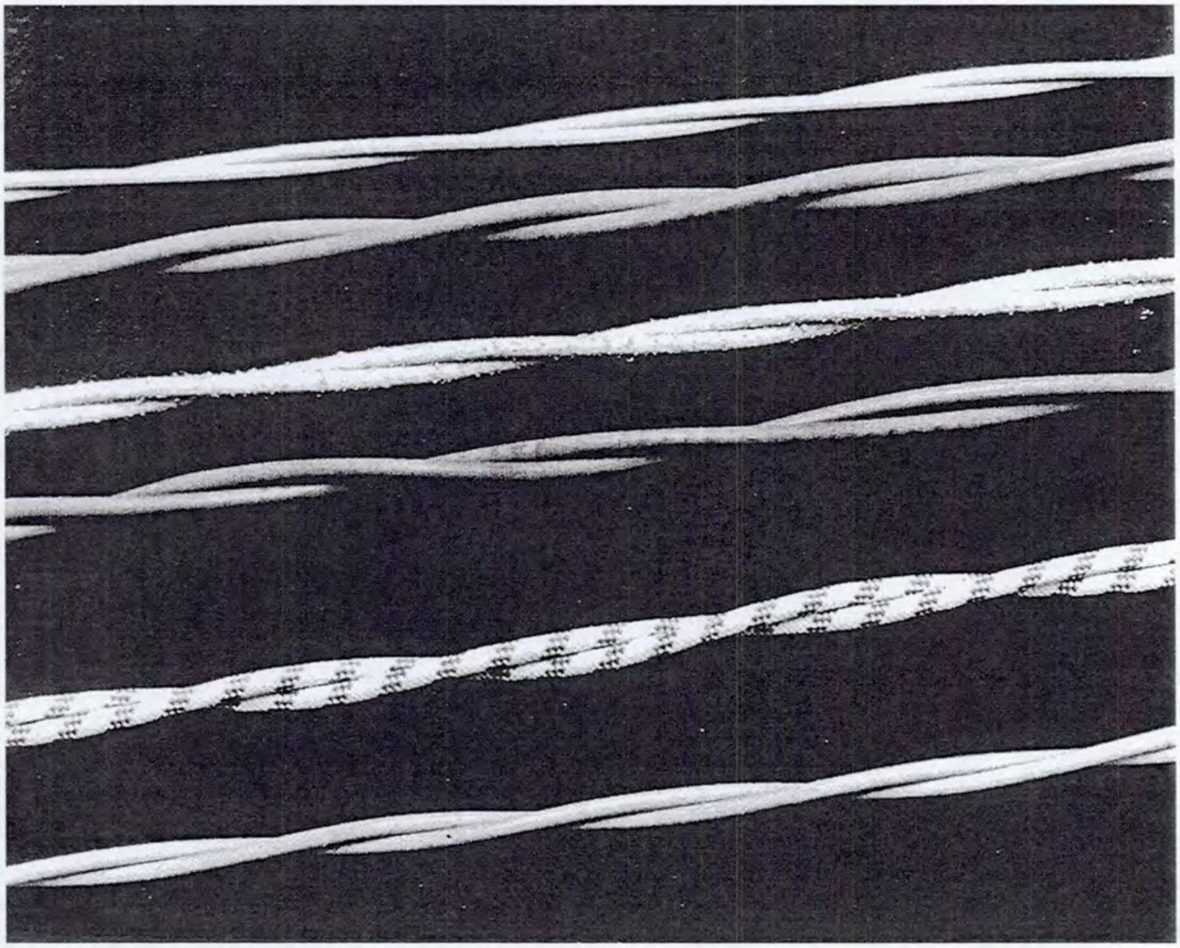

FIGURE 6.5 COV AS A FUNCTION OF THERMAL AGING

THE EFFECT OF TIME AND TEMPERATURE ON COV




Wire Specimen Materials

| Specimen Number | Material Thickness, CM | Dielectric Materials |
|---|---|---|
| P1 | 0.047 | Glass covered teflon |
| R1 | 0.048 | Glass covered teflon |
| R2 | 0.036 | Polyimide covered teflon |
| R3 | 0.036 | Polyimide covered teflon |
| T1 | 0.056 | Teflon |
| T2 | 0.065 | Teflon |



# HIGH TEMPERATURE CORONA
AND
# ACCELERATED AGING TESTS

## CORONA AND PARTIAL DISCHARGE TESTS

High temperature partial discharge and corona tests were obtained by inserting the wire samples inside an oven constructed of lightweight firebrick. The oven was placed inside a vacuum chamber to attain depressurization. The pressure was kept between 0.1 and 2 torr.

The parallel twisted insulated wires were centered within a 4.0 inch diameter thin-wall stainless steel tube for equal temperature distribution for the full length of of the wire pair. The stainless steel tube was grounded to eliminate EMI conducted or radiated to the tube by the heater and heater electronic control elements.

The test wires were held in place with porcelain insulators--one fixed and the other spring loaded to provide tension to the test wires. All metal edges were rounded and taped to prevent discharges from forming in areas not under test

The temperature along the surface of the test articles was measured to be within +or-10C along the test article surface for a length of 30 inches.

## ACCELERATED AGING TESTS

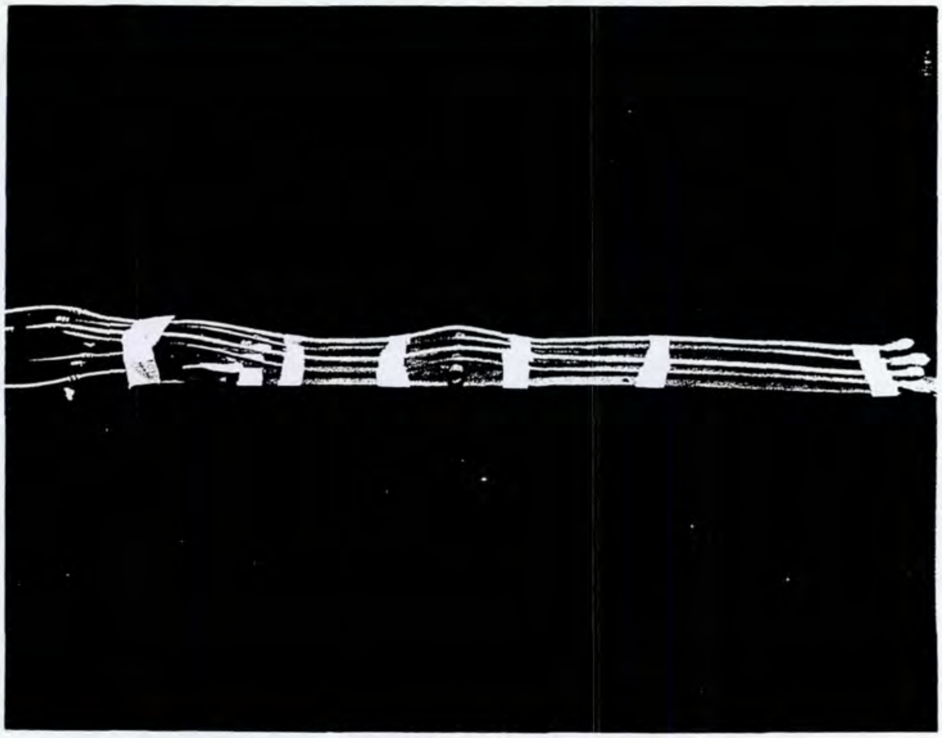
Accelerated aging tests were with and without a continuous glow discharge surrounding the test articles. The glow discharge was selected to simulate overvoltage conditions that may exist in a malfunctioning power system.

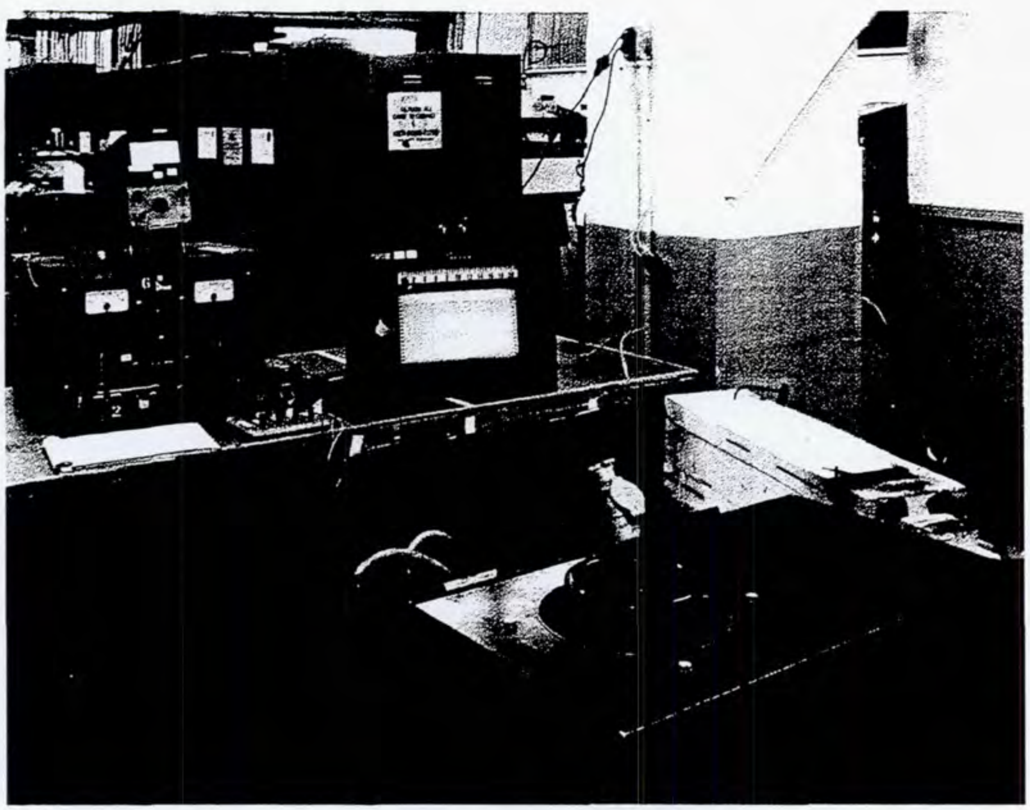
### Temperature Aging

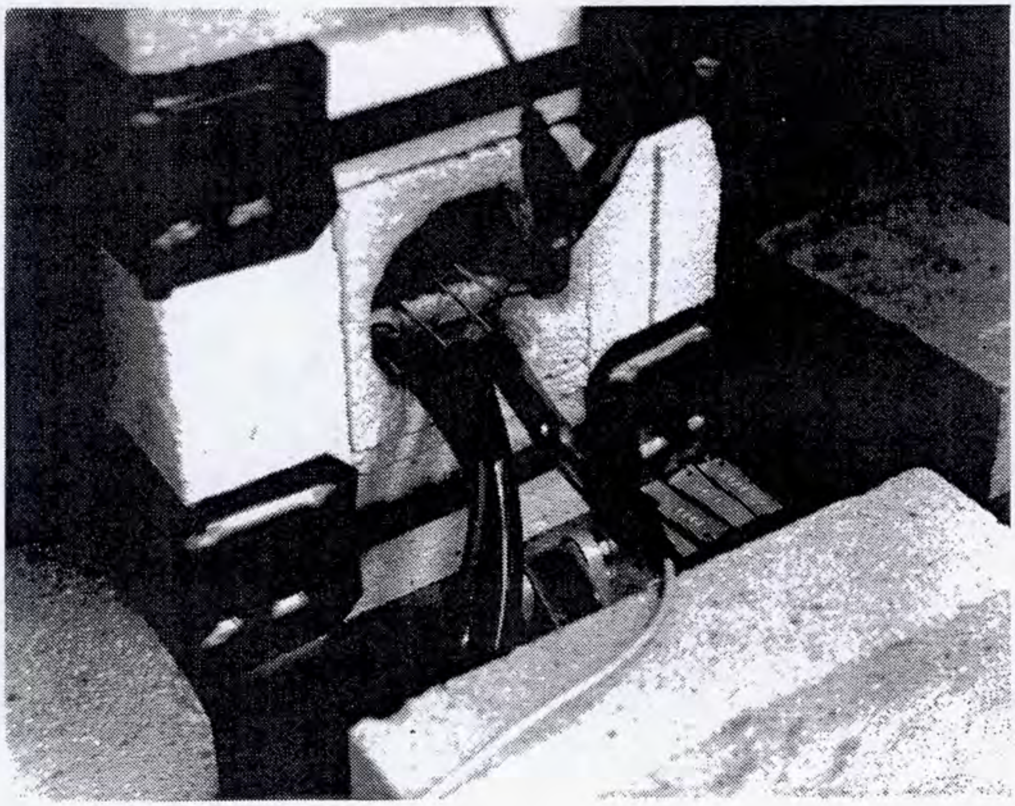
One group of seven insulated wire samples were attached to a metal ground plane to obtain wire to ground life information. Another group of seven twisted wire samples were tested to obtain twisted insulated wire aging information. The same oven and vacuum facility was used for both groups to obtain equal test information. The long term tests were tested at a constant 230+5C.

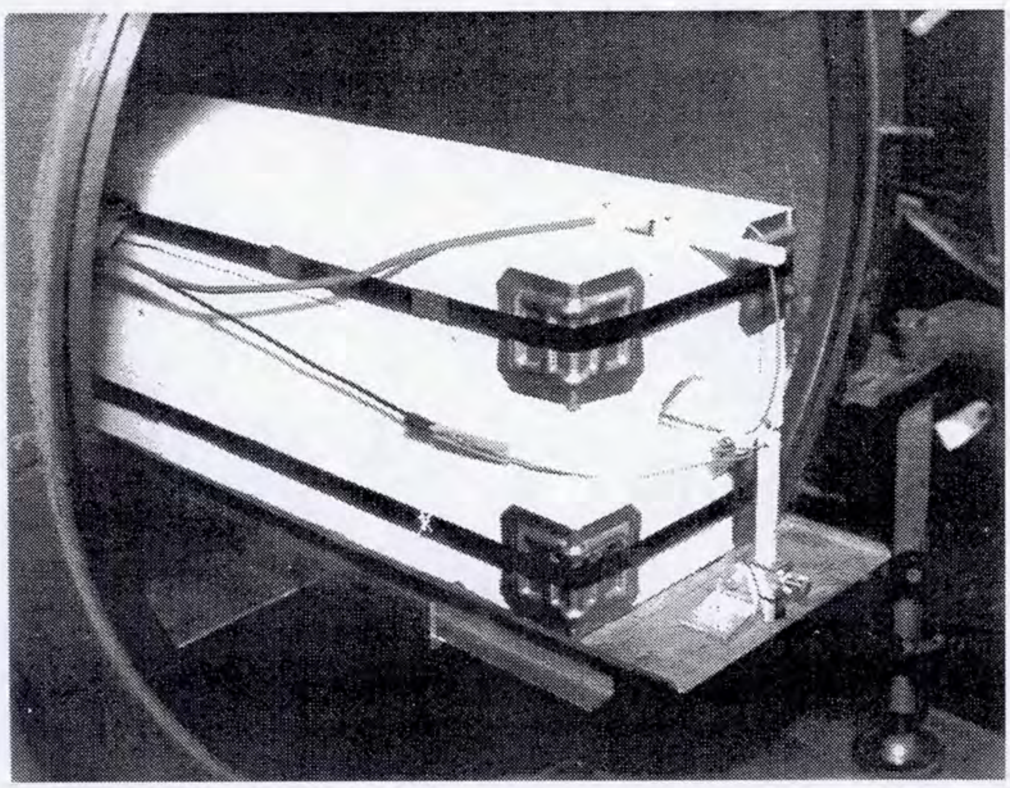
### Glow Discharge Aging

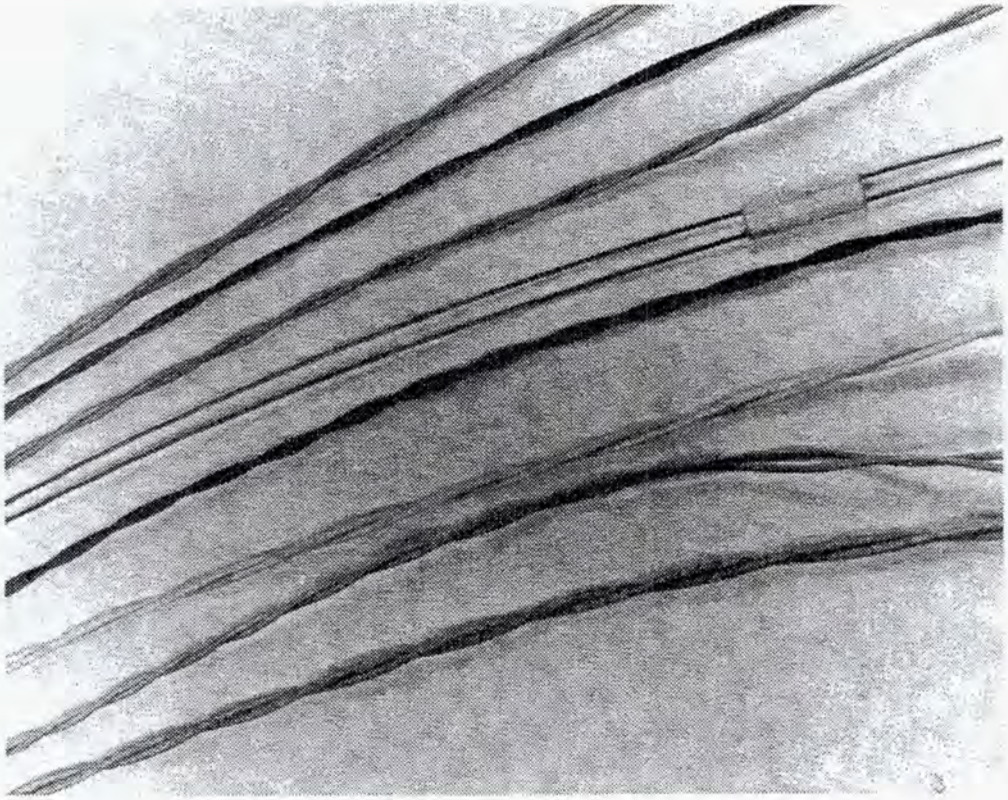
Same as temperature aging but with a continuous glow discharge added.











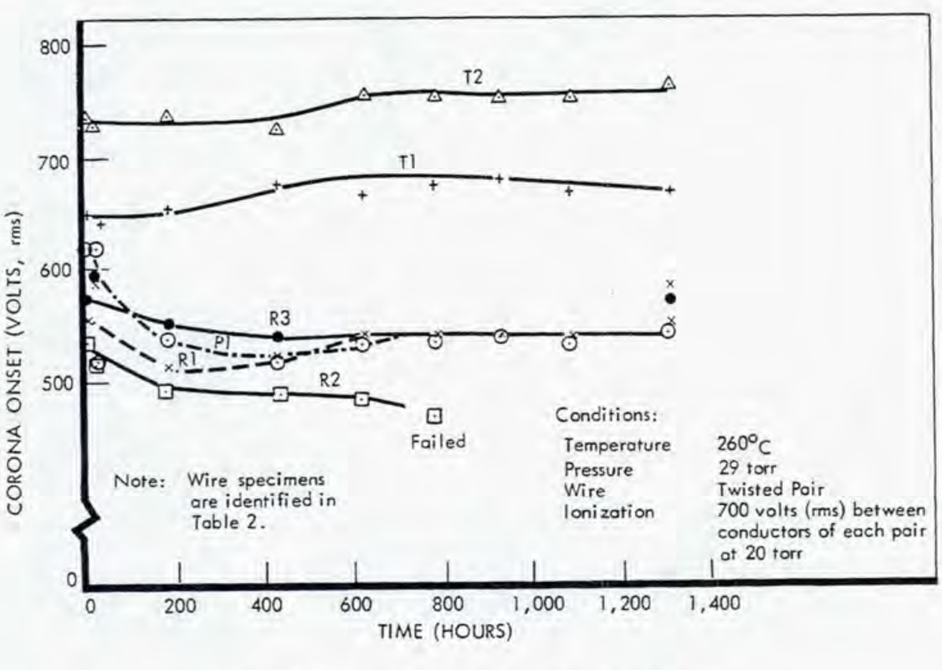
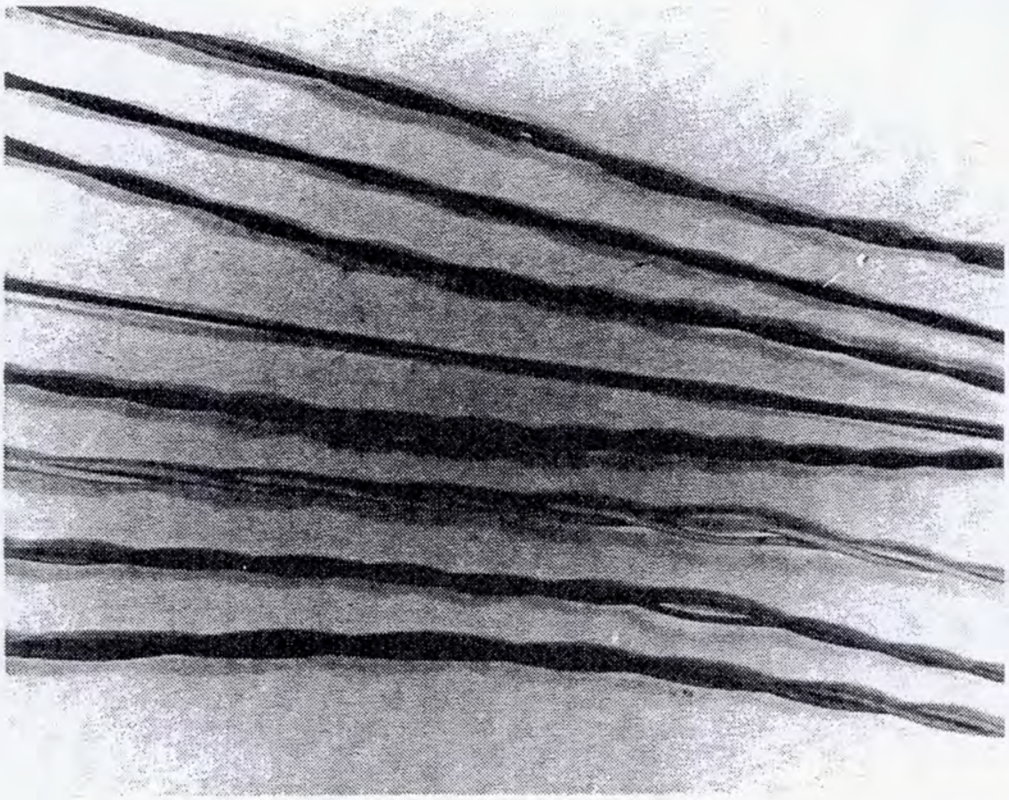



Figure 5: COV AS A FUNCTION OF TIME



# USAF/WL ROBUST 300 °C WIRE INSULATION SYSTEM PROGRAM STATUS

Wing Wong
TRW Space and Electronics
Redondo Beach, California



## ROBUST 300˚C WIRE INSULATION SYSTEM

### PROGRAMMATICAL INFORMATION

- WRIGHT LABORATORY PROGRAM MANAGER: JOHN NAIRUS (WL/POOC-1)
- TRW PROGRAM MANAGER: WING WONG* (SPACE & ELECTRONICS GROUP)
- KEY NON-TRW PROGRAM PARTICIPANTS

| COMPANY | ROLE |
| --- | --- |
| LAWRENCE TECHNOLOGY AND TELEDYNE THERMATICS | FILM ELECTRICAL PROPERTY TESTING<br>WIRE TESTING<br>WIRE QUALITY TESTING |
| MCDONNELL AEROSPACE - ST. LOUIS | DETAILED WIRE TESTING |
| POLY-MATERIALS | POLYIMIDE POLYMER PREPARATION |
| REXHAM | CONTINUOUS FILM PREPARATION |

*PREVIOUSLY MANAGED BY ROBERT J. JONES

## ROBUST 300°C WIRE INSULATION SYSTEM

### OBJECTIVE

THE OBJECTIVE OF THIS PROGRAM IS TO IDENTIFY, DEVELOP, AND DEMONSTRATE AN OPTIMUM WIRE INSULATION SYSTEM CAPABLE OF CONTINUOUS OPERATION AT 300°C WHICH POSSESSES A COMBINATION OF SUPERIOR ELECTRICAL (AC OR DC), MECHANICAL, AND PHYSICAL PROPERTIES OVER KAPTON® DERIVED INSULATIONS DESCRIBED IN MIL-W-81381 AND THOSE HYBRID MATERIALS COMMONLY KNOWN AS TKT CONSTRUCTIONS.

## ROBUST 300°C WIRE INSULATION SYSTEM

TASK 1 - FILM/ADHESIVE CANDIDATE SCREENING

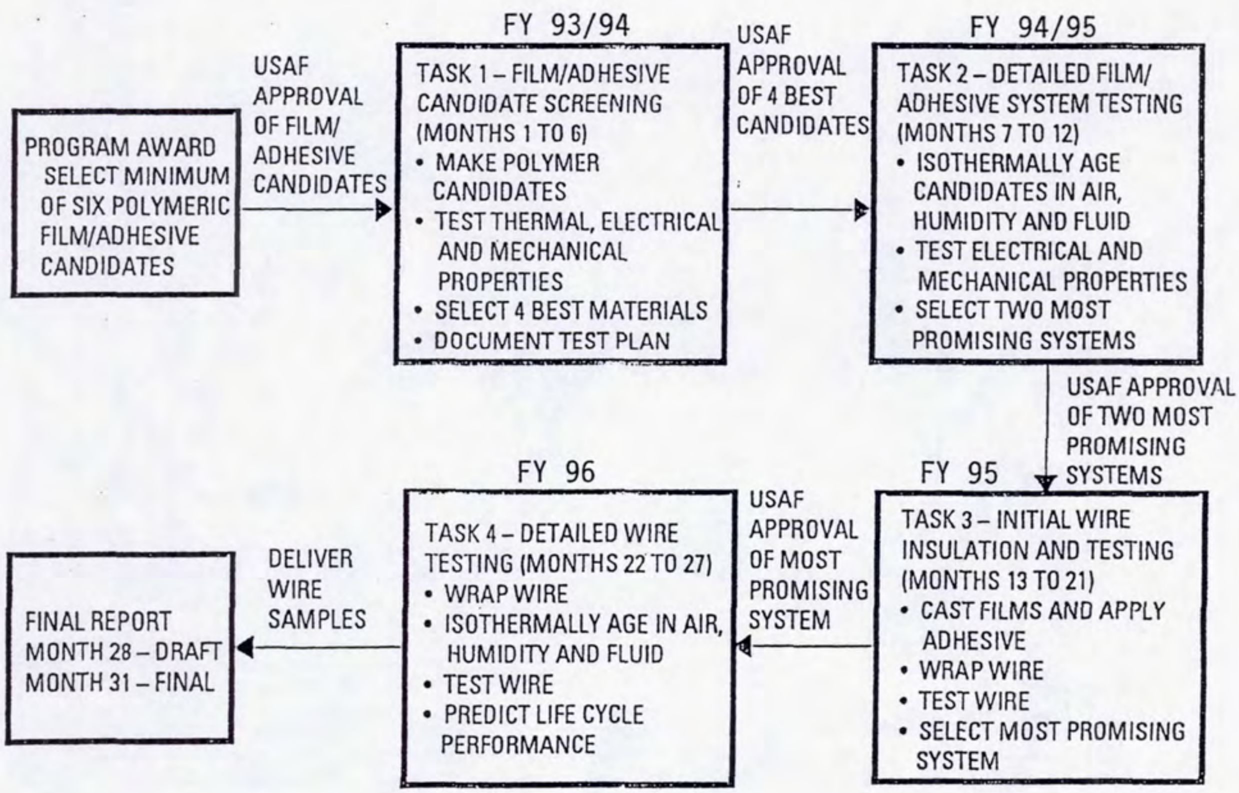
- SHALL BALANCE VARYING AMOUNTS OF FLUORINE CHARACTER FOR CANDIDATE POLYMERS AGAINST EXPECTED (OR KNOWN) EFFECTS OF THERMAL-MECHANICAL AND ELECTRICAL PROPERTIES.
- SHALL MAKE AND TEST A MINIMUM OF SIX FILM AND ADHESIVE CANDIDATES TAILORED TO CONTRIBUTE THEIR BEST PROPERTIES TO A SUPERIOR 300°C WIRE INSULATION SYSTEM.

SUBTASKS

- FILM/ADHESIVE SAMPLE PROCUREMENT/PREPARATION
  - PFPI (4-BDAF/PMDA FORMULATION)
  - FPE 265
  - AFR700B
  - FM680-1
  - MODIFIED AFR700
- DATABASE PROPERTY DETERMINATION
  - DYNAMIC MECHANICAL ANALYSIS FOR GLASS TRANSITION TEMPERATURE
  - TENSILE STRENGTH
  - TENSILE LAP SHEAR STRENGTH FOR FILM/ADHESIVE SYSTEM
  - ELECTRICAL PROPERTIES (DIELECTRIC PROPERTIES, BREAKDOWN VOLTAGE AND DRY ARC TRACK

# ROBUST 300°C WIRE INSULATION SYSTEM

## PROGRAM LOGIC DIAGRAM



# ROBUST 300°C WIRE INSULATION SYSTEM

## TASK 1 - Results

| Material | | Kapton | FPE-265 | PFPI | AFR700B | FM680-1 | Mod. AFR |
|---|---|---|---|---|---|---|---|
| Tg (G' Knee) | | 340 C | 333 C | 350 C | 375 C | 368 C | 265 C |
| Tensile Strength (ksi) | | | | | | | |
| | RT | 28.6 | 11.5 | 11.5 | | | |
| | 250C | 17.3(60%) | 4.2 (37%) | 7.0 (61%) | | | |
| | 300C | 11.6(41%) | 2.8 (24%) | 2.9 (25%) | | | |
| Dielectric Constant | | | | | | | |
| RT | .4KHz | 3.46 | 3.07 | 2.08 | | | |
| | 1KHZ | 2.45 | 3.1 | 2.08 | | | |
| 300C | .4KHz | 2.89 | 2.82 | 1.91 | | | |
| | 1KHz | 2.88 | 2.82 | 1.91 | | | |
| Dissipation Factor | | | | | | | |
| RT | .4KHz | 0.0045 | 0.0057 | 0.0028 | | | |
| | 1KHZ | 0.0051 | 0.0115 | 0.0011 | | | |
| 300C | .4KHz | 0.0051 | 0.0017 | 0.001 | | | |
| | 1KHz | 0.0044 | 0.0017 | 0.0008 | | | |
| Breakdown (kV/mil) | | | | | | | |
| RT | AC | 7.3 | 6.3 | 6.3 | | | |
| RT | DC | 9.9 | 11.4 | 10.4 | | | |

| System | | PFPI/AFR | PFPI/Cytec 680 | | FPE/AFR | FPE/Cytec | |
|---|---|---|---|---|---|---|---|
| Lap Shear (ksi) | | | | | | | |
| | RT | 1.55 | 1.52 | | 0.92 | 1.78 | |
| | 300 C | 1.00(65%) | .58 (38%) | | .20 (22%) | .33 (19%) | |

( ) Percentage of Strength Retention Compared to RT

# ROBUST 300°C WIRE INSULATION SYSTEM

## Approved Task 2 Film/Adhesive System Candidates
## Contract F33615-93-C-2367, Robust 300°C Wire Insulation System

| Polymer/Adhesive System Candidate | Selection Rationale |
|---|---|
| PFPI[(1)]/AF-R-700B<br>FPE 265/AF-R-700B<br>PFPI/Cytec 680-1[(2)]<br>FPE 265/Cytec 680-1 | • Demonstrated excellent potential for service at 300°C with glass transition temperature (by DMA, G' Knee) in excess of 320°C<br>• Demonstrated acceptable bonding capability with tensile lap shear testing at RT and 300°C<br>• Eliminate modified AF-R-700 as adhesive due to low glass transition temperature (260°C), lack of lap shear strength at 300°C and marginal processability |

[(1)] 4 BDAF/PMDA formulation

[(2)] Extracted resin from Cytec 680-1 film adhesive

## ROBUST 300°C WIRE INSULATION SYSTEM

TASK 2 - DETAILED FILM/ADHESIVE SYSTEM TESTING

- EMPLOY THE FOUR PROMISING POLYMERIC FILM AND ADHESIVE CANDIDATES RECOMMENDED AT THE CONCLUSION OF TASK 1 UPON AIR FORCE APPROVAL.
- SUBJECT THE COMBINATIONS OF EACH TO THE BONDING, AGING, AND TESTING NECESSARY TO FULLY ASSESS THEIR POTENTIAL. A MINIMUM OF ONE PROMISING SYSTEM WILL BE SELECTED AND RECOMMENDED TO USAF FOR ASSESSMENT ON WIRE IN TASK 3.

SUBTASKS

- SAMPLE BONDING

  - BONDING PROCESS DEVELOPMENT BY TRIAL AND ERROR APPROACH

- SAMPLE AGING

  - AIR-AGING AT 300°C FOR 1000 HOURS
  - IMMERSION IN CLEANING SOLVENT DS-108 AT ROOM TEMPERATURE FOR 168 HOURS
  - EXPOSURE TO 90°C/95% RH CONDITION FOR 1000 HOURS

- SAMPLE TESTING

  - WEIGHT CHANGE
  - PHYSICAL CHANGE
  - ELECTRICAL PROPERTIES

### Task 2 Isothermal Aging Studies - Results

Test A. Effect of Air - Aging at 300°C on Four Most Promising Insulation Systems

| | Percent Weight Loss on Air Aging By Candidate Film/Adhesive System[a),b)] | | | |
|---|---|---|---|---|
| Aging Duration (Hours) | PFPI/AFR700B | PFPI/Cytec 680-1 | FPE/AFR700B | FPE/Cytec 680-1 |
| 24 | 1.3 | 1.2 | 1.8 | 5.6 |
| 48 | 1.2 | 1.3 | 2.2 | 6.7 |
| 120 | 1.6 | 1.6 | 3.9 | 10.0 |
| 264 | 2.3 | 2.1 | 8.6[c)] | 18.2[c)] |
| 528 | 3.7 | 2.9 | 21.6 | 50.0 |
| 768 | 5.0 | 3.6 | 27.0 | 65.6 |
| 1000 | 6.2 | 4.6 | 28.5 | 70.7 |

[a)] Test sample dimensions approximately 1.25-inch wide x 1.25-inch long x .005-inch thick consisting of selected adhesive (thickness ~ .002-inch) laminated between two polymeric films (each ~.0015-inch thick)
[b)] Average of 2 samples
[c)] Onset of severe sample darkening/curling

# ROBUST 300°C WIRE INSULATION SYSTEM

## Task 2 Isothermal Aging Studies - Results

Test B. Effect of Cleaning Solvent DS-108 Aging at 25° on Four Most Promising Insulation Systems

| | Percent Weight Gain on Aging By Candidate Film/Adhesive System[a),b)] | | | |
|---|---|---|---|---|
| Aging Duration (Hours) | PFPI/AFR700B | PFPI/Cytec 680-1 | FPE/AFR700B | FPE/Cytec 680-1 |
| 24 | 0.9 | 7.4 | 2.1 | 8.0 |
| 48 | 0.9 | 3.3 | 1.4 | 4.8 |
| 120 | 2.5 | 7.5 | 2.2` | 6.7 |
| 168 | 2.7 | 6.3 | 1.8 | 5.4 |

[a)]Test sample dimensions approximately 0.5-inch wide x 1.0-inch long x .005-inch thick consisting of selected adhesive (thickness ~ .002-inch) laminated between two polymeric films (each ~.0015-inch thick)
[b)]Average of 2 samples, except for FPE/Cytec 680-1

## Task 2 Isothermal Aging Studies - Results

Test C. Effect of Humidity - Aging at 90°C/95% RH on Four Most Promising Insulation Systems

| | Percent Weight Loss (-) or Weight Gain (+) on Aging By Candidate Film/Adhesive System[a),b)] | | | |
|---|---|---|---|---|
| Aging Duration (Hours) | PFPI/AFR700B | PFPI/Cytec 680-1 | FPE/AFR700B | FPE/Cytec 680-1 |
| 24 | -0.9 | -0.1 | +1.1 | -1.6 |
| 48 | -0.9 | -0.1 | +1.0 | -2.1 |
| 120 | -0.9 | -0.1 | +1.1 | -2.6 |
| 264 | -0.9 | -0.1 | +1.0[c)] | -2.8[c)] |
| 528 | -0.9 | -0.1 | +1.2 | -2.4 |
| 768 | -0.8 | -0.1 | + 0.1 | -3.3 |
| 1000 | -0.7 | -0.1 | + 0.3 | -3.3 |

[a)]Test sample dimensions approximately 1.25-inch wide x 1.25-inch long x .005-inch thick consisting of selected adhesive (thickness ~ .002-inch) laminated between two polymeric films (each ~.0015-inch thick)
[b)]Average of 2 samples
[c)]Onset of severe sample darkening

## ROBUST 300°C WIRE INSULATION SYSTEM

### TASK 2 - RESULTS

- FPE FILM IS NOT A 300°C MATERIAL
- PFPI/AFR700B AND PFPI/CYTEC 680 DEMONSTRATED EXCELLENT THERMAL-OXIDATIVE STABILITY. BOTH SYSTEMS SHOWED ESSENTIALLY IDENTICAL DEGRADATION IN AIR-AGING AT 300°C FOR 1000 HOURS.
- BOTH SYSTEMS ALSO DEMONSTRATED EXCELLENT RESISTANCE TO 90°C AGING IN 95% RH.
- FILM SAMPLES BONDED WITH AFR700B ARE MORE RESISTANT TO THE ATTACK BY DS-108 CLEANING SOLVENT THAN THOSE WITH CYTEC 680-1.

CONCLUSION: PFPI/AFR700B SYSTEM IS THE TOP CANDIDATE FOR TASK 3.

### TASK 3 - INITIAL WIRE INSULATION & TESTING

- EMPLOY THE MOST PROMISING FILM/ADHESIVE INSULATION SYSTEM(S) RECOMMENDED AT THE CONCLUSION OF TASK 2 UPON AIR FORCE APPROVAL.
- SUBJECT THE SYSTEM(S) TO CASTING, INITIAL WIRE WRAPPING, AND INSULATED WIRE TESTING NECESSARY TO FULLY ASSESS POTENTIAL.

SUBTASKS

- FILM PREPARATION/PROCUREMENT

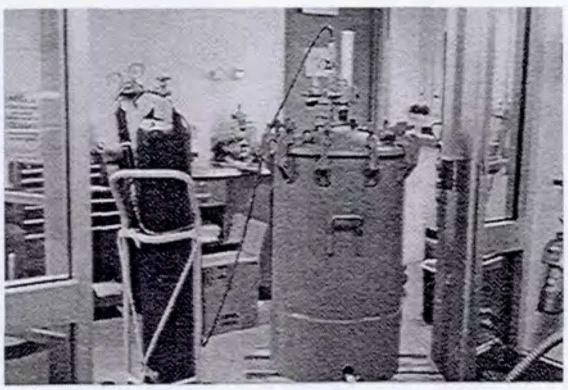
  - FILM CASTING AT REXHAM
  - COATING CONTINUOUS FILM WITH ADHESIVE AT TRW

- INITIAL WIRE WRAPPING
- INITIAL INSULATION TESTING

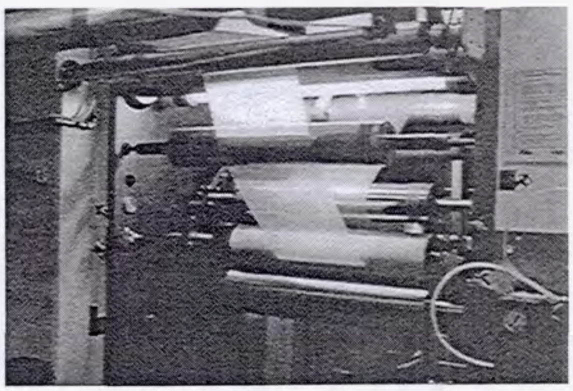
# ROBUST 300°C WIRE INSULATION SYSTEM

## REXHAM FILM CASTING PROCESS OVERVIEW

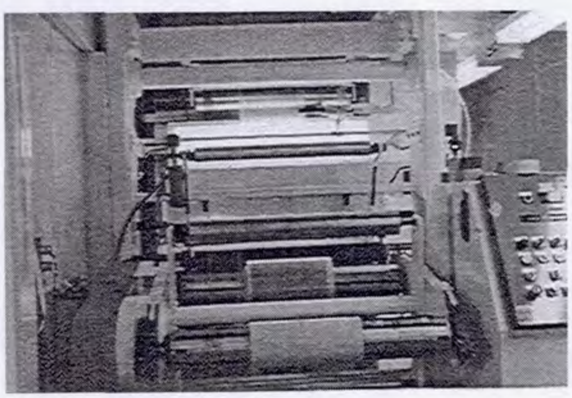
| | |
|---|---|
| SOLVENT: | N-METHYL PYRROLIDONE (NMP) |
| PFPI VARNISH SOLID LOADING: | 14.8% BY WEIGHT |
| SPEED: | 10 FEET PER MINUTE |
| CASTING SUBSTRATE: | 5-MIL X 18-INCH X 5000 FEET MYLAR FILM |
| DRYING OVEN LENGTH: | 40 FEET |
| DRYING OVEN TEMPERATURE (4 ZONES): | ZONE 1 = 250°F; ZONE 2 = 300°F; ZONE 3 & 4 = 350°F |
| HIGH QUALITY PFPI FILM PRODUCED: | 2 ROLLS OF ~ 1-MIL X 12-INCH X 400-FEET |



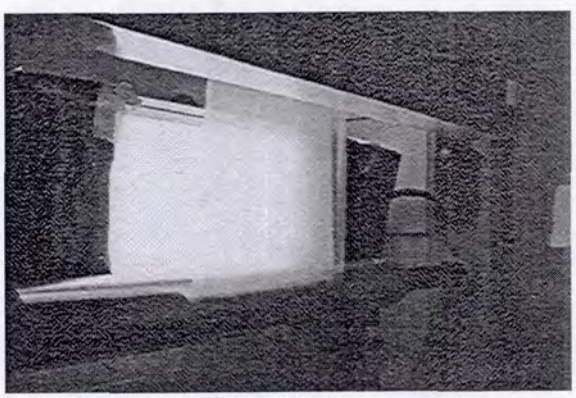
Casting Solution Preparation



Cast PFPI Film



Control Panel



Drying Oven

## ROBUST 300°C WIRE INSULATION SYSTEM

CONCLUDING REMARKS

- AFR700B DEMONSTRATED TO BE A 300°C STABLE ADHESIVE MATERIAL
- PFPI (4-BDAF/PMDA)/AFR700B SHOWN AS THE TOP CANDIDATE FOR 300°C WRAPPED INSULATION SYSTEM
- SUCCESSFUL CASTING OF PFPI RESIN VARNISH INTO CONTINUOUS FILM
- COATING OF THIN LAYER OF AFR700B ON CONTINUOUS PFPI FILM IS IN PROGRESS

# METAL CLAD ARAMID FIBERS FOR AEROSPACE WIRE AND CABLE

Edward W. Tokarsky, Michael G. Dunham, James E. Hunt,
E. David Santoleri, and David B. Allen
DuPont Company
Wilmington, Delaware

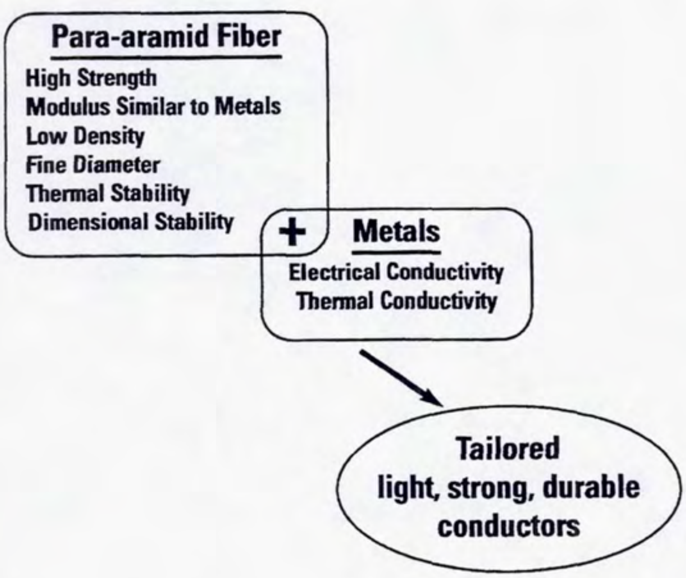


## Abstract

**High strength, light weight metal clad aramid fibers can provide significant weight savings when used to replace conventional metal wire in aerospace cable. This paper provides an overview of metal clad aramid fiber materials and information on performance and use in braided electrical shielding and signal conductor.**

## Background

**ARACON* combines DuPont para-aramid fiber technology with metal claddings...**




* ARACON is a tradename of a product manufactured by the DuPont Company. Trade names or manufacturers' names are used in this report for identification only. This usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

## Base P-aramid Fiber Properties

**Nominal**

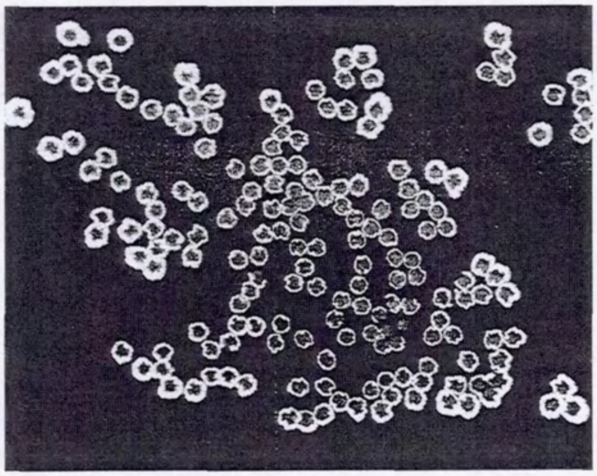
| | |
|---|---|
| **Tensile Strength** | **425 Ksi** |
| **Tensile Modulus** | **12 - 25 Msi** |
| **Elongation** | **3% - 4%** |
| **Specific Gravity** | **1.4** |
| **Filament Diameter** | **0.6 mil** |
| **Decomposition Temperature** | **500°C** |

## Comparison of Specific Gravities

| Material | Specific Gravity |
|---|---|
| Copper | 8.9 |
| Nickel | 8.9 |
| Tin | 7.3 |
| Silver | 10.5 |
| Aluminum | 2.7 |
| ARACON | |
| 65% metal | 3.1 |
| 85% metal | 5.0 |

## Product Offering

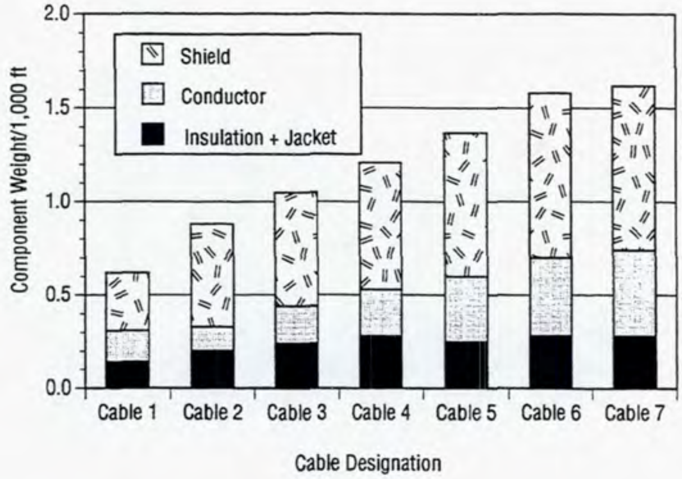
| Properties | Base Yarn | vs. Copper |
|---|---|---|
| Individual Fiber Diameter | 0.6 mil (~ 54 AWG) | — |
| Fiber Tensile Strength, Ksi | 350 min. | 35 - 95 |
| Fiber Tensile Modulus, Msi | 12 min. | — |



# Key Benefits of ARACON Over Traditional Copper Conductors Include:

- Weight savings
- Strength and durability
- Flexibility
- Tailored electrical/ mechanical property balance

## Weight Savings Potential for Cables (Variety of Aerospace Cable Types)




# Concept

## Replace Wire in Shield and/or Conductor with Metal Clad Aramid Fiber

## Product Types

| ARACON™ Size | No. of Filaments (No. of Conductors) | Apprx. AWG |
|---|---|---|
| 55 | 24 | 38 |
| 200 | 89 | 32 |
| 400 | 178 | 30 |
| 600 | 267 | 28 |
| 1125 | 500 | 26 |

**Metallic clads available:** **Nickel**
**Copper**
**Tin**
**Silver**

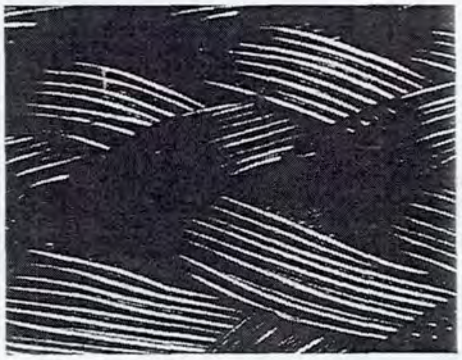
**Range of metal cladding possible: 15 wt% to 90 wt%**

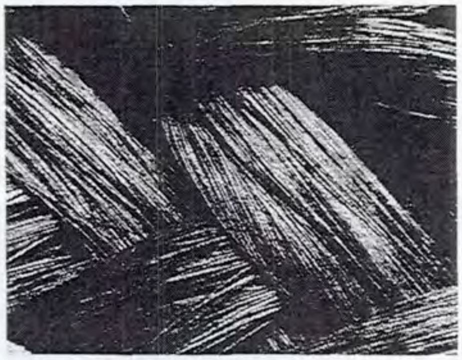
**Major interest to date in 65% to 85% metal content**

## Most Experience to Date in Braided Shielding

# Shielding

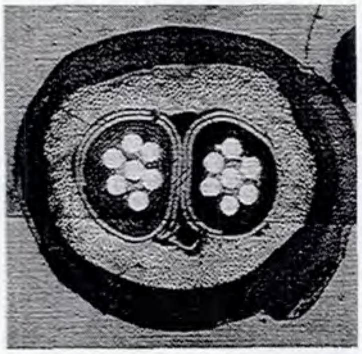
**Copper Wire Braid**

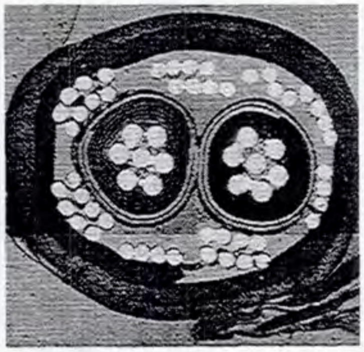




**ARACON Braid**

# Coverage

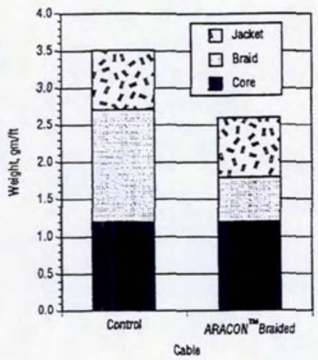




**ARACON offers greater coverage in shielding applications without impairing pushback capability.**

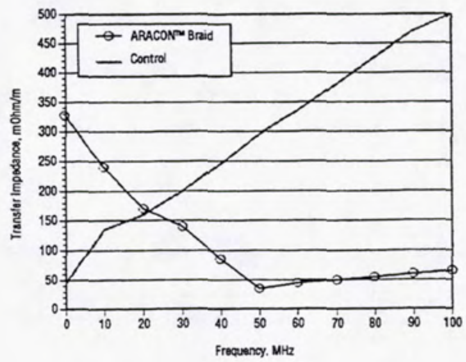
- **Large number of flexible, fine diameter conductors**

## Twisted Pair Cable Comparison




**Cable Component Weights**

**Transfer Impedance vs. Frequency**




## Case Study — Shielding

### Coaxial Cable Comparison

**At very high (GHz) frequencies, ARACON can improve shielding and reduce weight.**

| | % wt/ft | Shielding Effectiveness, dB 2 - 4 GHZ | Shielding Effectiveness, dB 16 - 18 GHz |
|---|---|---|---|
| *Single Braid* | | | |
| RG58 | 100 | 57 | 52 |
| RG58 ARACON | 77 | 68 | 85 |
| *Double Braid* | | | |
| RG223 | 100 | 94 | 107 |
| RG223 ARACON | 72 | 124 | 110 |

## Braid Resistance Before and After 10K amps Lightning Strike Tests

| Cable Number | Shield Description | Cable Dia. (in.) | Initial Resistance (mOhm/m) | Resistance After Six Strikes, Waveform 1* (mOhm/m) | Resistance After Six Additional Strikes, Waveform 5B** (mOhm/m) |
|---|---|---|---|---|---|
| 1 | Control - Wire | 0.40 | 3.80 | 3.70 | 3.60 |
| 2 | Control - Wire | 0.68 | 1.70 | 1.70 | 1.50 |
| 5 | ARACON 70% - 85% Cu/Ni | 0.40 | 12.00 | 12.50 | 11.00 |
| 6 | ARACON 70% - 85% Cu/Ni | 0.68 | 46.50 | 44.00 | 42.50 |
| 7 | ARACON 50% - 69% Cu/Ni/Sn | 0.40 | 80.50 | 68.00 | 57.50 |
| 8 | ARACON 50% - 69% Cu/Ni/Sn | 0.68 | 30.00 | 30.00 | 30.50 |
| 9 | ARACON 70% - 85% Cu/Ni/Sn | 0.40 | 11.50 | 10.50 | 10.20 |
| 10 | ARACON 70% - 85% Cu/Ni/Sn | 0.68 | 14.00 | 14.50 | 14.50 |

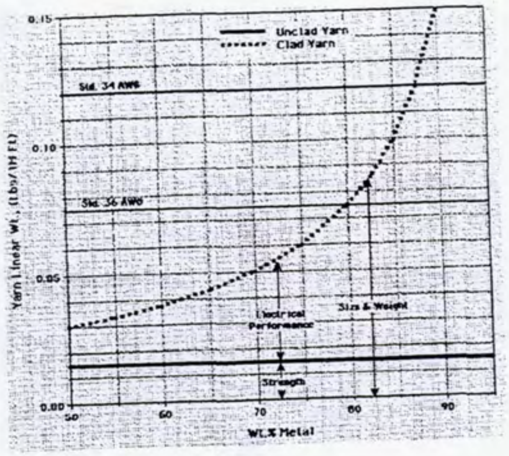
*Commercial aircraft test waveform
**Military aircraft test waveform

**Minimal effect of lightning strike, variations depend on metal content and diameter.**

# Conductor

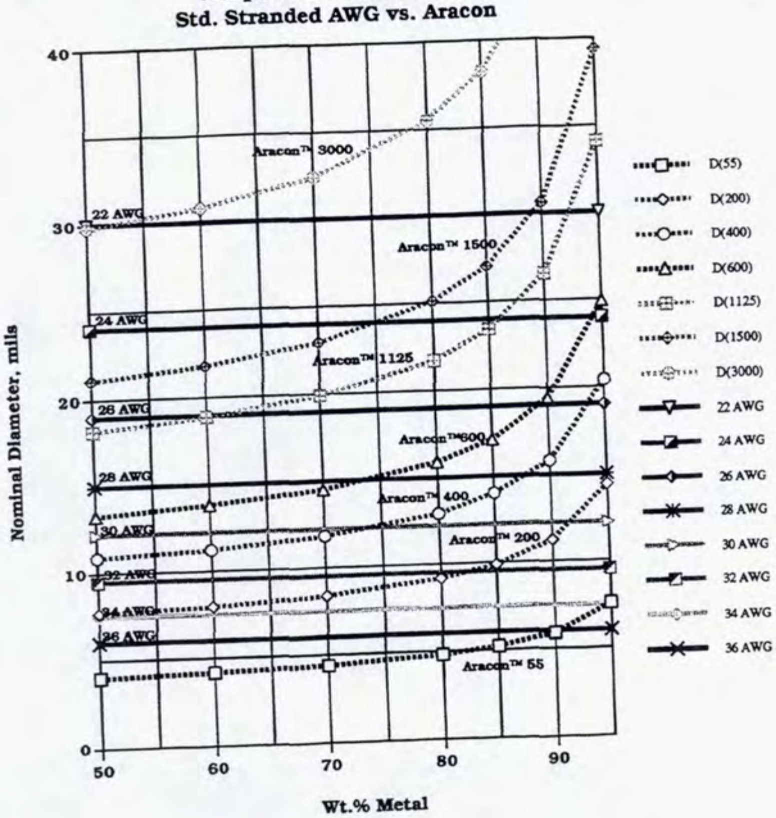
## ARACON Linear Weight vs. % Metal

**200d Base Product**



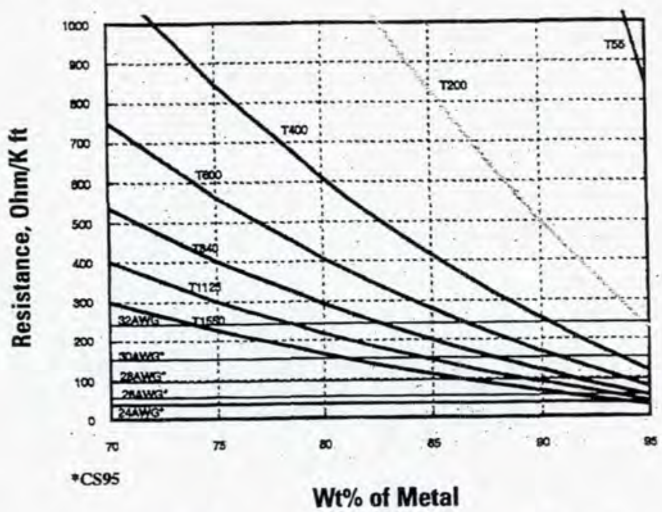

- **ARACON offers an opportunity to provide lightweight conductors with the ability to separately tailor weight, strength and electrical properties.**

**Comparison of Diameters**
**Std. Stranded AWG vs. Aracon**



## ARACON Resistivity vs. Metal Content

**Estimated Values**

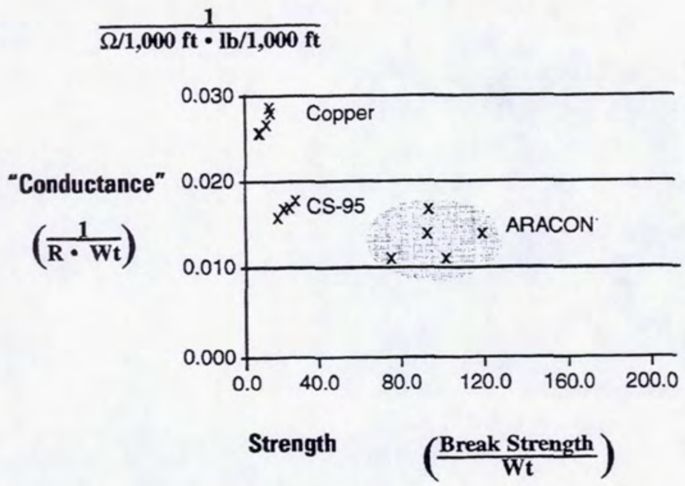



**ARACON resistivity can be tailored to meet design requirements.**

## Preliminary Typical Properties Comparison

| AWG | Material | Dia. (mil) | Construction | Type | DC Resistance Max. (Ohms/M) | Wt. Max. (lb/M ft) | Break Strength (lb) |
|---|---|---|---|---|---|---|---|
| 24 | Cu/Ag | 23.0-23.7 | 19/36 | Unilay | 23.6 | 1.45 | 13 |
| | CS-95 | 23.6-24.8 | 19/36 | Unilay | 36.4 | 1.51 | 34 |
| | CS-95/Ag | 23.6-24.8 | 19/36 | Unilay | 35.9 | 1.52 | 34 |
| | Cu/Ni | 23.0-24.0 | 19/36 | Unilay | 25.2 | 1.51 | 13 |
| | ARACON | 23-25 | 1500d/70-80 | Unilay | 170-305 | 0.37-0.56 | 55-60 |
| | ARACON | 23-25 | 1125d/84-88 | Unilay | 110-170 | 0.52-0.7 | 40-45 |
| | ARACON | 23-25 | 840d/90-92 | Unilay | 95-130 | 0.62-0.78 | 30-35 |
| **26** | **Cu/Ag** | **18.4-19.0** | **19/38** | **Unilay** | **37.3** | **0.932** | **9** |
| | **CS-95** | **18.8-20.0** | **19/38** | **Unilay** | **57.4** | **0.973** | **21.5** |
| | **CS-95/Ag** | **18.8-20.0** | **19/38** | **Unilay** | **56.4** | **0.982** | **21.5** |
| | **Cu/Ni** | **18.4-19.2** | **19/38** | **Unilay** | **41** | **0.979** | **9** |
| | **ARACON** | **18.5-20** | **1125d/50-70** | **Unilay** | **400-1200** | **0.18-0.28** | **40-45** |
| | **ARACON** | **18.5-20** | **840d/80-84** | **Unilay** | **210-300** | **0.31-0.39** | **30-35** |
| | **ARACON** | **18.5-20** | **400d/93-95** | **Unilay** | **120-160** | **0.39-0.6** | **16-18** |
| 28 | Cu/Ag | 14.0-14.9 | 19/40 | Unilay | 63.1 | 0.582 | 5 |
| | CS-95 | 14.4-15.6 | 19/40 | Unilay | 97 | 0.594 | 12.7 |
| | CS-95/Ag | 14.4-15.6 | 19/40 | Unilay | 94.9 | 0.599 | 12.7 |
| | Cu/Ni | 14.0-15.4 | 19/40 | Unilay | 67.6 | 0.603 | 5 |
| | ARACON | 14-15.5 | 400d/85-89 | Unilay | 190-240 | 0.2-0.27 | 16-18 |
| 30 | Cu/Ag | 12.0-13.0 | 19/42 | Con | 96.1 | 0.404 | 3 |
| | CS-95 | 11.9-13.0 | 19/42 | Con | 152 | 0.392 | 8.2 |
| | CS-95/Ag | 11.9-13.0 | 19/42 | Con | 148 | 0.397 | 8.2 |
| | Cu/Ni | 11.8-14.0 | 19/42 | Con | 109 | 0.469 | 3 |
| | ARACON | 12-14 | 400d/72-85 | Unilay | 400-1000 | 0.11-0.2 | 16-18 |
| | ARACON | 12-14 | 200d/92-95 | Unilay | 220-400 | 0.18-0.3 | 7-9 |
| 32 | Cu/Ag | 9.0-9.6 | 7/40 | Con | 166 | 0.224 | 2 |
| | CS-95 | 9.4-10.5 | 19/44 | Con | 242 | 0.256 | 5.1 |
| | CS-95/Ag | 9.4-10.5 | 19/44 | Con | 234 | 0.26 | 5.1 |
| | Cu/Ni | 9.0-9.8 | 7/40 | Con | 177 | 0.231 | 2 |
| | ARACON | 9-10.5 | 200d/78-88 | Unilay | 600-1300 | 0.07-0.12 | 7.9 |

## Conductance vs. Strength




# Termination Performance

## Braided Shield

*Soldered:*

- Good results from Raychem solder sleeve connection.
- Other soldered connections — no problems.

*Crimped:*

- Excellent results from band-type connectors made by Glenair, Inc.

## Conductor

*Crimped:*

- Preliminary data from Daniels Mfg. Corp. showed consistent pull-out strengths with 22 D contacts with high setting on crimping tool.

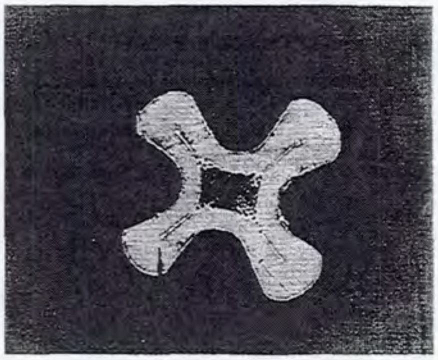
*Soldered:*

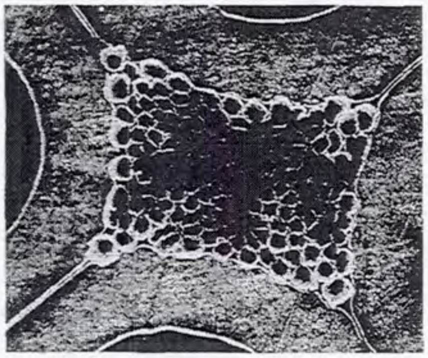
- Data not yet complete, no problems anticipated.

**Experience to date shows that ARACON can be terminated utilizing present industry procedures.**

**Conductor Crimped Termination**
**400d Based ARACON**

**Polished Cross Sections**
**Low and High Magnifications**





# ARACON Crimp Test Results

*Daniels Manufacturing Corporation*

ARACON *Yarn Sizes*
- **200d, 400d**

*Contacts*
- Wire Barrel Size — 22D
- M39029/57-354
- Tri-Star Electronics

*Tooling*
- Tool Frame M22520/2-01
- Positioner M22529/2-06

*Results*

| Denier | Number of Tests | Break Load (lb) Low | High | Avg. | Number of Pullouts | Number Broken at Crimp | Number Broken Outside Crimp |
|---|---|---|---|---|---|---|---|
| 200 (≅32 AWG) | 45 | 3.7 | 7.0 | 5.2 | 0 | 6 | 39 (87%) |
| 400 (≅30 AWG) | 50 | 7.2 | 12.3 | 9.2 | 8 | 0 | 42 (84%) |

# Daniels Manufacturing Corporation Conclusions

- ARACON fibers are crimpable and void-free terminations are achievable.
- Strength of crimp is comparable to copper conductors of similar diameter, but with a far greater strength-to-weight ratio.
- ARACON compresses and becomes more dense on crimping, whereas metal extrudes from the crimp joint.
- ARACON is likely to be less sensitive to flex damage.
- There is no evidence of work hardening as with copper.

# Safety/Handling/Disposal

- Three-day test during braiding, rewinding for respirables; better than OSHA and DuPont permissible exposure levels.
- Safe to bury or incinerate.
- MSDS sheets available.

## ARACON Disposal Recommendation

- Safe to bury.
  - P-aramid is *not* listed as hazardous waste by RCRA.
  - No new hazards for metallic components.

- Incineration OK where allowed for cable.
  - P-aramid can be incinerated.
    > High carbon yield, low smoke.
    > Off-gases similar to wool.

- Recyclability?
  - No defined route at this time.
  - Will consider after commercialization.

**We do not believe ARACON to be a worse hazard than current cable disposal.**

## Summary and Conclusions

**ARACON — New technology for conductors and shielding in signal cable.**

- *Features:*
  - Greater strength
  - Reduced weight
  - Better flexibility
  - Wide temperature capability
  - Tailored electrical properties
  - High braid coverage with pushback
  - Cables can be made with present equipment
  - Terminates with existing tools
- *Trial test results — better than anticipated plus added benefits observed.*
- *Willing to work with you on new trial installations.*

N96- 17096

# EVALUATION OF HIGH TEMPERATURE POLYMERS

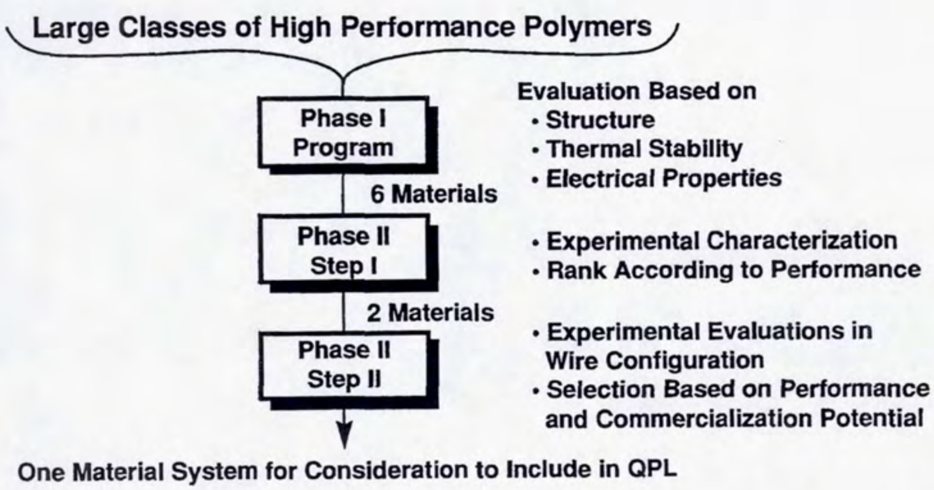
K. Jayaraj, W. Dorogy, B. Farrell, and N. Landrau
Foster-Miller, Inc.
Waltham, Massachusetts

S19-27
6340
P-11

## High Temperature Aerospace Insulation

- Goal
  - Identify and develop arc-track resistant insulation materials that can operate reliably at 300°C
- Phase I SBIR program, July 1991 to January 1992
- Monitored by Mr. George Slenski, and Mr. Eddie White of USAF Wright Laboratory/Materials Directorate
- Phase II program: October 1992 to September 1995
- Contract monitor: Mr. John Nairus

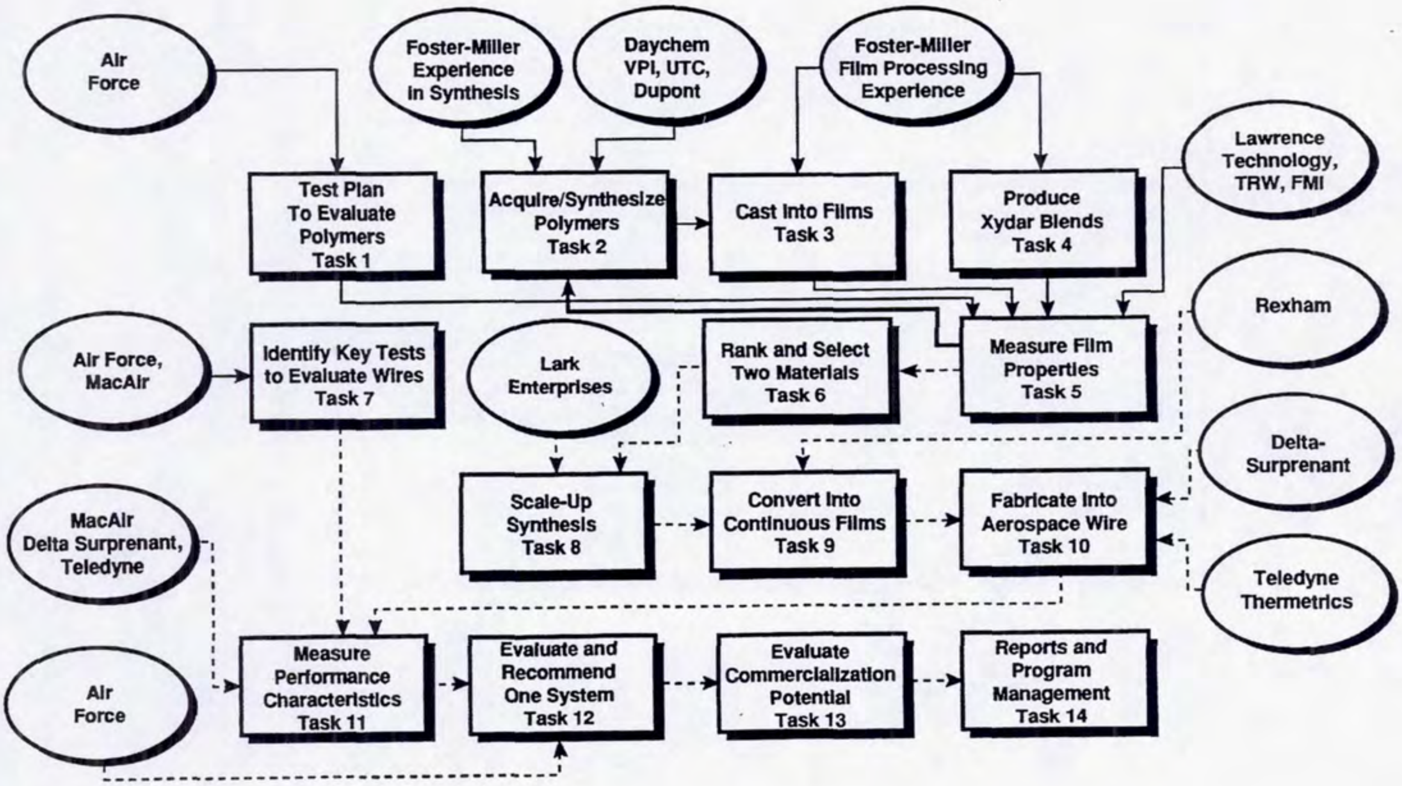
## Foster-Miller Approach to Develop a 300°C Rated, Arc-Track Resistant Aerospace Insulation



## Advantages and Disadvantages of Key Structural Features

| Structural Features | Advantages | Disadvantages |
|---|---|---|
| Fluorine content | For low dielectric constant, low loss factor, high volume resistivity, uniform electrical properties over a wide range of temperatures, resistance to arc-tracking | Aliphatic fluoropolymers, such as Tefzel, have poor mechanical properties at high temperatures. To overcome this limitation, must incorporate other features |
| Liquid crystalline | Solvent resistance, high thermal stability, and possible improved resistance to arc-tracking | Liquid crystalline polymers are difficult to process, need to incorporate additional features, e.g., polyimide |
| Polyimide | High thermal stability, abrasion resistance, and good processability | Poor resistance to arc-tracking. Improved through introduction of additional features, e.g., flourinated groups, crystallinity |
| Aromatic | High thermal stability | Highly aromatic polymers yield conducting char upon pyrolysis |
| Rigidity/ stiffness | Rigidity increases thermal and mechanical capability, and reduces susceptibility to solvents | High rigid polymers can be intractable, difficult to process, and low elongation to break. Some degrees of flexibility desired |
| Cross-linking | X-linking significantly increases thermal stability. This process is widely used in the development of 371°C-rated composites | X-linking greatly reduces flexibility, reduces elongation to break, and embrittles |
| Carbon /hydrogen ratio | High carbon to hydrogen ratio increases thermal capability of polymers | High carbon to hydrogen ratio may cause the formation of conductive char and susceptibility to arc-tracking |

# Detailed Program Plan



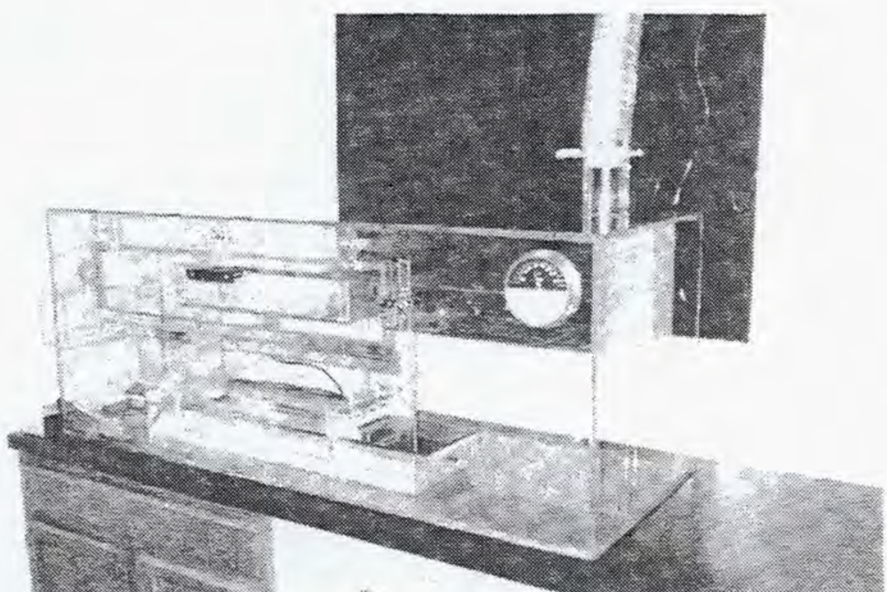

## Performance Goals for Selected Materials

- Arc-track resistance
  - >180 sec using ASTM D495
  - Concern: 0.125 in. thick samples
  - Develop alternate test for thin films
- Lifetime > 15,000 hr at 300°C
- Cost comparable to Kapton
- Amenable to manufacture into aerospace wire configurations on current equipment with little or no modification

# Initial Set of Materials

| | |
|---|---|
| 6F-PBO-PI | Hoechst Celanese/Foster-Miller |
| 6F-PBO thermoplastic benzoxazole polymer | Daychem Laboratories, Dayton, OH |
| 3F-PBO-PE | Virginia Polytechnic Institute |
| Low-char Polyimide | Dupont |
| 6FDA (20%) PMDA (80%)-4BDAF | Virginia Polytechnic Institute |
| 36FDA-PDA | United Technologies, Hartford, CT |
| Xydar blends | AMOCO/Foster-Miller |

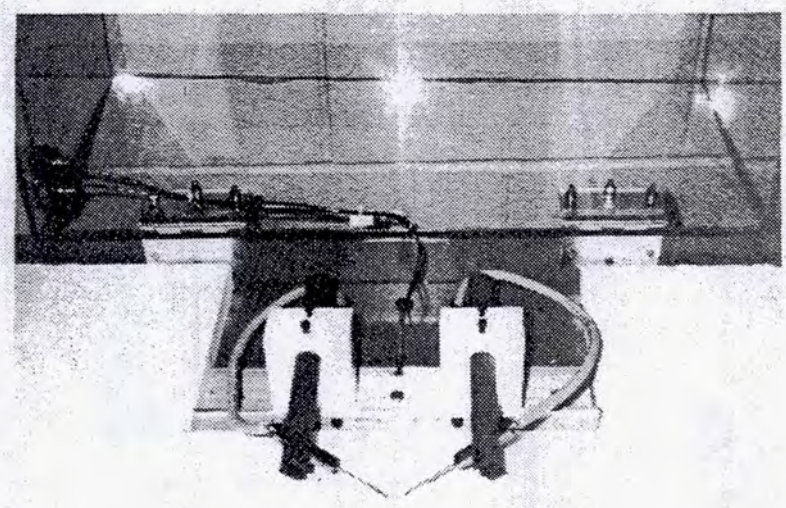
# Mechanized Film Casting Setup



## Verification of Procedures

- Polyamic acid of Kapton was cast into films, cured and tested to verify procedures
- Arc tracking results agree with published data
- Film cashing, thermal treatment and test procedures validated

## Arc Track Resistance Tester



- Test method ASTM D495
- Apparatus

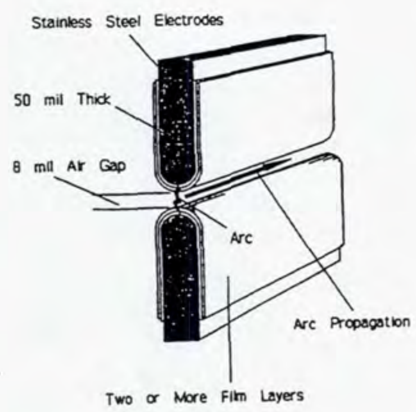
## Arc Track Resistance - Critical Parameters

- Film thickness
  - Test method requires 125 mil
  - Our tests indicate 5 mil thickness is sufficient
- Pressure of electrodes on films
- Angle of electrodes
- Volatile content of films
- Heat generation during testing
- Surface cleanliness

## Arc Tracking Resistance - Ribbon Test

### *A High-Voltage, Low-Current Test was Developed by Sigma Labs which Highly Differentiates Test Films*

Arc Tracking Test Setup




- Steel electrodes, 2 in. long covered with layers of film
- Distance arc tracks in 3 min at 7.5 KV is noted
- Smaller distance that arc tracks equals better arc tracking resistance

# Initial Evaluation

- Arc-track testing indicated that these materials may not meet program goals
- A new set of polymers were included in the evaluation

# New Materials

| | |
|---|---|
| 6FDA-TFMB | - High Tg, high fluorine content (31%) |
| LaRC-CPI | - Highly crystalline material |
| Aorimide | - Arylene ether phosphene oxide<br>- Expected to form a non-conductive char |
| Siloxane Copolyimides | - "in situ" silicon dioxide formation |
| DuPont fluorinated polyimide | - High fluorine content (43%) |
| Polyimide-clay hybrids, proprietary polymer | |

# Candidate Arc-Track Resistant Polymer
## *Electrical Properties*

| Polymer | D-495 Arc Track Resistance (seconds) | Ribbon Arc Track Resistance (inches) | Dielectric Constant | Dissip'n Factor | Dielectric Strength (KV/mil) |
|---|---|---|---|---|---|
| Kapton HN200 | 120-180 | 0.75 | 3.40 | 0.002 | 6100 |
| Upilex | 180-240 | - | 3.50 | 0.001 | 5100 |
| PBO | 180-240 | 1.6 | 3.48 | 0.011 | 6000 |
| 6FDA/PMDA/4BDAF (30 mins, 400°C) | 60-120 | 0.69 | 3.25 | 0.003 | 6740 |
| 6F-PBO-PI (30 mins, 420°C) | 60-120 | - | 3.22 | 0.006 | 5400 |
| 6F-PBO-PE (20 mins, 400°C) | < 60 | 1 | 2.66 | 0.007 | 5570 |
| Proprietary HT Polymer | 180-300 | - | 2.92 | 0.006 | 7000 |
| 36FDA/m-PDA (40 mins, 400°C) | < 60 | - | 3.12 | 0.003 | 7200 |
| LARC CPI | < 60 | - | - | - | |
| TRW Partially Fluorinated Polyimides | - | - | 3.1 | 0.001 | 6000 |
| PerFluoro(Ethylene ethoxyethylene) | 180-240 | - | 2.1 | .0001 | 4050 |
| 3F-PBO-PE (20 mins, 400°C) | < 60 | - | 4.04 | 0.014 | |
| DuPont Low Char Polyimide (15 mins, 400°C) | < 60 | - | 4.83 | 0.013 | |
| DuPont Fluorinated Polyimide | < 60 | 2 | - | - | |
| 6FDA/TFMB | < 60 | - | 3.12 | 0.005 | |
| AORIMIDE | < 60 | - | - | - | |
| 52% Siloxane Copolyimide | < 60 | - | 2.72 | 0.003 | |
| Polyimide 8% Clay Hybrid | < 60 | - | - | - | 6200 |

# Candidate Arc-Track Resistant Polymer
## *Thermomechanical Properties*

| Polymer | Tg (°C) | Thermogravimetric Analysis (°C @ 5% wt. loss in air) | Coefficient Of Thermal Expansion (ppm/°C) |
|---|---|---|---|
| Kapton HN200 | 360-410 | 527 | 20 |
| Upilex | > 500 | 590 | 0.8 (20-100°C) |
| PBO | None | - | - |
| 6FDA/PMDA/4BDAF (30 mins, 400°C) | 279 | 439 | 44 (< 0°C)<br>64 (>100°C) |
| 6F-PBO-PI (30 mins, 420°C) | - | - | 40 (-100->200°C) |
| 6F-PBO-PE (20 mins, 400°C) | 290 | 501 | 35 (< 0°C)<br>55 (>100°C) |
| Proprietary HT Polymer | None | - | 0 |
| 36FDA/m-PDA (40 mins, 400°C) | 325 | - | 34 (-100->200°C) |
| LARC CPI | 258 | - | - |
| TRW Partially Fluorinated Polyimides | - | - | - |
| PerFluoro(Ethylene ethoxyethylene) | - | 466 | 130 (-100 -> 200° |
| 3F-PBO-PE (20 mins, 400°C) | 299 | - | - |
| DuPont Low Char Polyimide (15 mins, 400°C) | 230 | - | - |
| DuPont Fluorinated Polyimide | - | - | - |
| 6FDA/TFMB | 335 | - | - |
| AORIMIDE | - | - | - |
| 52% Siloxane Copolyimide | - | - | - |
| Polyimide 8% Clay Hybrid | 363 | 478 | 16(-100 -> -50°C)<br>20(100 -> 250°C) |

# Candidate Arc-Track Resistant Polymer
## *Physical and Chemical Properties*

| Polymer | Peak Stress (KSI) | % Strain at Break | Modulus (KSI) |
|---|---|---|---|
| Kapton 200HN | 28.9 | 43 | 320 |
| Upilex | - | - | - |
| PBO | -140 | 2.5 | 7.5 |
| 6FDA/PMDA/4BDAF (30 mins, 400°C) | 12.7 | 6.7 | 280 |
| 6F-PBO-PI (30 mins, 420°C) | 13.3 | 4.6 | 350 |
| 6F-PBO-PE (20 mins, 400°C) | 13.3 | 7.7 | 276 |
| Proprietary HT Polymer | 38.1 | 6 | 1680 |
| 36FDA/m-PDA (40 mins, 400°C) | 16.4 | 4.4 | 370 |
| LARC CPI | 60 | - | - |
| TRW Partially Fluorinated Polyimides | - | - | - |
| PerFluoro(Ethylene ethoxyethylene) | - | - | - |
| 3F-PBO-PE (20 mins, 400°C) | - | - | - |
| DuPont Low Char Polyimide (15 mins, 400°C) | - | - | - |
| DuPont Fluorinated Polyimide | - | - | - |
| 6FDA/TFMB | - | - | - |
| AORIMIDE | - | - | - |
| 52% Siloxane Copolyimide | - | - | - |
| Polyimide 8% Clay Hybrid | - | - | - |

## Summary

- Most candidate materials failed due to a conductive char
- Fluorine content is not solely responsible for arc-track resistance
- Materials believed to generate non-conductive char failed
- Highly crystalline materials also failed
- Film quality appears to impact arc-track resistance
- Proprietary material, upilex and perfluoro (ethylene ethoxyethylene) are better than Kapton
- 6FDA/PMDA/4BDAF is comparable to Kapton in arc-track resistance

N96- 17097

# ARC TRACK RESISTANT POLYMERS FOR SPACE APPLICATIONS

Ross Haghighat
Triton Systems, Inc.
Chelmsford, Massachusetts

S20-27
6341
p. 8

## TRITON SYSTEMS, INC.

**Develops Materials & Process Technologies in:**

- **Specialty Materials - Advanced Polymers, Ceramics & MMC's**
- **Scratch Resistant/Antireflective Coatings**
- **Lasers Media - Biomedical Applications**

**and Pursues Technology Transfer Through:**

- **Joint Development**
- **Licensing**
- **Joint Ventures**

## TRITON'S MISSION FOR NASA

**ECONOMICALLY COMMERCIALIZE
AORIMIDE POLYMERS FOR
SPACE, ELECTRICAL AND ELECTRONIC
APPLICATIONS**

## New Electrical Insulation Materials Requirements

- **Easily Processed**
- **Amenable to Scale Up**
- **Arc Track Resistant**
- **Atomic Oxygen Resistant**
- **Light Weight**

# AORIMIDE * (PAEBI) Is

- **Highly Processible**
- **Can Be Applied as Varnish or Tape**
- **Exceptionally Resistant to Atomic Oxyegn**
- **Light Weight (ρ 1.2 g/cc vs 2.1 for Teflon)**
- **Is Exceptionally Arc Track Resistant**

* AORIMIDE is a tradename of a product manufactured by Triton Systems, Inc. Tradenames or manufacturers' names are used in this report for identification only. This usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

| PROPERTIES | KAPTON * | FEP TEFLON * | AORIMIDE | Test Method |
|---|---|---|---|---|
| Tensile strength (ksi)<br>MPa | 10 - 25 [1]<br>70 - 170 | 2.7 - 3.1 [2]<br>18 - 21 | 19-23 [6], 20.2 [7]<br>130-160, 139 | ASTM D-882 |
| Tensile modulus (ksi)<br>GPa | 290 - 450 [1]<br>2.0 - 3.1 | 50 [2]<br>0.34 | 556 [6], 611 [7]<br>3.83, 4.21 | ASTM D-882 |
| Initial tear strength<br>g /µm | 20.0 [1] | | 13.6 [7] | ASTM-1004<br>(JIS C-2318) |
| Propogated Tear strength<br>g/µm | 0.47 [3] | | | ASTM-1922<br>(JIS C-2318) |
| Elongation at break % | 70 [1] | 250 - 330 [2] | 17.8 [6], 16.5 [7] | ASTM D-882 |
| $T_g$ °C. | 350-380 | 275 ($T_m$) [2] | 350 - 375 | |
| CTE | 30 - 60 ppm [1] | 53-108 ppm [4] | 20 - 30 ppm | ASTM D-696 |
| Thermal conductivity<br>@ 23 C W/m K | 0.10 - 0.35 [1] | 0.25 [2] | | ASTM C-177 or<br>ASTM F-433 |
| Dielectric constant<br>@ 1MHz | 3.4 [1] | 2.10 [4] | 2.95 [8] | ASTM D-150 |
| Dielectric strength<br>@ 25µm thick | 7000 v/mil<br>(280 kv/mm) [1] | 500 - 600 v/mil [2]<br>(1/8 " thick) | 7000 v/mil [7] | ASTM D149<br>(JIS C-2318) |
| Dissipation Factor<br>@ 1MHz | 0.010 [1] | 0.0003 [4] | 0.0199 [8] | ASTM D-150 |
| Surface resistivity Ω | $1 \times 10^{16}$ [1] | | $> 1.0 \times 10^{15}$ [8] | ASTM D-257 |
| Volume Resistivity Ω-cm | $1 \times 10^{18}$ [1] | $> 2 \times 10^{18}$ [4] | $>3.1 \times 10^{15}$ [8] | ASTM D-257 |
| Moisture absorption<br>24 hrs | 0.2 - 2.9 % [1] | < .01 % [2] | 2.11% [7] | ASTM D -570 |
| Density (g/cc) | 1.42 | 2.2 | 1.35 | ASTM D-792 |
| A/O resistance | low | good | EXCEPTIONAL | |
| Resistance to Ultra violet | good [1] | good | EXCELLENT | |
| Optical | Transparent<br>( brown ) | Transparent<br>( clear ) | Transparent<br>( yellow ) | |

* KAPTON and FEP TEFLON are tradenames of products manufactured by the DuPont Company. Trade names or manufacturers' names are used in this report for identification only. This usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

# APPROACH

DEVELOP THE INFRASTRUCTURE TO SUPPORT:

- Synthesis of the Polymer
- Processing into Useful Structures
- Identify End Applications
- Identify Performance Criteria
- Develop Prototypes
- Characterize Performance
- Provide Prototype Parts to End-Users
- Commercialize

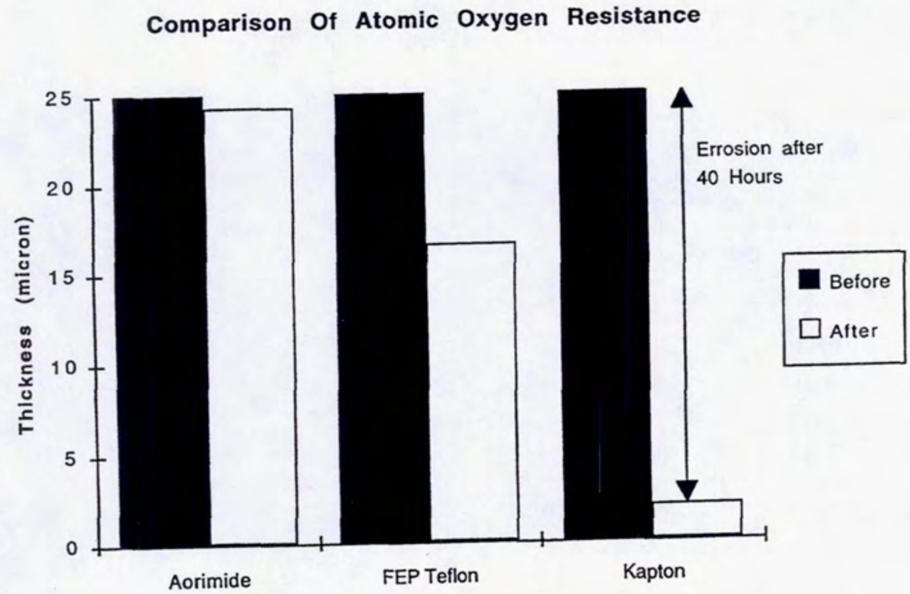
## Conclusions on AO Tests on TOR & AORIMIDE Los Alamos, 1993 , and MSFC, 1994

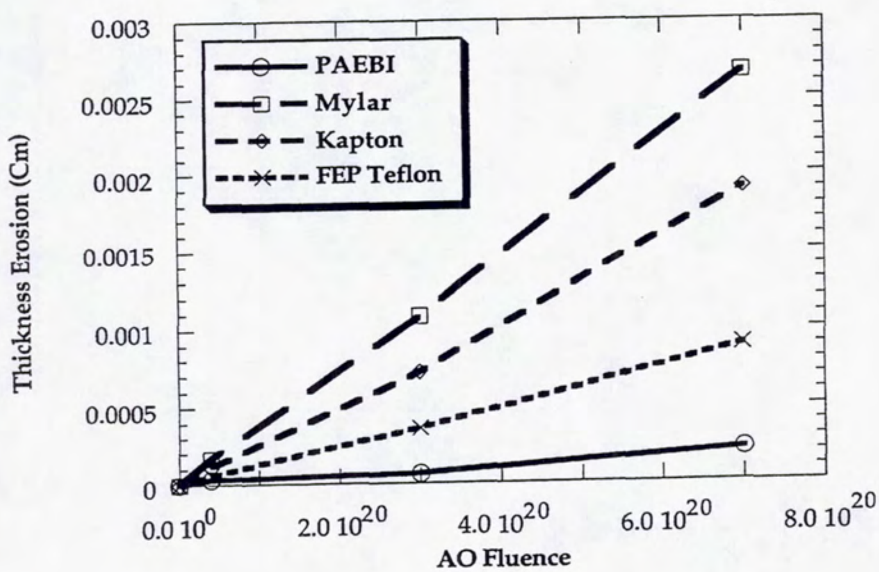
- Fast AO testing at $10^{21}$ AO/cm2

  Aorimide 20 X more AO Resistant than Kapton
  Aorimide 3 X more AO Resistant than Teflon

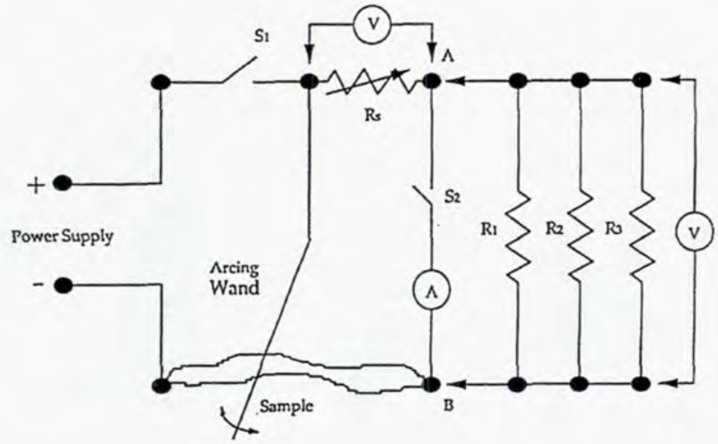
- Slow Asher Testing at $1.4 \times 10^{21}$ AOcm2

  Aorimide > 5 X more AO Resistant than Kapton
  Aorimide not tested versusTeflon


Comparison Of Atomic Oxygen Resistance
25
20
15
10
5
0
Thickness (micron)
Errosion after
40 Hours
Before
After
Aorimide
FEP Teflon
Kapton


0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Thickness Erosion (Cm)
PAEBI
Mylar
Kapton
FEP Teflon
0.0 10^0
2.0 10^20
4.0 10^20
6.0 10^20
8.0 10^20
AO Fluence

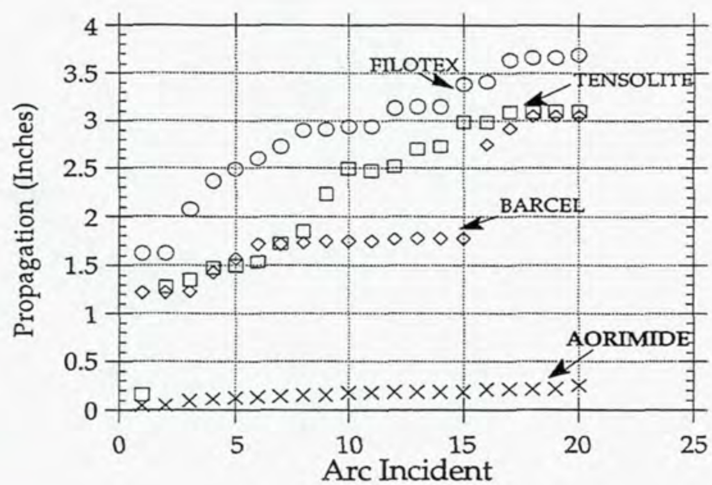
# Arc Track Resistance Set-Up

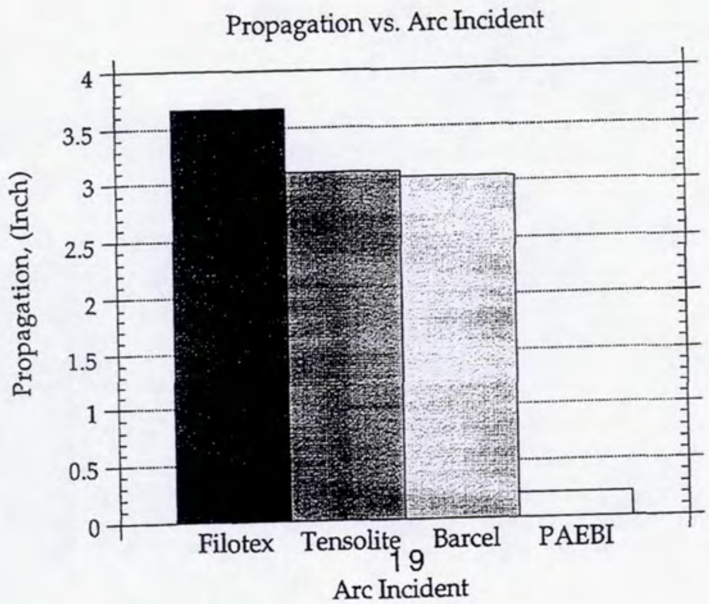


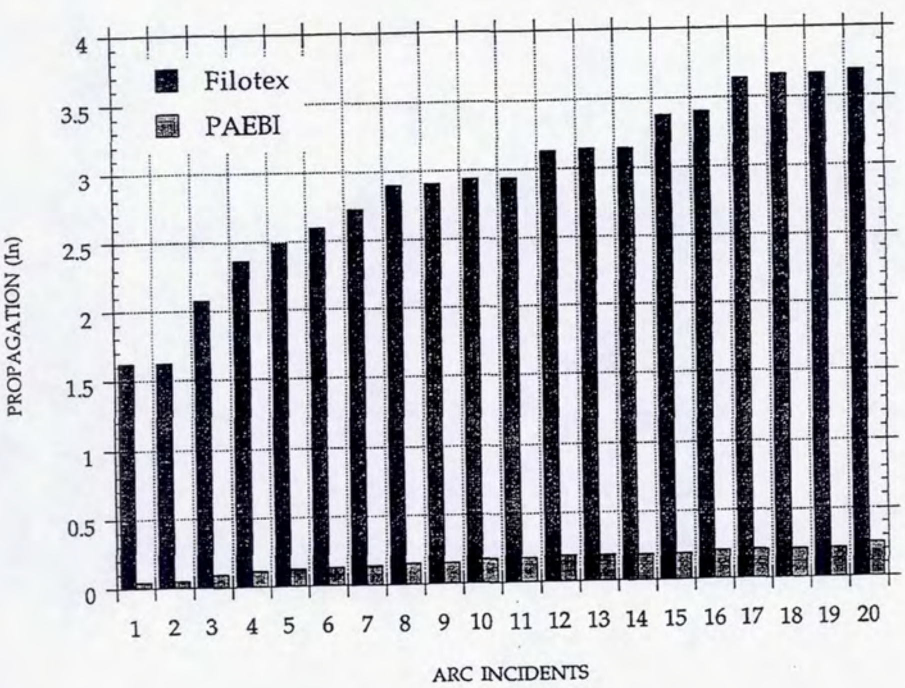

Rs: Series Resistor, 10Ω, 225W

R1, R2, R3: 100Ω, 225W

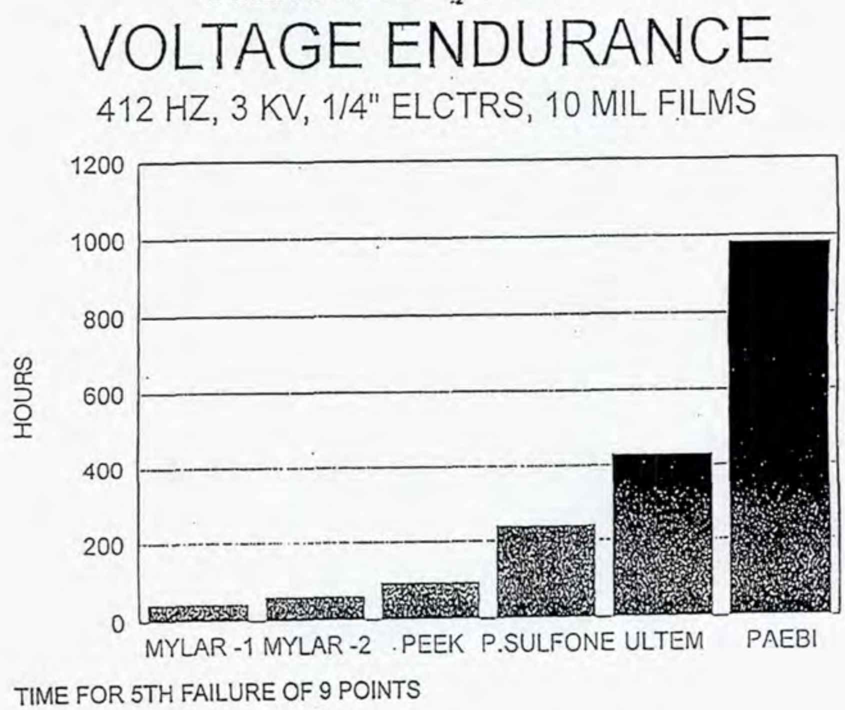
Power Supply: 0 - 200 VDC, 0 - 17 A, 1000W




Propagation vs. Arc Incident
Propagation, (Inch)
4
3.5
3
2.5
2
1.5
1
0.5
0
Filotex
Tensolite
Barcel
PAEBI
19
Arc Incident


Filotex
PAEBI
PROPAGATION (In)
4
3.5
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
ARC INCIDENTS

## AORIMIDE - The Most Corona Resistant Unfilled Polymer




# UPCOMING ACTIVITIES

- **Optimize Wire Coating Application**
- **Verify Test Performance**
- **Coordinate with NASA Missions**
- **Develop Prototypes**
- **Space- Qualify**

N96- 17098

# WIRING DESIGN FOR THE CONTROL OF ELECTROMAGNETIC INTERFERENCE (EMI)

George Kopasakis
Power Technology Division
NASA Lewis Research Center
Cleveland, Ohio

S21-32
6342
p-6

- **WIRING DESIGN IS ONLY ONE IMPORTANT ASPECT OF EMI CONTROL. OTHER IMPORTANT AREAS FOR EMI CONTROL ARE:**

  - CIRCUIT DESIGN
  - FILTERING
  - GROUNDING
  - BONDING
  - SHIELDING
  - OTHER AREAS LIKE; LIGHTING, ELECTROSTATIC DISCHARGE (ESD), TRANSIENT SUPPRESSION, AND ELECTROMAGNETIC PULSE (EMP).

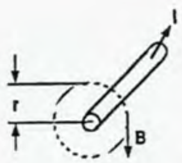
- **A WIRE CARRYING CURRENT GENERATES MAGNETIC AND ELECTRIC FIELDS DESCRIBED BY MAXWELL'S EQUATIONS, AND FUNCTIONS AS AN ANTENNA. THE CABLE EFFICIENCY OF THE ANTENNA DEPENDS ON ITS LENGTH COMPARED TO THE WAVELENGTH OF THE SIGNAL.**

- **LOW FREQUENCY EMISSIONS ARE CONSIDERED WHERE THE LENGTH ~~OF~~ OF THE WIRE IS LESS THAN 10% OF THE SIGNAL WAVELENGTH, WHICH IS NORMALLY THE CASE WITH POWER CABLES.**

- **COUPLING MACHENISMS ARE:**

  - CONDUCTIVE, E.G., COMMON MODE NOISE
  - INDUCTIVE (RADIATING MAGNETIC FIELD), E.G., CURRENT IN A CABLE
  - CAPACITIVE (RADIATING ELECRIC FIELD), E.G.. HIGH TENSION LINES

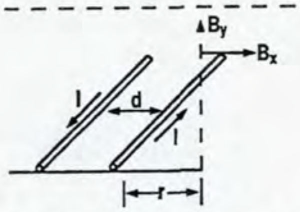
## • WIRE MAGNETIC FIELD EMISSIONS AT LOW FREQUENCIES




SINGLE WIRE

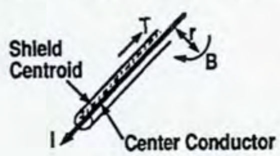
$$B = \frac{\mu_o I}{2\pi r}$$

B(Weber/m$^2$) - Magnetic Flux Density
$\mu_o = 4\pi 10^{-7}$ H/m

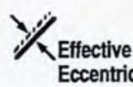



PARALLEL PAIR

$$B_{max} = \left| B_y \right| = \frac{\mu_o I d}{2\pi r\,(r+d)} \cong \frac{\mu_o I d}{2\pi r^2}$$

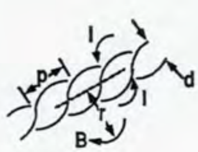



COAXIAL CABLE




$$B_{max} = \frac{\mu_o I \delta}{2\pi r\,(r+\delta)}$$

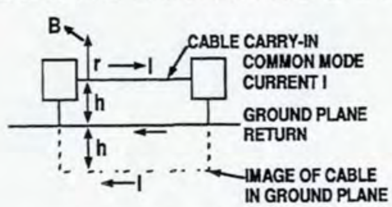
## • WIRE RADIATED MAGNETIC FIELD EMISSIONS AT LOW FREQUENCIES




TWISTED PAIR CABLE

$$B_{max} = \frac{\mu_o I}{pr}\, q\, I_o(q)\, e^{-2\pi r/p} \qquad q = \frac{\pi d}{p}$$

$I_o(q)$ is a oth order modified Bassel function of 1st kind




COMMON MODE

$$B_{max} = \frac{\mu_o I 2h}{2\pi r\,(r+2h)}$$

ELECTRIC FIELD PICK UP DUE TO MAGNETIC FIELD EMISSIONS

$$E = A\,\frac{dB}{dt} \qquad \text{A - loop area}$$

# WIRE DESIGN GUIDELINES FOR EMI CONTROL

- **WIRE DESIGN APPROACHES FOR EMI CONTROL**
  - PARELLEL WIRE PAIR
  - WIRE PAIR TWISTING
  - COAXIAL DESIGN
  - BALANCED LINES
  - FLAT CABLE

- PARALLEL WIRE PAIR, ASSUMING THE CURRENT IS A PERFORMANCE REQUIREMENT AND CAN NOT BE CHANGED, AND THE DISTANCE "r" IS A GEOMETRICAL OR SPECIFICATION CONSTRAINT, THEN "d" CAN BE MADE AS SMALL AS THE WIRE INSULATION WILL ALLOW. THIS IS AN EFFECTIVE WAY OF REDUCING MAGNETIC FIELD EMISSION FROM A WIRE PAIR. IF r CAN BE CHANGED THEN ATTENUATION IS 40 dB PER DECADE OF DISTANCE CHANGE.

- IDEALLY THE COAX CABLE HAS NO MAGNETIC FIELD EMISSIONS, BUT BECAUSE OF MANUFACTURING TOLERANCES SOME ECCENTRICITIES "$\delta$" WILL BE PRESENT. THE COAX CAN BE REPLACED FOR ANALYTICAL PURPOSES BY A WIRE PAIR SEPARATED BY THIS ECCENTRICITY "$\delta$".

- THE SINGLE WIRE WITH A GROUND PLANE RETURN IS TYPICAL EXAMPLE OF DC POWER ON AIRCRAFT, WHERE THE AIRCRAFT SKIN FUNCTIONS AS THE RETURN. USING THE IMAGE THEORY THIS ARRANGEMENT CAN BE REPLACED BY A WIRE PAIR SEPARATED BYA DISTANCE "2h". CONTROLLING THIS DISTANCE, KEEPING IT TO A MINIMUM, WILL LIMIT THE MAGNETIC FIELD.

- FOR THE TWISTED PAIR THE DIRECTION OF CURRENT FLOW IN ADJACENT LOOPS IS OPPOSITE. AT AN OBSERVATION POINT, SITUATED SYMMETRICALLY BETWEEN THE LOOPS, THE MAGNETIC FIELD VECTORS FROM EACH LOOP CANCEL EACH OTHER. AS EACH LOOP CANCELS THE FIELD FROM ITS NEIGHBOR, THE ONLY UNCANCELLED LOOPS WILL BE AT THE EXTREME ENDS.
  - THE FIELD DROPS OFF AT A RATE OF 60 dB/DECADE CHANGE IN DISTANCE
  - AT CLOSE DISTANCE THE LOOP DIAMETER OR PITCH OF TWIST HAVE DOMINATE EFFECTS
  - PRACTICAL LIMIT IS 60 dB
  - AT HIGH FREQUENCIES ATTENNATION DROPS OFF WHEN THERE IS PHASE DIFFERENCE OF THE CURRENT IN THE WIRE.
  - HIGH FREQUENCY LIMITATION

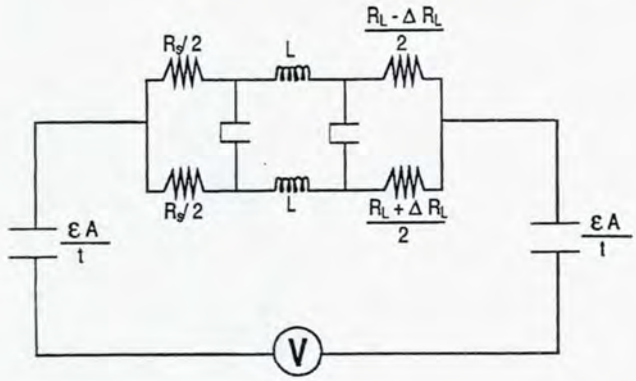
$$|H| = \frac{H_o}{N} \cdot \frac{\mathrm{Sin}(\pi S/\pi\lambda)}{\mathrm{Cos}(\pi S/N\lambda)}$$

$H_o$ - Magnitude of Field of Untwisted Pair
S - Length of Untwisted Wire

  - REDUCTION OF PICKUP DUE TO TWISTING COMPARED TO A PARALLEL WIRE PAIR IS EXPRESSED IN TERMS OF THE RATION OF THEIR AREAS
  - TWISTING HAS LITTLE EFFECT ON THE REDUCTION OF ELECTRIC FIELD EMISSIONS. THESE SHOULD BE SUPPRESSED BY AN OVERALL SHIELD.

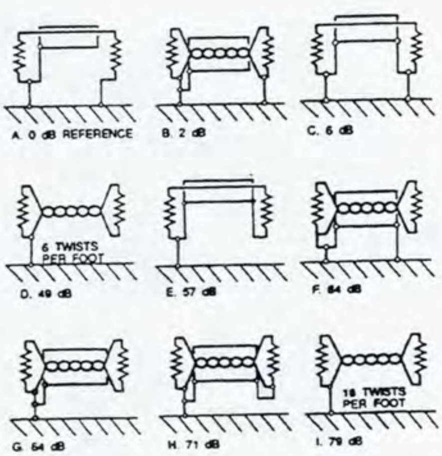
# WIRE DESIGN GUIDELINES FOR EMI CONTROL

- **BALANCED WIRE PAIRS, EFFECTIVE IN LMITING COMMON-MODE PICKUP AND EMISSIONS**
  - BALANCED SYSTEMS CAUSES EQUAL VOLTAGE DROPS ON EACH WIRE CANCELING EACH OTHER
  - DEGREE OF UNBALANCE IS CHARACTERIZED BY $\pm \Delta R_L$ WITH THE FOLLOWING EQUIVALENT CIRCUIT




$$CMRR = 20 \log \left(\frac{V_{CM}}{V_{DM}}\right)$$

- **FLAT CABLE, BASIC CHARACTERISTIC RELATIVE TO EMISSION IS THAT IT ACTS AS LOW PASS FILTER, NOT ALLOWING CURRENT AT HIGH FREQUENCIES AND ASSOCIATED REDUCTION IN MAGNETIC FIELD EMISSIONS**




*PREFERRED CIRCUIT FOR HIGH FREQUENCIES

VALUES GIVEN ARE FOR CIRCUITS 1" ABOVE GROUND PLANE BUT ARE ABOUT THE SAME FOR OTHER DISTANCES FROM GROUND PLANE.

**A. BASELINE REFERENCE, GROUND PLANE AS THE RETURN**

**B. UNBALANCED TWISTED PAIR**

**C. SHIELD GROUNDED AT BOTH ENDS**

**D. TWISTED PAIR**

**E. COAX INTO A BALANCED LOAD**

**F. TWISTED BALANCED PAIR**

**G. TWISTED PAIR**

**H. SIMILAR TO G**

**I. TIGHT TWIST**

**RELATIVE SUSCEPTIBILITY TO MAGNETIC INTERFACE**

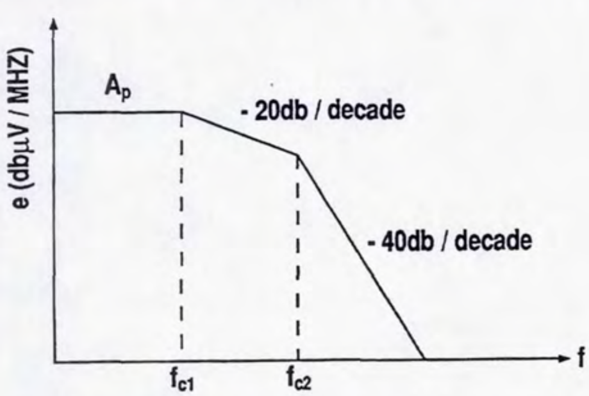
## HIGH FREQUENCY EMISSIONS FROM CABLES

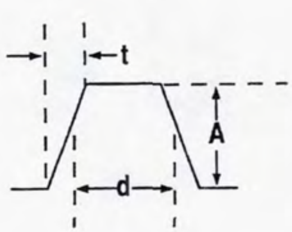
- AT HIGH FREQUENCIES SOURCES OF RADIATION ARE DIVIDED INTO TWO BASIC TYPES, ELECTRIC DIPOLE AND MAGNETIC DIPOLE
- ELECTRIC DIPOLES HAVE HIGH IMPEDANCE, LOW CURRENTS, WHERE MAGNETIC DIPOLES HAVE LOW IMPEDANCE, HIGH CURRENTS
- THE ELECTRICAL DIPOLE STRENGTH IS PROPORTIONAL TO 'CVL', WHERE 'C' IS THE CAPACITANCE BETWEEN THE ELEMENTS OF DIPOLE, 'V' IS THE VOLTAGE DRIVING THE DIPOLE, AND 'L' IS THE DISTANCE BETWEEN THE DIPOLE ELEMENTS.
- THE MAGNETIC DIPOLE STRENGTH IS PROPORTIONAL TO 'IA', WHERE 'I' IS THE CURRENT THROUGH THE MAGNETIC DIPOLE AND 'A' IS THE AREA OF THE MAGNETIC DIPOLE LOOP.

  REDUCING THE STRENGTH OF THE ELECTRIC DIPOLE IS IMPORTANT TO MINIMIZE ITS AREA (LENGTH OF WIRES AND THEIR SPACING) REDUCING THE AREA OF THE MAGNETIC DIPOLE RESULTS IN REDUCTION IN EMISSIONS. IN ADDITION REDUCING HIGH FREQUENCY COMPONENTS OF 'V' AND 'I' REDUCES EMISSIONS BECAUSE BOTH DIPOLES ACCENUATE HIGH FREQUENCY. THE DISTANCE FROM THE DIPOLE IS ANOTHER CONTROL PARAMETER.

## PULSE FREQUENCY SPECTRA

- DECREASING HIGH FREQUENCY COMPONENTS IN THE CABLE VOLTAGE BY INCREASING PULSE RISE TIMES OR INSTALLING FILTERS IF THAT IS AN OPTION




DATA SIGNAL: $A_P = 20 \log (2Ad \cdot 10^6)$ $\quad f_{c1} = 1 / \pi d$, A - in μ V

CLOCK SIGNAL: $A_P = 20 \log \left(\frac{2Ad \cdot 10^6}{T}\right)$ $\quad f_{c2} = 1 / \pi t$

| ELECTRIC DIPOLE | | MAGNETIC DIPOLE | |
|---|---|---|---|

$\beta \cdot r \ll 1$

**NEAR FIELD**

| ELECTRIC DIPOLE | | MAGNETIC DIPOLE | |
|---|---|---|---|
| $H_\phi = \frac{f \cdot C \cdot V \cdot L}{2 \cdot r^2}$ | $\theta = \frac{\pi}{2}$ | $E_\phi = \frac{f \cdot \mu \cdot I \cdot A}{2 \cdot r^2}$ | $\theta = \frac{\pi}{2}$ |
| $E_r = \frac{C \cdot V \cdot L}{2 \cdot \pi \cdot \varepsilon \cdot r^2}$ | $\theta = 0$ | $H_r = \frac{I \cdot A}{2 \cdot \pi \cdot r^3}$ | $\theta = 0$ |
| $E_\theta = \frac{C \cdot V \cdot L}{4 \cdot \pi \cdot \varepsilon \cdot r^3}$ | $\theta = \frac{\pi}{2}$ | $H_\theta = \frac{I \cdot A}{4 \cdot \pi \cdot r^3}$ | $\theta = \frac{\pi}{2}$ |
| $\frac{E\theta}{H\phi} = \frac{1}{2 \cdot \pi \cdot f \cdot \varepsilon \cdot r}$ | | $\frac{E_\phi}{H_\theta} = \omega \cdot \mu \cdot r$ | |

$\beta \cdot r \gg 1$

**FAR FIELD**

| ELECTRIC DIPOLE | | MAGNETIC DIPOLE | |
|---|---|---|---|
| $H_\phi = \frac{\pi \cdot f^2 \cdot C \cdot V \cdot L}{v \cdot r}$ | $\theta = \frac{\pi}{2}$ | $E_\phi = \frac{\pi \cdot f^2 \cdot \mu \cdot I \cdot A}{v \cdot r}$ | $\theta = \frac{\pi}{2}$ |
| $E_r = \frac{f \cdot C \cdot V \cdot L}{v \cdot \varepsilon \cdot r^2}$ | $\theta = 0$ | $H_r = \frac{f \cdot I \cdot A}{v \cdot r^2}$ | $\theta = 0$ |
| $E_\theta = \frac{\pi \cdot f^2 \cdot C \cdot V \cdot L}{v \cdot \varepsilon \cdot r}$ | $\theta = \frac{\pi}{2}$ | $H_\theta = \frac{f^2 \cdot \pi \cdot I \cdot A}{v^2 \cdot r}$ | $\theta = \frac{\pi}{2}$ |
| $\frac{E\theta}{H\phi} = 120 \cdot \pi$ | | $\frac{E\phi}{H\theta} = 120 \cdot \pi$ | |

$\beta = 2 \cdot \pi/\lambda \qquad v = 3 \cdot 10^8$ m/sec

OMIT TO END

## List of Attendees


David Allen
DuPont Company
3332 Coachman Rd.
Wilmington, DE 19803-1942
302-478-3198

John Okyere Attia
Prairie View A&M University
College of Engineering &
Architecture
Prairie View, TX 77446
409-857-3923

Rex Beach
Naval Air Warfare Center
6000 East 21st Street
Indianapolis, IN 46219-2189
317-306-7410

John Beatty
Tensolite
100 Tensolite Drive
St. Augustine, FL 32092
904-829-5600

Robert W. Bercaw
NASA Lewis Research Center
M.S. 301-5
21000 Brookpark Road
Cleveland, OH 44135
216-433-6164

Patricia Cahill
FAA
ACD-240, Bldg. 203
Atlantic City Airport, NJ 08405
609-485-6571

Ron Cull
NASA Lewis Research Center
M.S. 301-5
21000 Brookpark Road
Cleveland, OH 44135
216-433-3948

Rose Delgadillo
Hughes Space & Communications
Bldg. S25, M.S. C371
P.O. Box 92919
Los Angeles, CA 90003-2919
310-416-4069

William Dunbar
1065 149th Place SE
Belleville, WA 98007
206-746-1274

Lily Facca
NASA Lewis Research Center
M.S. 500-102
21000 Brookpark Road
Cleveland, OH 44135
216-433-2833

Robert Friedman
NASA Lewis Research Center
M.S. 500-115
21000 Brookpark Road
Cleveland, OH 44135
216-433-5697

Adam Haghighat
Triton Systems, Inc.
114 Turnpike Rd.
Chelmsford, MA 01824
508-250-4200

Ross Haghighat
Triton Systems, Inc.
114 Turnpike Rd.
Chelmsford, MA 01824
508-250-4200

Ahmad Hammoud
NYMA, Inc.
M.S. 301-5
21000 Brookpark Rd.
Cleveland, OH 44135
216-433-8511

Josef Hanson
Technical University Darmstadt
FG Hochspannungstechnik, FB 17
Landgraf-George-Str. 4
64283 Darmstadt, Germany
(49) 6151 163268

Thomas Hill
NASA Lewis Research Center
M.S. 86-5
21000 Brookpark Road
Cleveland, OH 44135
216-433-2722

Rich Hoeck
Chemfab Corporation
701 Daniel Webster Hwy
P.O. Box 1137
Merrimack, NH 03054
603-424-9000

Ed Hoffman
Hughes Space & Communications
Bldg. S25, M.S. C371
P.O. Box 92919
Los Angeles, CA 90003-2919
310-416-4063

Andrew Hovanec
Unisys/NASA Goddard SFC
Mail Code 313
Greenbelt, MD 20771
301-286-6368

Paul Hubis
W.L. Gore & Associates
555 Paper Mill Road
P.O. Box 9329
Newark, DE 19714
302-738-4880

K. Jayaraj
Foster Miller Inc.
195 Bear Hill Road
Waltham, MA 02154
617-290-0992

M. David Kankam
NASA Lewis Research Center
M.S. 301-5
21000 Brookpark Road
Cleveland, OH 44135
216-433-6143

Terry King
Unisys/NASA Goddard SFC
4700 Boston Way
Lanham, MD 20706
301-731-8660

George Kopasakis
NASA Lewis Research Center
M.S. 301-5
21000 Brookpark Road
Cleveland, OH 44135
216-433-5327

Todd May
NASA Johnson Space Center
M.S. OB111
Houston, TX 77058
713-244-7075

Rondal Mize
NASA Marshall Space Flight Center
MSFC, AL 35812
205-544-2485

James Ogorek
DISC
700 Robbins Ave.
Mail Code ECA
Philadelphia, PA 19111
215-697-6666

Melanie Ott
Unisys/NPPO
4700 Boston Way
Lanham, MD 20706
301-731-8644

Heinz-Josef Reher
DASA-ERNO Postfach 10 59 09
Hünefeldstraße 1-5
W-2800 Bremen 1
Germany
+421-539-4301

Paul Schreiber
McDonnell Douglas Aerospace
5301 Bolsa Ave.
M.S. A3-J072 (17-6)
Huntington Beach, CA 92647-2099
714-896-3311

Norm Schulze
NASA-HQ
Code XS
Washington, DC 20546
202-358-0537

George Slenski
USAF
WL/MLSA
Wright Patterson AFB, OH 45433
513-255-3623

David Somers
Lockheed Martin Astro Space
P.O. Box 800
M.S. 61, Rm. 93
Princeton, NJ 08543
609-490-2626

Mark W. Stavnes
NYMA, Inc.
2001 Aerospace Parkway
Brook Park, Ohio 44142
216-977-1295

Tom Stueber
NYMA, Inc.
M.S. 309-2
21000 Brookpark Rd.
Cleveland, OH 44135
216-433-2218

Robert Sullivan
Allied-Apical Co.
83 Watchung Ave.
Upper Montclair, NJ 07043
201-783-3307

Neil Swanson
Lockheed Martin Astronautics
M.S. S4019
P.O. Box 179
Denver, CO 80201
303-933-9623

Ed Tokarsky
DuPont Company
3332 Coachman Road
Wilmington, DE 19803-1942
302-999-3493

Wing Wong
TRW Space and Technology Group
One Space Park, 01/2236
Redondo Beach, CA 90278
310-813-2287

Alan Ziemba
Barcel Wire and Cable
2851 Alton Ave.
Irvine, CA 92714
714-863-0300

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. AGENCY USE ONLY (*Leave blank*) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | November 1995 | Conference Publication |

**4. TITLE AND SUBTITLE**

Third NASA Workshop on Wiring for Space Applications

**5. FUNDING NUMBERS**

WU–297–50–00

**6. AUTHOR(S)**

Ahmad Hammoud and Mark Stavnes, compilers

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135–3191

**8. PERFORMING ORGANIZATION REPORT NUMBER**

E–9946

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

National Aeronautics and Space Administration
Washington, D.C. 20546–0001

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

NASA CP–10177

**11. SUPPLEMENTARY NOTES**

Responsible person, Ahmad Hammoud, organization code 5430, (216) 433–8511.

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

Unclassified - Unlimited
Subject Category 20

This publication is available from the NASA Center for Aerospace Information, (301) 621–0390.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** ***(Maximum 200 words)***

This document contains the proceedings of the Third NASA Workshop on Wiring for Space Applications held at NASA Lewis Research Center in Cleveland, Ohio, July 18–19, 1995. The workshop was sponsored by NASA Headquarters/ Code XS Office of Space Access and Technology, Spacecraft Systems Division and hosted by the NASA Lewis Research Center, Power Technology Division, Electrical Components and Systems Branch. The workshop addressed key technology issues in the field of electrical power wiring for space applications, and transferred information and technology related to space wiring for use in government and commercial applications. Speakers from space agencies, U.S. Federal labs, industry and academia presented program overviews and discussed topics on arc tracking phenomena, advancements in insulation materials and constructions, and new wiring system topologies. Presentation materials provided by the various speakers are included in this document.

**14. SUBJECT TERMS**

Space power; Wiring insulation; Aircraft; Arc tracking

**15. NUMBER OF PAGES**

246

**16. PRICE CODE**

A11

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | |