Second NASA Workshop on Wiring for Space Applications

Proceedings of a workshop cosponsored by NASA Headquarters, Office of Safety and Mission Quality, and NASA Lewis Research Center, and held in Cleveland, Ohio, October 6–7, 1993
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PREFACE

This document contains the proceedings of the Second NASA Workshop on Wiring for Space Applications held at NASA Lewis Research Center, Cleveland, Ohio, October 6-7, 1993. The workshop was sponsored by NASA Headquarters/Code QW Office of Safety and Mission Quality, Technical Standards 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. Topics discussed included wiring insulation constructions, manufacturing technologies, and protection systems. In addition to reviewing the ongoing NASA and other related programs on space wiring, the workshop provided a forum in which the government and industry representatives could discuss the results of their research programs on the development of arc track-resistant wiring systems.

The workshop organizers express their appreciation to the session chairmen, speakers, and participants, whose efforts contributed to the technical success of this event. Thanks are also due to Ms. Billie Hurt, Ms. Ruth Clark, Ms. Barbara Coles, and Ms. Brunilda Quinones for their relentless efforts in providing a well prepared and very efficient and organized workshop.
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<td>Joe C. Landers, NASA George C. Marshall Space Flight Center</td>
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<td>MSFC Inspections of Installed Polyimide Wire</td>
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<td>Joe C. Landers, NASA George C. Marshall Space Flight Center</td>
<td>NASA Wiring Program Office Responsibilities</td>
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SECOND NASA WORKSHOP ON WIRING FOR SPACE APPLICATIONS

SUMMARY

The Second NASA Workshop on Wiring For Space Applications was held at NASA Lewis Research Center, Cleveland, Ohio, October 6-7, 1993. The workshop was sponsored by NASA Headquarters, Code QW, Office of Safety and Mission Quality, Technical Standards Division and hosted by LeRC's Power Technology Division, Electrical Components and Systems Branch. Like its predecessor, the First NASA Workshop on Wiring For Space Applications, which was also hosted by NASA Lewis on July 23-24, 1991, this 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 the NASA Office of Safety and Mission Quality, and the various ongoing programs on space wiring. These included the European Space Agency Wiring Program to understand the arc tracking phenomenon and develop detection techniques, the US Air Force Program to develop a 300°C wire insulation system for the aircraft environment, and the NASA Space Wiring Program to provide a technology base for the development of lightweight, arc track-resistant and reliable wiring systems for aerospace applications.

Session II discussed the role of the various organizations and programs involved in the qualification, certification, and standardization of electrical wiring. These included the NASA Goddard Space Flight Center Parts Project Office (NPPO), Naval Air Warfare Center (NAWC), and the National Electrical Manufacturers Association (NEMA). A survey of space wiring failures, the effects of improper wiring system design and installation, and the wiring requirements for the Space Station Freedom were also presented in this session.

Session III focused on the results of wiring tests performed by numerous organizations to address NASA's unique testing requirements. Experimental investigations on the effect of space environmental stresses on the performance of electrical wiring were presented and discussed. These stresses included atomic oxygen exposure, vacuum, ultraviolet radiation, high temperature, and low gravity. A proposed new test method for the assessment of arc tracking was also discussed and compared to the conventional testing techniques. Presentations were also given by industry representatives in this session on the state of the art development in the area of high temperature, high performance, arc track-resistant wiring insulation and dielectrics for aerospace applications. The workshop was attended by approximately 60 individuals from the United States, comprising government, industry, and academia and 3 visitors from Germany. A list of the attendees is included on page ix and the final workshop agenda is listed on page xii.
The general consensus of the workshop was that space wiring failures are of a major concern and are detrimental to mission safety and success. Among the issues that were identified and recommended for further investigation include the development of new arc track-resistant wiring insulation constructions, better system designs, adequate circuit protection, and proper handling procedures. These factors, when implemented, will certainly improve the reliability and lifetime of space power systems. It is anticipated that a better understanding of arc tracking in wiring insulations will be achieved through the NASA Wiring For Space Applications Program, in conjunction with the efforts of other agencies and organizations. The resulting database of information will help in the development of lightweight, safe, and reliable power systems with new wiring constructions which are resistant to arc tracking and suitable for use in aerospace applications.

The organizers once again express their appreciation to the volunteers and participants in making this workshop a very interesting and successful event. The support of NASA Headquarters Code QW for this program is gratefully acknowledged.
SECOND NASA WORKSHOP ON WIRING FOR SPACE APPLICATIONS

AGENDA

October 6 - 7, 1993
NASA Lewis Research Center
NASA Administration Building (Bldg. No. 3)
Auditorium

Wednesday, October 6

Session I: Organizations and Programs

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<th>Organization</th>
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<tr>
<td>8:30 - 8:45</td>
<td>Opening Remarks</td>
<td>R. Bercaw</td>
<td>NASA/LeRC</td>
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<tr>
<td>8:45 - 9:15</td>
<td>NASA Code Q Overview</td>
<td>D. Mulville</td>
<td>NASA/HQ/QE</td>
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<tr>
<td>9:15 - 9:45</td>
<td>Wiring for Space Applications</td>
<td>N. Schulze</td>
<td>NASA/HQ/QE</td>
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<tr>
<td>9:45 - 10:15</td>
<td>Break</td>
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<tr>
<td>10:15 - 10:45</td>
<td>ESA Program Overview</td>
<td>H. Reher</td>
<td>MBB Deutsche Aerospace</td>
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<tr>
<td>10:45 - 11:15</td>
<td>Robust 300 C Wire Insulation System</td>
<td>J. Nairus</td>
<td>Wright Laboratory</td>
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<tr>
<td>11:15 - 11:30</td>
<td>Discussion</td>
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<td>11:30 - 12:30</td>
<td>Lunch</td>
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Session II: Wiring Applications and Standards

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<tr>
<td>12:30 - 1:00</td>
<td>NASA Wiring Program - Survey of NASA</td>
<td>M. Stavnes</td>
<td>NASA/LeRC</td>
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<td></td>
<td>Experiences in Wiring System Safety</td>
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<td>1:00 - 1:30</td>
<td>SSF Wiring Requirements</td>
<td>D. Emerson</td>
<td>NASA/LeRC</td>
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<td>1:30 - 2:00</td>
<td>NASA Parts Program Office Responsibilities</td>
<td>P. Kilroy</td>
<td>NASA/GSFC</td>
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<td>2:00 - 2:30</td>
<td>NASA Parts Project Office - Basic Goals</td>
<td>J. Plante</td>
<td>NPPO/Paramax</td>
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<tr>
<td>2:30 - 3:00</td>
<td>Break</td>
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<tr>
<td>3:00 - 3:30</td>
<td>NAVAIR Aircraft Wiring Standardization</td>
<td>T. Meiner</td>
<td>NAWC</td>
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<tr>
<td></td>
<td>and Qualification Program</td>
<td></td>
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<tr>
<td>3:30 - 3:45</td>
<td>Organized Wiring Systems</td>
<td>T. Meiner</td>
<td>NAWC</td>
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</table>
3:45 - 4:15  NEMA Wire and Cable Standards Development Activities  R. Baird  NEMA
4:15 - 4:45  Inspection of Installed Wiring Systems  J. Landers  NASA/MSFC
6:00 - 7:00  Cash Bar  NASA/LeRC Main Cafeteria
7:00 - 9:00  Dinner  NASA/LeRC Main Cafeteria

Thursday, October 7

Session III: Wiring Test Results

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<tr>
<th>Time</th>
<th>Topic</th>
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<tr>
<td>8:30 - 9:00</td>
<td>NASA Wiring Program - Test Program</td>
<td>A. Hammoud</td>
<td>NASA/LeRC</td>
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<tr>
<td>9:00 - 9:30</td>
<td>Flammability, Odor, Outgassing, and Compatibility with Aerospace Fluids of Wire Insulation</td>
<td>D. Hirsch</td>
<td>Lockheed</td>
</tr>
<tr>
<td>9:30 - 10:00</td>
<td>Electrical and Mechanical Testing of Wire Insulation for Space Applications</td>
<td>L. Burkhardt</td>
<td>McDonnell Aerospace Co.</td>
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<td>10:00 - 10:30</td>
<td>Evaluation of Pyrolysis and Arc Tracking on Candidate Wire Insulation for Space Applications</td>
<td>T. Stueber</td>
<td>NASA/LeRC</td>
</tr>
<tr>
<td>10:30 - 11:00</td>
<td>Break</td>
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<td></td>
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<tr>
<td>11:00 - 11:30</td>
<td>Wire Insulation Degradation and Flammability in Microgravity</td>
<td>R. Friedman</td>
<td>NASA/LeRC</td>
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<tr>
<td>11:30 - 12:00</td>
<td>Breakdown Testing of Wiring Insulation</td>
<td>J. Laghari</td>
<td>Univ. Buffalo</td>
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<tr>
<td>12:00 - 12:45</td>
<td>A New Test Method for the Assessment of Arc Tracking</td>
<td>D. König</td>
<td>Univ. Darmstadt</td>
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<tr>
<td>12:45 - 1:45</td>
<td>Organized Lunch Buffet</td>
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<td>NASA/LeRC Main Cafeteria</td>
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<td>2:00 - 2:30</td>
<td>High Temperature Polymer Dielectric Film Insulation</td>
<td>R. Jones</td>
<td>TRW</td>
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<tr>
<td>2:30 - 3:00</td>
<td>High Temperature, Arc Track Resistant Aerospace Insulation</td>
<td>W. Dorogy</td>
<td>Foster Miller, Inc.</td>
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<tr>
<td>3:00 - 3:30</td>
<td>3M High Temperature Dielectric Film</td>
<td>E. Hampl</td>
<td>3M Co.</td>
</tr>
<tr>
<td>3:30 - 4:00</td>
<td>Closing Remarks/Discussions</td>
<td>R. Bercaw</td>
<td>NASA/LeRC</td>
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SESSION I

ORGANIZATIONS AND PROGRAMS
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NASA CODE Q OVERVIEW

Daniel Mulville
NASA Headquarters
Washington, DC

OVERVIEW

• CODE Q ORGANIZATION
• CODE Q VISION AND MISSION
• CODE QW MISSION AND KEY ACTIVITIES
• MAJOR APPLIED TECHNOLOGY PROJECTS

OFFICE OF SAFETY AND MISSION ASSURANCE

• CHARTER
  – NMI 1103.39E, APRIL 9, 1993

• VISION
  – WE ARE RECOGNIZED AS AN INTERNATIONAL LEADER IN THE SAFETY, QUALITY, AND MISSION ASSURANCE OF U.S. AERONAUTICS AND SPACE PROGRAMS

• MISSION
  – PROVIDE LEADERSHIP IN THE DEVELOPMENT AND OPTIMIZATION OF SAFETY AND MISSION ASSURANCE POLICIES, STRATEGIES, AND TECHNOLOGIES FOR NASA PROGRAMS. ADVOCATE A SYSTEMATIC AND DISCIPLINED APPROACH FOR ACHIEVING SAFETY AND MISSION SUCCESS AND SUPPORTING THE TECHNICAL RISK DECISION-MAKING PROCESS
ENGINEERING AND QUALITY MANAGEMENT DIVISION

MISSION: DEVELOP AND ESTABLISH AND INTEGRATED ENGINEERING AND QUALITY MANAGEMENT CAPABILITY TO ENHANCE THE QUALITY OF NASA MISSIONS

KEY ACTIVITIES:

- ESTABLISH ENGINEERING AND QUALITY MANAGEMENT POLICY AND GUIDANCE FOR NASA PROGRAMS
- ENHANCE NASA'S ASSURANCE CAPABILITY THROUGH DEVELOPMENT OF IMPROVED ENGINEERING ANALYSIS, TEST, AND QUALIFICATION METHODS
- ESTABLISH NASA-WIDE ENGINEERING AND QUALITY STANDARDS, PRACTICES, AND PROCESSES TO SUPPORT DESIGN, MANUFACTURE, TEST, AND ASSURANCE OF FLIGHT SYSTEMS
- DEVELOP SYSTEMS ENGINEERING PRACTICES, TOOLS, AND METHODS TO IMPROVE NASA'S PROGRAM/PROJECT MANAGEMENT PROCESS
- UTILIZE ASSURANCE TECHNOLOGIES TO IMPROVE RELIABILITY AND PERFORMANCE OF FLIGHT PROJECTS (e.g., NDE, EEE PARTS AND PACKAGING, MECHANICAL PARTS, AEROSPACE BATTERIES, WIRING)
- ENHANCE QUALITY ASSURANCE SKILLS DEVELOPMENT AND TRAINING PROGRAMS
MAJOR PROGRAM ELEMENTS

• ENGINEERING STANDARDS AND PRACTICES
  – POLICY AND STANDARDS
  – ENGINEERING CAPABILITY ENHANCEMENT
  – STRUCTURAL INTEGRITY
  – METRIC TRANSITION

• SOFTWARE ENGINEERING AND ASSURANCE
  – POLICY STANDARDS, METHODS, PROCESSES
  – INDEPENDENT VERIFICATION AND VALIDATION (IV&V)
  – PROGRAM ASSESSMENTS

• SYSTEMS ENGINEERING AND MANUFACTURING
  – STANDARDS AND GUIDELINES
  – PROGRAM DEVELOPMENT LIFE CYCLE
  – PRODUCT DATA EXCHANGE INITIATIVE
  – MANUFACTURING PROCESS IMPROVEMENT

MAJOR PROGRAM ELEMENTS (CONT.)

• EEE PARTS AND ELECTRONIC PACKAGING
  – POLICY AND STANDARDS
  – EEE PARTS CONTROL PROCESSES
  – PARTS AND PACKAGING TECHNOLOGY
  – NASA/ARPA RELTECH PACKAGING PROGRAM

• APPLIED TECHNOLOGY
  – AEROSPACE FLIGHT BATTERY SYSTEMS
  – AEROSPACE WIRING
  – PYROTECHNIC ACTUATED SYSTEMS
  – INTERFEROMETRIC FIBEROPTIC GYROSCOPE
• GOAL:
  – ENHANCE SAFETY, RELIABILITY, QUALITY, AND PERFORMANCE OF NASA's SPACECRAFT SYSTEMS

• OBJECTIVES:
  – DEVELOP IMPROVED TECHNOLOGIES FOR NASA FLIGHT PROGRAMS
  – IMPROVE TOOLS AND METHODS FOR ENGINEERING ANALYSIS
  – DEVELOP DATA BASES TO SUPPORT APPLICATIONS
  – PERFORM FLIGHT QUALIFICATION FOR ADVANCED TECHNOLOGY
    • PYROTECHNIC DEVICES (LASER INITIATED)
    • INTERFEROMETRIC FIBEROPTIC GYROSCOPE

APPLIED TECHNOLOGIES

FY 1993 DELIVERABLES

• DRAFT SPECIFICATION FOR LASER INITIATED SAFE AND ARM
• PYROTECHNIC SYSTEMS SPECIFICATION GUIDELINE
• DRAFT PYROTECHNIC SYSTEMS CATALOG
• DESIGN CONCEPTS FOR NASA STANDARD GAS GENERATOR
• NASA WIRING APPLICATIONS REQUIREMENTS (INTERIM)
• WIRING INSULATION TEST PLAN
• INTERFACE CONTROL DOCUMENT FOR FIBEROPTIC GYRO
BACKGROUND

NEW FAILURE MODES WERE REPORTED IN WIRING SYSTEMS IN AIRCRAFT AND SPACE VEHICLES DUE TO DEGRADATION OF WIRING INSULATION

ARC TRACKING PHENOMENON

PROCESS:
- INITIATION OF ARC
- PYROLYSIS OF INSULATION
- ARC PROPAGATION

FACTORS:
- POWER LEVEL
- FREQUENCY
- INSULATION TYPE
- ENVIRONMENT

RESULT:
- SYSTEM SHUT DOWN AND POSSIBLE LOSS OF MISSION
# Background

## Space Missions with Electrical Wiring System Failures

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<th>Mission</th>
<th>Cause</th>
<th>Result</th>
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<td>Gemini 8</td>
<td>Electrical Wiring Short</td>
<td>Shortened Mission - Near Loss of Crew</td>
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<td>Apollo 204</td>
<td>Damaged insulation, Electrical Spark, 100% O₂</td>
<td>Fire, 3 Astronauts Lost</td>
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<tr>
<td>Apollo 13</td>
<td>Damaged Insulation/Short Circuit/Flawed Design</td>
<td>Oxygen Tank Explosion, Mission Incomplete</td>
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<td>STS - 6</td>
<td>Abrasion of Insulation/Arc Tracking</td>
<td>Wire Insulation Pyrolysis 6 Conductors Melted</td>
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<td>STS - 28</td>
<td>Damaged Insulation/Arc Tracking</td>
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<td>Magellan</td>
<td>Wrong Connection, Wiring Short</td>
<td>Wiring Insulation Pyrolysis - Ground Processing</td>
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<td>Spacelab</td>
<td>Damaged Insulation/Arc Tracking</td>
<td>Wiring Insulation Pyrolysis During Maintenance</td>
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<td>Mechanical or Electrochemical Insulation Damage</td>
<td>Loss of Vehicle</td>
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<td>ESA - Olympus</td>
<td>Electrical Wiring Short</td>
<td>Loss of Solar Array</td>
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## Ongoing Efforts

### R&D Programs

- SYSTEM DESIGN
- DIFFERENT CONSTRUCTIONS
- NEW INSULATION
- PROTECTION TECHNIQUES
- QUALITY CONTROL

### Organizations:

- NASA
- DOD LABS
- AEROSPACE INDUSTRY
- ACADEMIA
- ESA
- QUAL. & STAND. COMMITTEES
NASA Electrical Power Wiring Program

Workshop on Wiring for Space Applications
held at NASA LeRC, July 23-24, 1991

ATTENDEES

GOVERNMENT

NASA:
- HQ
- LeRC
- JSC
- MSFC
- KSC
- GSFC
- WSTF
- Wright Patterson AFB
- NRL
- Naval Air Systems Command

INDUSTRY AND ACADEMIA

Boeing
- Rockwell International
E.I. Dupont, Co.
- Teledyne Thermatics
Lawrence Technologies
- McDonnell Aircraft Co.
Foster Miller Inc.
- TRW
Engineering Teledyne Thermatics
- Aerospace Business Development Association
Allied - Apical
- Westinghouse Electric Co.
Auburn University
- University of Buffalo

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/GE0 ENVIRONMENTS
- LUNAR AND MARTIAN ENVIRONMENTS
PROGRAM ORGANIZATION

• TOP LEVEL MANAGEMENT BY NASA HEADQUARTERS, OFFICE OF SAFETY AND MISSION QUALITY, TECHNICAL STANDARDS DIVISION (CODE QW).

• TECHNICAL MANAGEMENT BY THE NASA LEWIS RESEARCH CENTER, ELECTRICAL COMPONENTS AND SYSTEMS BRANCH, POWER TECHNOLOGY DIVISION.

• PARTICIPATION BY OTHER NASA CENTERS, OTHER GOVERNMENT AGENCIES, INDUSTRY, AND ACADEMIA.

Wiring for Space Applications

• Task #1: NASA Applications Requirements
• Task #2: Insulation Testing and Analysis
• Task #3: Wiring Systems Technology
NASA Mission Applications Environments

Pressurized Module Environments

LEO/GEO Environments

Trans-atmospheric Vehicle Environments

Lunar and Martian Environments

Task #1. NASA Applications Requirements

OBJECTIVE

Identify NASA requirements and application environments and relate these to previous wiring studies.

APPROACH

- Identify the environmental and operational conditions for various NASA missions.
- Establish a database on wiring based on previous and current wiring studies.
- Develop mission requirements and determine NASA unique test requirements.
TASK #1 NASA APPLICATIONS REQUIREMENTS

- REPORT "OPERATIONAL ENVIRONMENTS FOR ELECTRICAL POWER WIRING ON NASA SPACECRAFT"

- REVIEW
  - NASA
  - DOD
  - INDUSTRY

- PUBLICATION

NASA WIRING PROGRAM
PUBLICATIONS


"AN ANALYSIS OF WIRING SYSTEM SAFETY IN SPACE POWER SYSTEMS," PAPER PRESENTED AT THE INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE, ATLANTA, GEORGIA, AUGUST, 1993.
NASA WIRING PROGRAM
PRESENTATIONS


### NASA Electrical Power Wiring Program - Tentative Testing Schedule

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<td>Arc Tracking Tests</td>
<td>Report</td>
<td>Additional Tests</td>
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<td>LeRC (gravity Branch)</td>
<td>Arc Tracking Tests</td>
<td>Report</td>
<td>Sigma 400 Connector Tests</td>
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<tr>
<td>LeRC EC&amp;SB</td>
<td>Test Planning, Sample delivery/Tests Setup</td>
<td>Program Overview, Workplan</td>
<td>Final Report</td>
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<tr>
<td>NASA Parts Project Office</td>
<td>Test Plan/Information Transfer</td>
<td>Final Report</td>
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<tr>
<td>University at Buffalo</td>
<td>Testing Report</td>
<td>Additional Testing (TRW) Report</td>
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<tr>
<td>Naval Air Warfare Center</td>
<td>Recommend Testing</td>
<td>Military Standard Tests Report</td>
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## PROGRAM SCHEDULE

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<th>FY91</th>
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<td>Task 2: Insulation test/analysis Requirements</td>
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<td>Task 3: Wiring Systems Technology</td>
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<td>Management Planning</td>
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<td>Program Plan</td>
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<td>Annual report</td>
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<td>Final report</td>
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### Program Products

- **Final Report: FY95**
  - Operational environments report: Task 1
  - Test report: Task 2
  - Wiring systems technology report: Task 3
  - Conclusions

- Recommended applications for wiring designs tested
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

ADDITIONAL REQUIREMENTS FOR MANNED SPACECRAFT

- THE FOLLOWING ADDITIONAL PROPERTIES, SPECIFIC TO MANNED SPACECRAFT (I.E. COLUMBUS AND HERMES) REQUIRE EVALUATION

1. FLAMMABILITY
2. OFFGASSING
3. ARC TRACKING
4. THERMAL DECOMPOSITION
5. MICROBIAL SURFACE GROWTH

NOTE: 4. AND 5. ARE TEST METHODS DERIVED IN THE FRAME OF THE COLUMBUS PROJECT

- IN ADDITION, THE EFFECTS OF AGEING ON CERTAIN OF THESE PROPERTIES REQUIRE INVESTIGATION
FLAMMABILITY

- WIRE FLAMMABILITY TESTING IS DEFINED IN TEST 2 OF ESA-PSS-01-721 Iss. 2. THIS TEST METHOD WAS DEVELOPED BY DASA/ERNO (UNDER ESA CONTRACT) AND WAS CHOSEN TO REPLACE THE ELECTRICAL OVERLOAD TEST OF NASA NHE 8060.1B.

- TEST METHOD IS BASED ON AN EXISTING ASTM SPEC. AND HAS THE FOLLOWING CHARACTERISTICS:
  - SINGLE WIRE, INCLINED AT 60 DEG.
  - FLOWING TEST ATMOSPHERE, AIR OR ENRICHED OXYGEN ATMOSPHERE
  - WIRE ELECTRICALLY HEATED TO MAX. RATED OPERATING TEMPERATURE DURING TEST
  - OPEN FLAME IGNITION (PROPANE/AIR MIXTURE SUPPLIED FROM OUTSIDE OF THE TEST CHAMBER)
  - ACCEPTANCE CRITERIA BASED ON BURN TIME AND BURN LENGTH.

- TEST HAS BEEN SHOWN TO GIVE VERY REPRODUCIBLE RESULTS IN BOTH REPLICATE TESTS ON THE SAME EQUIPMENT AND ON TESTS PERFORMED ON DIFFERENT TEST SET UPS.

- TEST METHOD PRESENTLY UNDER EVALUATION BY BRITISH STANDARDS INSTITUTE FOR POSSIBLE ADOPTION WITHIN THEIR WIRE TESTING SPECIFICATION.

ARC TRACKING

- ARC TRACKING IS A CONTENTIOUS SUBJECT AND MANY WOULD ARGUE THAT BY GOOD DESIGN PRACTICES AND CONTROL THE PROBLEM CAN BE ELIMINATED.

- MANY TEST METHODS EXIST BUT THE ONLY NATIONAL STANDARDS ARE THOSE DEFINED IN BSG 420 TEST 42 (WET METHOD) AND TEST 43 (DRY METHOD). A DRAFT ASTM SPEC. D3032 IS ALSO AVAILABLE BASED ON THESE TWO TESTS.

- A SURVEY OF EXISTING TEST METHODS, PERFORMED BY DASA/ERNO AND THE TECHNICAL UNIVERSITY OF DARMSTADT, SHOWED THAT NO METHOD WAS AVAILABLE WHICH COULD ADEQUATELY BE USED TO EVALUATE SPACECRAFT MATERIALS. IN PARTICULAR A METHOD WAS REQUIRED WHICH COULD BE USED IN AIR, VACUUM AND ENRICHED OXYGEN ATMOSPHERES AND COULD UTILISE THE DC VOLTAGES COMMONLY USED IN SPACECRAFT POWER SYSTEMS.

- A NEW TEST HAS THEREFORE BEEN DEVELOPED FOR THE TESTING OF SPACECRAFT MATERIALS. THIS WILL BE MORE FULLY DESCRIBED IN A SEPARATE PRESENTATION.

- FUTURE WORK:
  - WORK IN CONTINUING ON INVESTIGATING THE ARC TRACKING BEHAVIOUR OF DIFFERENT WIRE GAUGE SIZES (AWG6, 8, 12, 16) AND USING DIFFERENT VOLTAGE (IN THE RANGE OF 28-270V DC)
  - SOME PRELIMINARY STUDIES WILL BE PERFORMED ON EVALUATING THE EFFECTS OF HUMIDITY OF THE TEST ATMOSPHERE AND OF PRIHEATING THE WIRE UNDER TEST.
  - AN EXPERIMENT TO STUDY ARC TRACKING IN A MICROGRAVITY ENVIRONMENT WILL BE CONSTRUCTED STARTING EARLY NEXT YEAR WITH THE AIM OF FLYING ON A PARABOLIC FLIGHT AT THE END OF 1995.
THERMAL DECOMPOSITION

- There are classically two modes of testing when looking at the combustion products formed on decomposition of materials. These are flaming and non-flaming combustion. The method chosen will be dependent on the fire scenario envisaged obviously the products formed on decomposition are markedly different and thus it is essential that the baseline for testing is clearly defined prior to the start of any costly test programme.

- One approach is to try, with the best means available, to ensure that your wire insulation is not flammable and thus cannot act as a source of ignition assuming suitable circuit protection is also included in the design. If this is the case then it is not necessary to look at materials in a flaming mode but can be limited to lower temperatures at which smouldering may occur. In the case of the Columbus programme where all materials are subjected to very stringent flammability tests, such an approach has been adopted.

- There are many tests available for studying the decomposition of materials and assessing the toxicity of the degradation products. Most involve placing the material for a defined time at a defined temperature and analysing the decomposition products formed (by GC/MS, GC/FTIR or colorimetric tubes etc.)

THERMAL DECOMPOSITION (2)

- One method, studied via the Columbus project, is that developed by CERTSM, Toulon, France for looking at materials used in submarine construction. The method is based on French Standard NFC 20454 and involves heating the material at 800 deg. C for 20 minutes in a flowing atmosphere. Samples of the atmosphere are removed and analysed by GC/MS or GC/FTIR. Statistical analysis on 50 materials has shown that it is only necessary to look for 10 compounds ("key compounds") to obtain sufficient precision (less than 5% error) in classifying materials in terms of their toxicity.

- For Columbus, for the reason mentioned earlier, a series of tests will be performed using this method but at lower temperatures, namely 500°C and 200°C. This work should start early next year.

- In addition some preliminary studies have been performed in ESTEC using the Cone Calorimeter. This work is, however, at a very early stage.
MICROBIAL SURFACE GROWTH

- TEST METHOD BASED ON REPORT 881018 FROM SINTEF/SI (SENTER FOR INDUSTRIFORSKNING, NORWAY) ENTITLED "TEST PROCEDURES AND SPECIFICATIONS FOR ASSESSING THE SUSCEPTIBILITY OR RESISTIVITY TO MICROBIOLOGICAL SURFACE GROWTH OF MATERIALS TO BE USED IN SPACE HABITATS"

- REPORT DEFINES THREE TEST METHODS
  A. SCREENING TEST FOR BACTERIAL GROWTH
  B. SCREENING TEST FOR FUNGAL GROWTH
  C. LONG DURATION TEST

- IT IS PROPOSED TO PERFORM TESTS A. AND B. ON A SERIES OF WIRE SAMPLES STARTING EARLY 94.

AGE'ING

- AGEING IS A COMPLICATED PROCESS AND THE MECHANISMS BY WHICH THIS OCCURS VARY FROM MATERIAL TO MATERIAL. METHODS ARE AVAILABLE TO ARTIFICIALLY AGE MATERIALS. THESE FREQUENTLY INVOLVE THE USE OF ELEVATED TEMPERATURE BUT CARE HAS TO BE TAKEN TO ENSURE THAT THE TEMPERATURES USED DO NOT INDUCE ADDITIONAL CHANGES WITHIN THE MATERIAL ON TOP OF THOSE DUE TO AGEING.

- SINCE SOME OF THE PROPERTIES STUDIED BY THE TESTS REFERRED TO EARLIER MAY WELL CHANGE DUE TO AGEING IT IS INTENDED TO SUBJECT SEVERAL WIRE SAMPLES TO AN ARTIFICIAL AGEING PROCESS (METHOD PRESENTLY TBD, BUT UNDER PREPARATION BY DASA/ERNO) AND THEN TO REPEAT
  A. FLAMMABILITY TEST
  B. ARC TRACKING TEST

THIS WORK SHOULD BE COMPLETED BY END 1994.
OBJECTIVE

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 CONSTRUCTIONS IDENTIFIED IN AIR FORCE CONTRACT F33615-89-C-5606 COMMONLY KNOWN AS TKT CONSTRUCTIONS.

APPROACH

TASK I: FILM/ADHESIVE CANDIDATE SCREENING

TASK II: DETAILED FILM/ADHESIVE SYSTEM TESTING

TASK III: INITIAL WIRE INSULATION AND TESTING

TASK IV: DETAILED WIRE TESTING
FILM/ADHESIVE CANDIDATE SCREENING

DESIGN OF EXPERIMENTS (DOX) APPROACH FOR CANDIDATE SELECTION

- MINIMUM OF SIX CANDIDATES
- CAST FILM CANDIDATES
- DETERMINE KEY ELECTRICAL AND MECHANICAL PROPERTIES

TASK I PROPERTIES

<table>
<thead>
<tr>
<th>TABLE I: PROPOSED TASK I SCREENING PROPERTIES TO BE DETERMINED</th>
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<tbody>
<tr>
<td>Property to be Determined</td>
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<tr>
<td>---------------------------</td>
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<tr>
<td><strong>Electrical</strong></td>
</tr>
<tr>
<td>Dielectric Constant at 400 Hz and 1000 Hz at RT, 280°C, and 300°C</td>
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<tr>
<td>Dissipation Factor at conditions stated above</td>
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<tr>
<td>Breakdown Voltage (AC at 60 Hz and DC) at RT, 280°C, and 300°C</td>
</tr>
<tr>
<td>Arc Tracking at RT</td>
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<tr>
<td><strong>Mechanical</strong></td>
</tr>
<tr>
<td>Tensile strength, elongation to break, and modulus at RT, 280°C, and 300°C</td>
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<tr>
<td>Lap shear tensile strengths at RT, 280°C, and 300°C</td>
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<tr>
<td>Dynamic work loss (tan delta)</td>
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</tbody>
</table>
DETAILED FILM/ADHESIVE SYSTEM TESTING

FOUR TASK I CANDIDATES

BOND SAMPLES (PFPI / AFR700)
SAMPLE AGING (BONDED, UNBONDED, CONTROL)
- FLOWING AIR
- HIGH HUMIDITY
- AIRCRAFT FLUID(S)

SAMPLE TESTING → TWO CANDIDATES

INITIAL WIRE INSULATION AND TEST

TWO TASK II CANDIDATES

CAST/CUT FILMS AND ADHESIVES
INITIAL WIRE WRAP
INSULATED WIRE TESTS
ie: - ABRASION
- FLEX LIFE
- DRY ARC TRACK

MIL-W-81381 KAPTON DERIVED CONTROL

ONE CANDIDATE
DETAILED WIRE TESTING

ONE TASK III CANDIDATE — FINAL WIRE WRAP

MIL-W-81381 KAPTON DERIVED CONTROL — DETAILED WIRE TEST (BEFORE, DURING, AFTER AGING) (TESTS BEYOND TASK III) ie: - DYNAMIC CUT THROUGH - WET ARC TRACK

LIFE CYCLE ANALYSIS

NASA ENVIRONMENTS

PRESSURIZED MODULE
- PROPOSED MATERIAL HAS SUCCESSFULLY COMPLETED LONG TERM AGING TESTS IN OXYGEN IN PREVIOUS AF PROGRAM

TRANS-ATMOSPHERIC VEHICLE
- PROPOSED MATERIAL HAS SUCCESSFULLY COMPLETED VACUUM, UV AGING, AND TEMPERATURE TESTS IN PREVIOUS AF PROGRAM
- HAVE NOT DONE COMBINED TESTS (ie: PLASMA EFFECTS)

LUNAR AND MARTIAN
- POLYIMIDES KNOWN FOR RADIATION RESISTANCE

LEO/GEO
- WL HAS SPACE TESTED FILM SAMPLES WHICH ARE BEING DELIVERED FOR TEST AND ANALYSIS

ADDITIONAL NOTES
- PROPOSED SYSTEM SHOULD NOT BE AFFECTED BY GRAVITY
- EXISTING POLYIMIDE TECHNOLOGY ALREADY EXCEEDS LIFETIME REQUIREMENTS
- 160 VDC SHOULD BE FEASIBLE BASED ON BDV TESTS
NASA APPROACH

TASK I: NASA OPERATIONAL ENVIRONMENTS

TASK II: INSULATION TEST AND ANALYSIS

TASK III: WIRING SYSTEMS TECHNOLOGY

TASK IV: MANAGEMENT PLANNING

CONCLUSIONS

OPPORTUNITIES EXIST FOR COOPERATIVE NASA/AIR FORCE EFFORTS

- INSULATION CONTRACT IS FLEXIBLE BUT ALREADY ADDRESSES NASA CONCERNS/ISSUES

- GENERIC AIR FORCE ELECTRICAL LOAD MANAGEMENT TECHNOLOGY IS APPLICABLE
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NASA Wiring Program

Wiring System Technology

OBJECTIVE

To address safety and reliability issues of complete wiring systems.

PLANS

- Determine Wiring System Design Factors
- Investigate Circuit Protection Technologies
- Address Manufacturing and Maintenance Procedures
NASA Wiring Program

Wiring System Failure Survey

PURPOSE

Form a comprehensive view of wiring safety, not only including the insulation, but also taking into account the wiring system factors.

JUSTIFICATION

For failures such as arc tracking and others to happen, insulation degradation of some degree must have occurred. The wiring system factors can often lead to degradation.

Overview of Space Missions with Wiring System Failures

<table>
<thead>
<tr>
<th>Mission</th>
<th>Cause</th>
<th>Result</th>
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<tbody>
<tr>
<td>Gemini 8</td>
<td>Electrical Wiring Short</td>
<td>Shortened Mission - Near Loss of Crew</td>
</tr>
<tr>
<td>Apollo 204</td>
<td>Damaged Insulation, Electrical Spark, 100% O₂</td>
<td>Fire, 3 Astronauts Lost</td>
</tr>
<tr>
<td>Apollo 13</td>
<td>Damaged Insulation/Short Circuit/Flawed Design</td>
<td>Oxygen Tank Explosion, Mission Incomplete</td>
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<tr>
<td>STS - 6</td>
<td>Abrasion of Insulation/Arc Tracking</td>
<td>Wire Insulation Pyrolysis</td>
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<tr>
<td>STS - 28</td>
<td>Damaged Insulation/Arc Tracking</td>
<td>Teleprinter Cable Insulation Pyrolysis</td>
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<tr>
<td>Magellan</td>
<td>Wrong Connection, Wiring Short</td>
<td>Wiring Insulation Pyrolysis - Ground Processing</td>
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<tr>
<td>Spacelab</td>
<td>Damaged Insulation/Arc Tracking</td>
<td>Wiring Insulation Pyrolysis During Maintenance</td>
</tr>
<tr>
<td>Delta 178/GOES-G</td>
<td>Mechanical or Electrochemical Insulation Damage</td>
<td>Loss of Vehicle</td>
</tr>
<tr>
<td>ESA - Olympus</td>
<td>Electrical Wiring Short</td>
<td>Loss of Solar Array</td>
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</table>
Electrical Wiring System Failures

Influenced by a Combination of Factors

- Wiring System Design
- Circuit Protection Technology
- Manufacturing/Maintenance Procedures
- Insulation Construction/Material

Electrical Wiring System Failures

EXAMPLES


Wiring System Design

Space Shuttle (STS-28)

Original Teleprinter Cable

- Wire makes 180° bend.
- Repeated bending damaged insulation.

Redesigned Teleprinter Cable

- 90° Strain relief added.
- More flexible insulation used.

Wiring System Design

Command and Service Module (Apollo 13)

Oxygen Tank Failure

- Tanks contained ignition sources, combustible materials, and oxygen.
- Electrical wiring conduit constrictive.
- Wiring in close proximity to heaters.
- Pressure against sharp edges could lead to "Cold Flow".
- Failure modes were not detectable by normal post assembly testing.
Maintenance Procedures

Space Shuttle Orbiters

- During 1984 and 1985 there were 532 cable and connector problems reported.
- Problems resulted due to maintenance procedures.

Circuit Protection Technology

Space Shuttle (STS-28)

- Circuit breakers based on the thermal energy in the fault, may be ineffective in detecting arc-tracking.
- NASA Johnson Space Center Test Program - arc propagation limited to lengths of less than 1" up to 6".
- New technologies may improve detection.
Electrical Wiring System Improvements

EXAMPLES

Wiring System Design Improvements

• Awareness of designers to fault mechanisms.

• Specify new insulation constructions and materials for use in NASA spacecraft.

Manufacturing/Maintenance Procedure Improvements

• Improved training of personnel in "Wiring Awareness" techniques

• Routing/Protecting of wiring to avoid physical damage

• Improved quality control, including non-intrusive inspections

• Application of methods such as dynamic system engineering and total quality management.
Wiring Protection Measures

Space Shuttle Orbiters

Advanced Protection Technology

"Instantaneous Trip" Circuit Breakers

- Commercially Available Solid State Power Controllers (SSPC)
- Air Force 270 VDC SSPC Program
Advanced Protection Technology

"Smart" Fuses

Dual-element Time-delay Fuse

- Provide protection against low-level overload current or a short circuit current.
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Differential Protection of DCSU Using Fiber Optic Current Sensing

Fault Signal \( \propto I_{SSU} + I_{BCDU1} + I_{BCDU2} + I_{BCDU3} + I_{DDCU} + I_{MB} + I_{FAULT} \)

\( \bigcirc \) = Fiber Optic Coil

RWB-92.01-pm.1
Advanced Protection Technology

"Intelligent" Fault Detection Methods

• Incipient fault detection via "footprint" or "signature"
• Knowledge based expert systems
• Neural network methods
• Fuzzy logic methods

Summary

• The wiring system is an important consideration in designing a spacecraft power system.

• Arc-tracking has recently been identified as a failure mode which may not be completely eliminated through the use of new wiring constructions/materials

• The total wiring system including insulation, system design, handling procedures, and circuit protection need to be considered further.
SELECTION OF THE SPACE STATION FREEDOM (SSF) FLAT COLLECTOR CIRCUIT (FCC) INSULATION MATERIAL

Dawn Emerson
NASA Lewis Research Center
Cleveland, Ohio

FUNCTION OF FCC:

A FLEXIBLE CABLE WHICH PROVIDES MULTIPLE ELECTRICAL PATHS FOR THE DISTRIBUTION OF ELECTRICAL POWER FROM CIRCUIT COMPONENTS ON THE SSF SOLAR ARRAY.
REQUIREMENTS OF THE FCC WHICH AFFECT THE SELECTION OF THE INSULATION MATERIAL

THE FCC SHALL PERFORM AS SPECIFIED AFTER EXPOSURE TO THE FOLLOWING ENVIRONMENTS:

- ATOMIC OXYGEN EXPOSURE - TOTAL FLUENCE $5.4 \times 10^{22} \text{ AO/CM}^2$. (15 YEARS OF EXPOSURE)
- ULTRAVIOLET RADIATION EXPOSURE - 10 SUN YEARS (2/3 OF ILLUMINATED ORBITAL TIME OVER 15 YEARS).
- THERMAL CYCLES - 87,000 THERMAL CYCLES BETWEEN $\pm 100^\circ\text{C}$.
- STORAGE LIFE - 5 YEARS SHELF LIFT UNDER FOLLOWING ENVIRONMENT:
  
  \[
  \begin{align*}
  \text{TEMPERATURE} & = +10, +40^\circ\text{C} \\
  \text{RELATIVE HUMIDITY} & = 20 \text{ TO } 60\% \\
  \text{PRESSURE} & = 650 \text{ TO } 810 \text{ TORR}
  \end{align*}
  \]

OTHER REQUIREMENTS:

- THE FCC SHALL NOT ADHERE TO ITSELF. (BLOCKING)
- THE SURFACE OF THE FCC SHALL HAVE A SOLAR ABSORPTIVITY $\leq .45$ BOL.
- THE SURFACE OF THE FCC SHALL HAVE AN INFRARED EMISSIVITY $\geq .85$ AT BOL.
DATA TO SUPPORT THE SELECTION OF THE FCC INSULATION MATERIAL WAS OBTAINED THRU DEVELOPMENT WORK ASSOCIATED WITH THE SA COVERLAY.

- THE SAME MATERIAL IS USED FOR THE FCC INSULATION AND THE SA COVERLAY.

- THE DEVELOPMENT WORK TO BE PRESENTED WAS DONE ON THE SOLAR ARRAY COVERLAY MATERIAL. THE FINDINGS ARE APPLICABLE TO THE FCC APPLICATION.
  - COVERLAY IS THE STRUCTURAL LAYER OF THE SOLAR ARRAY TO WHICH THE SOLAR CELLS ARE BONDED.
  - COVERLAY ALSO FUNCTIONS AS THE DIELECTRIC BETWEEN THE INTERCONNECTING CIRCUITRY ON THE SA AND THE LEO ENVIRONMENT.

DEVELOPMENT HISTORY

INITIAL SELECTION (1989):
SiOx COATED 1 MIL THICK KAPTON H.

- INITIAL DESIGN WAS BASED ON MILSTAR AND SAFE FLEXIBLE SOLAR ARRAY DESIGNS AND MATERIAL DEVELOPMENT WORK PERFORMED BY LMSC UNDER LeRC CONTRACT.

TESTS PERFORMED:
SHORT EXPOSURE TO RF GENERATED OXYGEN PLASMA (1 WK).

TEST RESULTS:
SiOx COATED KAPTON EXHIBITED A DECREASE IN THE AO INDUCED MASS LOSS RATE RELATIVE TO BARE KAPTON (REDUCTION IN MASS LOSS RATE UP TO 100x).

TEST LIMITATIONS:
LONG DURATION TESTS NECESSARY FOR SSF APPLICATIONS WERE OUTSIDE THE SCOPE OF THE INITIAL MATERIAL DEVELOPMENT PROGRAM.
INITIAL SELECTION (1989)

FURTHER TESTING FOR SSF APPLICATIONS

TESTS PERFORMED:
SIMULATED LONG DURATION AO STABILITY TESTS (SIMULATED 15 YR EXPOSURE).

TEST RESULTS:

- SiOx COATING ITSELF DISPLAYED SUPERIOR STABILITY AGAINST AO ATTACK.
- ANY BREAKS INITIALLY PRESENT IN COATING RESULTED IN EROSION OF THE UNDERLAYING MATERIAL.
- TENSILE STRENGTH OF THE COVERLAY DECREASES RAPIDLY DUE TO THE LOW TEAR PROPAGATION STRENGTH OF KAPTON.

CONCLUSION:

- COVERLAY APPLICATION REQUIRED A MATERIAL WITH GREATER MECHANICAL STRENGTH RETENTION TO MEET SA LOAD REQUIREMENTS.
- EROSION OF THE KAPTON INSULATION MATERIAL IN THE FCC APPLICATION MAY INCREASE THE PROBABILITY OF SHORT CIRCUIT...
MODIFIED DESIGN

E-GLASS TESTING:

<table>
<thead>
<tr>
<th>ENVIRONMENT</th>
<th>DURATION/EXPOSURE</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>HUMIDITY</td>
<td>30 DAY AT 90% RH 85°C</td>
<td>EXHIBITED ADEQUATE PROPERTIES FOR LONG TERM STORAGE.</td>
</tr>
<tr>
<td>SIMULATED ATOMIC OXYGEN ON UNSIZED E-GLASS</td>
<td>EFFECTIVE FLUENCE 1.5 x 10^{22} AO/CM^2 30% EXPECTED SSF EXPOSURE</td>
<td>NO CHANGE IN MATERIAL STRENGTH</td>
</tr>
<tr>
<td>SIMULATED AO (S-938* SIZING) ON SIZED E-GLASS</td>
<td>.07 x 10^{22} AO/CM^2 1% EXPECTED SSF EXPOSURE</td>
<td>30% LOSS IN TENSILE STRENGTH/ STRENGTH OF SIZED CLOTH REMAINED ABOVE STRENGTH OF UNSIZED CLOTH</td>
</tr>
</tbody>
</table>

*SILANE SIZING (S-938) INCREASES THE TENSILE STRENGTH AND IMPROVES THE ADHESION OF FIBERS TO SILICONE.

MODIFIED DESIGN (1990) BASELINE:

- 1300Å SiOx COATING
- 1 MIL KAPTON H
- 1300Å SiOx COATING
- 1.5 MIL THICK STYLE 106 E-GLASS IMPREGNATED WITH NUSIL TECHNOLOGY CV1-2502 SILICONE
- 1 MIL BARE KAPTON HN

ADVANTAGES OF NEW DESIGN:

- FIBERGLASS PROVIDES STRENGTH RETENTION (ASSUMES LOAD CARRYING ROLE).
- 2 LAYERS OF SiOx COATING PROTECT THE FIBERS IN THE SILICONE MATRIX.
- EVEN AFTER THE FIBERS IN THE SILICONE MATRIX ARE EXPOSED, STABILITY OF THE GLASS UNDER AO EXPOSURE WILL AID IN MAINTAINING TEAR RESISTANCE AND STRENGTH.
- OUTER LAYER OF SiOx PREVENTS BLOCKING.
COVERLAY TESTING - ASSUMED END-OF-LIFE CONFIGURATION

EOL CONFIGURATION REPRESENTS WORST-CASE CONDITION AFTER BOTH LAYERS OF KAPTON ARE ERODED AWAY. CONFIGURATION CONSIDERED TO PRODUCE CONSERVATIVE RESULTS.

ENVIRONMENT DURATION/EXPOSURE RESULTS

1. AO EFFECTIVE FLUENCE
   2.9 x 10^{22} AO/CM^2
   60% SSF EXPOSURE LEVEL
   o* EMBRITTLED REGIONS
   o LOSS OF TENSILE STRENGTH

*RESULTS WERE NOT CONSIDERED WITH EXPECTED RESULT BASED ON LDEF DATA, WHICH INDICATED SILICONE HAS GOOD RESISTANCE TO AO EMBRITTLEMENT.

UV 8000 EQUIVALENT INCREASE IN TENSILE STRENGTH FROM 30-40 LB/IN SUN HRS AT 2 SUNS INTENSITY NO CRACKING OBSERVED. SLIGHT DARKENING

ENVIRONMENT DURATION/EXPOSURE RESULTS

2. AO 80% SSF RETENTION OF TENSILE STRENGTH PROPERTIES ON BOTH BOL, EOL SPECIMENS (RECENT DATA EXPOSURE LEVEL SEPARATE LOT)

*THE VARIATION IN TEST VALUES EXHIBITED IN AO TEST 1 COMPARED TO EARLIER DATA AND CURRENT DATA ARE ATTRIBUTED TO EITHER:

   o DEPENDENCE OF TEST CONFIGURATION
   o LOT TO LOT VARIATION
CONCLUSION

THE MOST SIGNIFICANT ENVIRONMENTAL EXPOSURE EFFECTS ARE FROM ATOMIC OXYGEN.

THE MODIFICATION TO THE COVERLAY PROVIDE FOR GREATER ROBUSTNESS TO THE EFFECTS OF LONG LEO EXPOSURE.

EFFECTS ON MODIFIED DESIGN ON FCC

0 CHANGES TO THE COVERLAY DRIVEN BY THE NEED TO IMPROVE THE SA STRENGTH RETENTION SERVED TO BENEFIT THE FCC:

1. PROVIDES BETTER PROTECTION AGAINST THE OCCURRENCE OF EXPOSED COPPER CONDUCTOR.

   (INITIAL DESIGN - IMPERFECTIONS IN SiOx COATING RESULTED IN EROSION OF KAPTON AND SUBSEQUENT TEARING, LEADING TO EXPOSED CONDUCTOR.)

*2. A. TESTS INDICATE THE MODIFIED DESIGN IS MORE RESILIENT TO ARC TRACKING INITIATION.

   B. MODIFIED DESIGN ELIMINATED FLASH OVER.

* NASA CONTRACTOR REPORT 191106, THOMAS J. STUEBER
ARC TRACKING TESTS PERFORMED ON FCC CHARACTERRISTIC OF KAPTON:

KAPTON POLYIMIDE WIRING INSULATION IS VULNERABLE TO PYROLIZATION (CHARRING), ARC TRACKING AND FLASHOVER WHEN MOMENTARY SHORT CIRCUIT ARCS APPEAR.

- ARC TRACKING OCCURS WHEN THE SHORT CIRCUIT ARC PROPAGATES DOWN THE WIRE THRU CONTINUED PYROLIZATION.
- FLASHOVER OCCURS WHEN AN ARC INVOLVING ONE PAIR OF WIRES CHARS ADJOINING WIRING Resulting in MULTIPLE FAILURES.

ARC TRACKING TEST WERE CONDUCTED BY:

1. GENERATING A DEFECT LOCATED BETWEEN ONE OF THE SUPPLY LINES AND ITS CORRESPONDING RETURN LINE WHICH EXPOSES A SMALL AREA OF THE COPPER RETURN LINE.

2. SAMPLES WERE PREPYROLIZED BY CREATING A MOMENTARY SHORT CIRCUIT ARC. POWER WAS THEN TURNED OFF.

3. TEST WAS CONDUCTED TO DETERMINE THE MINIMUM OPEN CIRCUIT VOLTAGE AND SHORT CIRCUIT CURRENT NECESSARY TO RESTART THE ARC TRACKING EVENT.

FLASHOVER TESTS WERE CONDUCTED ON 3 SIDE-BY-SIDE ENERGIZED CHANNELS.

1. FLASHOVER TEST WAS CONDUCTED BY PROMOTING THE ARC TRACKING EVENT BY SHORTING THE MIDDLE CHANNEL WITH ADJOINING CHANNELS ENERGIZED.
ARC TRACKING TEST RESULTS

ARC TRACKING:

A MOMENTARY SHORT CIRCUIT DID INITIATE KAPTON PYROLYSIS AT POWER LEVELS BELOW SSF OPERATING LEVELS. HOWEVER, NEW DESIGN WAS MORE RESILIENT TO ARC TRACKING INITIATION THAN PREVIOUS DESIGN.

PREVIOUS DESIGN:
ARC TRACKING WAS INITIATED AT THE EPOCH OF THE FIRST MOMENTARY SHORT CIRCUIT.

NEW DESIGN:
TYPICALLY SEVERAL MOMENTARY SHORT CIRCUITS WERE NEEDED TO PYROLYZE THE POLYIMIDE ENOUGH TO INITIATE ARC TRACKING.

FLASHOVER:

THE FLASHOVER EVENT OBSERVED IN EARLIER DESIGNS DID NOT OCCUR WITH THE MODIFIED DESIGN.
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NASA PARTS PROGRAM OFFICE RESPONSIBILITIES

Patrick L. Kilroy
NASA Goddard Space Flight Center
Greenbelt, Maryland

NASA PARTS PROGRAM OFFICE RESPONSIBILITIES

- DESIGNATED AS LEAD CENTER OFFICE FOR ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL PARTS STANDARDIZATION
- PROGRAM FUNDING FROM NASA HEADQUARTERS OFFICE OF SAFETY AND MISSION ASSURANCE, CODE Q
- LEAD CENTER RESPONSIBILITIES DEFINED THROUGH A NASA MANAGEMENT INSTRUCTION

NASA PARTS PROJECT OFFICE RESPONSIBILITIES

- NMI 5320.6B REQUIREMENTS:
  - ESTABLISH AND ENSURE COMPLIANCE FOR EEE PARTS TECHNICAL REQUIREMENTS
  - OBTAIN CENTER PARTS USAGE DATA
  - DEVELOP AND SUPPORT THE EEE PARTS INFORMATION MANAGEMENT SYSTEM
  - ESTABLISH GROUNDRULES FOR STANDARD PART SELECTIONS
  - EVALUATE AND COORDINATE GOVERNMENT AND MILITARY SPECIFICATIONS, STANDARDS, AND HANDBOOKS
  - ESTABLISH STANDARD PART QUALIFICATION REQUIREMENTS, PERFORM MANUFACTURER AUDITS AND SURVEYS, LEVERAGE OFF QPL AND QML ACTIVITIES
  - UPDATE AND MAINTAIN STANDARD PART DOCUMENTS (MIL-STD-975, MIL-HDBK-978, ETC...)
  - DEVELOP TEST AND ANALYSIS REQUIREMENTS, PERFORM PRODUCT EVALUATIONS, DISSEMINATE TEST RESULTS AND REPORTS TO CENTERS, PARTICIPATE IN THE GIDEP PROGRAM
Development Priorities
Identified by the NASA Parts Steering Committee

• GIDEP
  - NASA internal problem rating and status notification system for projects
  - closed-loop system
  - remote notification of impacts to contractors, PI's
• MIL-STD-975
  - complete version with notes, etc.
  - grandfathered versions
  - part selection by attributes
  - nomination of parts; status of candidate parts
• NASA Advisories
  - link to project problem reporting system
• Project Parts Lists
  - enhanced reports
  - direct capture from CAD applications
• Derating Criteria
  - derating calculation
• Manufacturer Surveys/Audits
• Radiation Data
• Parts Library — specification information, selection of parts by parameters

Development Priorities
Identified by the NASA Parts Steering Committee
(continued)

• Parts Selection Lists
• NASA In-House Parts Inventory
• NSPAR's
• Part Specifications
• Reliability Data
• MIL-HDBK-978
• FA's, DPA's, & Evaluations — input function for NASA centers
• Additional reporting capabilities (all functions and applications)
• Functions to download and export data to PC client
• Contractor node implementations
• Technical Documents
• Technical News
Candidate Functions for EPIMS baseline

- GIDEP FEDI and NASA Advisories
- CAGE Directory
- FSC Directory
- User Directory
- Project Parts Lists
- Alert/Advisory Impact Cross-Reference
- MIL-STD-975
- Parts Lists Comparison
- NSPAR's
- Manufacturer Surveys/Audits
- Parts News and Technical Document Archives
- FA/DPA/Evaluation Reports
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BASIC GOALS

1. Determine Standard Parts

2. Route Information Through the Standards and Users Communities

3. Encourage Standardization

A Standard Part
Per MIL-STD-975

1. Application Need

2. Technological Maturity

3. Availability of Manufacturers

4. Test or Usage History

5. Characterization Data

6. Evaluation Tests

7. Specification

8. Qualification
Standard Wire in MIL-STD-975

MIL-W-22759 Fluoropolymer
MIL-W-81381 Polyimide Removed 1993
MIL-W-16878 Fluoropolymer (non-QPL) Removed 1993
MIL-C-17 RF Cable
MIL-C-27500 Cable

What Is Space Grade? or
What Is Grade 1 and Grade 2?

- Outgassing - Flammability
- Toxicity - Odor
- Atomic Oxygen - Toxicity
- Arc Tracking - Cold Flow

Center Specific and Application Specific

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Conduit and Catalyst for Information Transfer

<table>
<thead>
<tr>
<th>Conduit and Catalyst for Information Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SAE</strong></td>
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<tr>
<td><strong>EIA</strong></td>
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</tr>
<tr>
<td><strong>DESC/DISC/Army Lakehurst</strong></td>
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<tr>
<td><strong>NAWC</strong></td>
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<tr>
<td><strong>ESA</strong></td>
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<tr>
<td><strong>NASA</strong></td>
</tr>
<tr>
<td><strong>NASA Interconnection Standardization Working Group</strong></td>
</tr>
<tr>
<td><strong>Space Parts News</strong></td>
</tr>
<tr>
<td><strong>NASA Advisories</strong></td>
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<tr>
<td><strong>NAS Database</strong></td>
</tr>
<tr>
<td><strong>NASA Parts Steering Committee</strong></td>
</tr>
</tbody>
</table>

**I S W G**

NASA Interconnection Standardization Working Group

<table>
<thead>
<tr>
<th>NASA</th>
<th>Performance Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEMs</td>
<td>Procurement, Available Part Quality</td>
</tr>
<tr>
<td>Military</td>
<td>Performance Requirements, Qualification, Specifications</td>
</tr>
<tr>
<td>Industry</td>
<td>Standards, Manufacturing Techniques, Available Product (planned)</td>
</tr>
<tr>
<td>Academia</td>
<td>Test Data</td>
</tr>
</tbody>
</table>

Past and Present Wire Issues

- Red Plague
- Circular Mil Area
- Flammability of ETFE and XL-ETFE
- Degree of Crosslinking
- Conductor Plating
- Arc Tracking — Hybrid Wire
- Derating
WIRING RESPONSIBILITIES

PURPOSE OF PROGRAM

MEASUREMENT OF PROGRAM EFFECTIVENESS

RESULTS

SUMMARY

RESPONSIBILITIES

- DESIGN AND DEVELOP WIRING SYSTEMS
- CONDUCT ENGINEERING INVESTIGATIONS
- WIRING TESTING AND EVALUATION ACTIVITY
  (INCLUDING RECEIVING/INSPECTION)
- QUALIFICATION AGENT/TEST FACILITY
- WIRING MAINTENANCE AND LOGISTICS ENGINEERING
- HARNESS MANUFACTURING
PURPOSE OF PROGRAM

- TO PROVIDE THE MOST COST EFFECTIVE, RELIABLE WIRING COMPONENTS AND SYSTEMS TO OUR CUSTOMERS
WORKLOAD OF PROGRAM
(NUMBERS ARE APPROXIMATE)
- TECHNICAL AGENT FOR 90 SPECIFICATIONS
- QUALIFICATION AGENT FOR 80 OF THESE SPECIFICATIONS
- 300 QUALIFICATION PROJECTS PER YEAR
- 10 - 15 MAJOR COMPONENT EVALUATIONS PER YEAR

EFFECTIVENESS OF PROGRAM
- 50% FAILURE RATE ON INITIAL QUALIFICATION SUBMITTALS
- 30% FAILURE RATE IN RETENTION OF QUALIFICATION PROGRAM
- CORRECTIVE ACTION RESULTS IN OVER 90% APPROVAL RATE
- 80 - 90% OF FAILURES ARE PERFORMANCE RELATED VS. DOCUMENTATION
- 20% REJECTION RATE ON RECEIVING/INSPECTION, 25% OF THESE REJECTIONS ARE QPL PRODUCTS

RESULTS
QUALIFICATION CAN IMPROVE QUALITY BY 75%
QUALIFICATION PROGRAM REDUCES TESTING/COST
HIGHER QUALITY PRODUCTS REDUCE SYSTEM DOWNTIME
MUST BE SUPPLEMENTED BY CUSTOMER’S QUALITY ASSURANCE PROGRAM
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ORGANIZED WIRING SYSTEMS

Thomas Meiner
Naval Air Warfare Center
Indianapolis, Indiana

SUMMARY

- THE WIRING SYSTEM IS THE LINK FOR ALL SYSTEMS, AND MUST BE INCLUDED IN THE QUALITY ASSURANCE PROGRAM.

- WITHOUT QUALIFICATION AND STANDARDIZATION, WIRING MAINTENANCE COSTS WOULD BE EXORBITANT.

- NAVY STUDIES SHOW THAT WIRING (TAKEN COLLECTIVELY) IS CONSISTENTLY ONE OF THE TOP FIVE "BAD ACTOR" SYSTEMS OF EVERY AIRCRAFT TYPE FOR:

- NON-MISSION CAPABLE (NMC)
- PARTIAL MISSION CAPABLE (PMC)
- MAINTENANCE MAN HOURS (M/MHRS)
TRADITIONAL HARNESING PITFALLS

- EXPENSIVE AND DIFFICULT TO MANUFACTURE,
- NORMALLY INSTALLED PARTIALLY ASSEMBLED,
- DIFFICULT TO MAINTAIN AND MODIFY,
- REQUIRES TWISTED AND SHIELDED COMPONENTS TO CONTROL EMI,
- SIZE AND WEIGHT REDUCTION LIMITED BY MECHANICAL AND ELECTRICAL FACTORS,
- REQUIRES HIGH-COST TRAINING AND PIECE-PARTS LOGISTICS THAT IS OFTEN INEFFECTIVE, AND

- ALL MAINTENANCE IS "O" OR "D"

ORGANIZED WIRING: "WIRING WITH FIXED RELATIVE POSITIONING OF CIRCUITS. THIS IS TYPICALLY A RECTANGULAR BUNDLE."

ORGANIZED WIRING SYSTEMS

/  \  /
ROI  I^2S

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TYPICAL HARNESS CROSS SECTIONS

CONVENTIONAL HARNESS

ROI HARNESS

ALL WIRES

UNSHIELDED

OWS IS APPLICABLE TO:

• NEW DESIGN,
• REWORK,
• ECP’S, AND
• ALSO APPLIES TO MISSILES, STORES, PODS, SUSPENSION EQUIPMENT, AND AVIONIC’S SUITES
ADVANTAGES

• WEIGHT SAVINGS
• IMPROVED RELIABILITY
• PREDICTABLE EMI PERFORMANCE
• IMPROVED MAINTAINABILITY
• LIFE CYCLE COST SAVINGS
• ACTIVE WIRING FEATURES

RIBBON HARNESSES REDUCE WEIGHT BY:

• ELIMINATION OF INDIVIDUAL SHIELDS AND JACKETS,
• LESS OUTER BRAID PER UNIT HARNESS LENGTH,
• ELIMINATION OF SHIELD - TERMINATORS AND EMI BACKSHELLS,
• DOWN-GUAGING OF WIRES DUE TO IMPROVED MECHANICAL AND ELECTRICAL CHARACTERISTICS OF RIBBONS, AND
• REPLACING HEAVY COAX WITH STANDARD WIRE IN CERTAIN APPLICATIONS
WIRING SYSTEM WEIGHT REDUCTION TECHNIQUES
DOWNGAUGING VS. SHIELD ELIMINATION
(WEIGHTS USED ARE TYPICAL)

<table>
<thead>
<tr>
<th>24 GAUGE</th>
<th>26 GAUGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHIELDED WIRE</td>
<td>SHIELDED WIRE</td>
</tr>
<tr>
<td>7.3 LBS/KFT</td>
<td>6.2 LBS/KFT</td>
</tr>
<tr>
<td>15% REDUCTION</td>
<td></td>
</tr>
<tr>
<td>24 GA REG WIRE</td>
<td>26 GA REG WIRE</td>
</tr>
<tr>
<td>2.5 LBS/KFT</td>
<td>1.8 LBS/KFT</td>
</tr>
<tr>
<td>66% REDUCTION</td>
<td>75% REDUCTION</td>
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</tbody>
</table>

ORGANIZATION METHODOLOGY

• CIRCUITS ARE GROUPED BY AMPERAGE ONTO POWER RIBBONS AND SIGNAL RIBBONS

• CIRCUITS ARE POSITIONED ON RIBBONS TO ELIMINATE DETRIMENTAL CROSSTALK; FOR EXAMPLE,
  - LOW IMPEDANCE GROUPING
  - HIGH IMPEDANCE GROUPING
  - SPIKE CIRCUITS POSITIONING

• HIGH AMPERAGE CIRCUITS MAY BE SEPARATED TO ENHANCE HEAT DISSIPATION; FOR EXAMPLE,
  - “ON/OFF” CIRCUIT SEQUENCING

• RESULTS IN RELIABLE, PREDICTABLE E³ PERFORMANCE
WIRING INTEGRATION UNITS
PERFORM MANY FUNCTIONS:

• CIRCUIT COLLECTION AND REDISTRIBUTION POINTS,
• RIBBONS HARNESS CIRCUIT ORGANIZATION POINTS,
• WIRE GAUGE CHANGE POINTS,
• RIBBON HARNESS/ENDPOINT HARNESS INTERFACE

WIU's CAN INCORPORATE:

• ACTIVE CIRCUITRY (RELAYS, IC'S, FUEL QUANTITY SYSTEM SIMULATORS, ETC.),
• DISCRETE FILTERS,
• DATA BUS COUPLERS/FIBER OPTIC DECODERS,
• BUILT-IN-TEST (BIT) SYSTEMS,
• SYSTEM MONITORING CIRCUITRY, AND
• SELF-HEALING CAPABILITIES
• MODULARITY PROVIDES:

- SYSTEM GROWTH POTENTIAL AND SIMPLIFIES MODIFICATION

- ENHANCED REPAIR CAPABILITIES BOTH ON AND OFF AIRCRAFT

- THE CAPABILITY TO REPLACE DAMAGED/REPAIRED HARNESSES AND WIUs TO BRING WIRING SYSTEM BACK TO "LIKE NEW" CONDITION DURING THE ENTIRE SERVICE LIFE OF THE AIRCRAFT

- FOR THE FULL APPLICATION OF THE LOGISTICS SUPPORT ANALYSIS (LSA) PROCESS TO WIRING SYSTEMS

- LIFE CYCLE COST SAVINGS

END POINT HARNESSES:

• ARE SHORT AND SIMPLE

• R&R AT "O" AND REPAIR AT "1"

• EASILY UPGRADED OR REPLACED FOR SYSTEM UPGRADES, AND

• CAN INCORPORATE CERTAIN RIBBON HARNESS FEATURES
MEMORANDUM

From: AIR-546
To: AIR-511A
Via: AIR-516

Subj: CHANGE TO SD-24

1. During a meeting among AIR-546, AIR-516, and AIR-411 it was decided to revise paragraph 3.16.5 of SD-24 as follows:

   a. 3.16.5 WIRING - The signal and power distribution wiring shall be an organized wiring system such that all circuits are maintained in the same relative position to one another throughout their entire length. The design of the organized wiring system and the selection of its electrical components shall be proposed by the contractor and approved by NAVAIR. Conventional electrical wiring...

2. We all concur with this approach. I am preparing a separate package that will be routed for AIR-05 and AIR-04 endorsement of this change.

3. If there are any questions my point of contact is Mr. David Felmeyer, 692-T125, AIR-546D4

Copy to:
AIR-411
AIR-546D4
AIR-516


BENEFITS OF ROI

- WEIGHT SAVINGS THROUGH ORGANIZATION AND ELIMINATION OF INDIVIDUAL SHIELDS AND ASSOCIATED HARDWARE
- LIFE CYCLE COST SAVINGS
- RELIABLE, PREDICTABLE E² PERFORMANCE
- UTILIZES EXISTING TOOLS, LITTLE ADDITIONAL TRAINING
- DESIGN FLEXIBILITY TO MEET SYSTEM REQUIREMENTS
- INTERFACES WITH EXISTING AVIONICS
ADVANTAGES OF WOVEN RIBBON ELEMENTS:

ROI RIBBONS:

- Are not restricted to "standard" ribbon widths,
- Can incorporate any gauge size wires,
- May be designed with a mixture of gauge sizes,
- Are easily fabricated, and
- Are compatible with existing fleet maintenance equipment

ROI HARNESS TERMINATION FLEXIBILITY

ROI HARNESSES:

- Are not design restricted to any specific connector type,
- May be terminated using either rectangular or circular connectors,
- Are compatible with most MILSPEC connectors,
- May be crimped or soldered, and
- The wires terminate directly into all connectors without the use of any transitional element
ROI HARNESSSES REDUCE BATTLE DAMAGE EFFECTS

- ROI HARNESSSES SUSTAIN MINIMAL DAMAGE FROM PROJECTILE PENETRATION AS COMPARED TO CONVENTIONAL WIRING BUNDLES,

- ROI DESIGN EXPEDITEES BATTLE DAMAGE ASSESSMENT AND REPAIRS,

- DAMAGED RIBBONS ARE "ZIPPED" BACK TOGETHER WITH STANDARD CRIMP SPLICES WITHOUT THE NEED FOR I.D. MARKING,

- REPLACING SEVERLY DAMAGED ROI HARNESSSES IS PLAUSIBLE AND GREATLY SIMPLIFIED COMPARED TO REPLACING CONVENTIONAL SPIDER HARNESSSES.

A-6E RELIABILITY & MAINTAINABILITY (R&M) PYLON

ORIGINAL WEAPONS CONTROL SYSTEM IMPROVEMENT (WCSI) PYLON DESIGN
V-22 WIRING IMPROVEMENT STUDY
WEIGHT SUMMARY 24 JAN 1991

<table>
<thead>
<tr>
<th></th>
<th>BASELINE</th>
<th>ROI</th>
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<tbody>
<tr>
<td>MIDWING HARNESS</td>
<td>239 LBS</td>
<td>132 LBS</td>
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<tr>
<td>REDUCTION</td>
<td>------</td>
<td>45%</td>
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<tr>
<td>FULL AIRCRAFT</td>
<td>1546 LBS</td>
<td>1185 LBS</td>
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<tr>
<td>ESTIMATE *</td>
<td>------</td>
<td>23.4%</td>
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</table>

* EXTRAPOLATED FROM MIDWING RESULTS USING BELL BOEING GROUND RULES.
V-22 WIRING IMPROVEMENT STUDY
COST SUMMARY 24 JAN 1991
(MIDWING AREA ONLY)

<table>
<thead>
<tr>
<th></th>
<th>BASELINE</th>
<th>ROI</th>
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</thead>
<tbody>
<tr>
<td>R&amp;D (NRE)</td>
<td>$1,216,600</td>
<td>$1,473,300</td>
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<tr>
<td>INVESTMENT (PRODUCTION)</td>
<td>$152,921,900</td>
<td>$110,656,121</td>
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<tr>
<td>O&amp;S (SPARES)</td>
<td>$6,108,800</td>
<td>$3,571,700</td>
</tr>
<tr>
<td></td>
<td>$160,247,300</td>
<td>$115,701,121</td>
</tr>
</tbody>
</table>

% REDUCTION: 28%

1) BASED ON 913 A/C PRODUCTION RUN.

- OWS PROVIDES BENEFITS IN COST, WEIGHT, R&M, E³ PERFORMANCE, AND GROWTH POTENTIAL
- MODULARITY OF HARNESSES AND WIUs SIGNIFICANTLY IMPROVES WIRING SYSTEM LOGISTICS SUPPORT
- COMPLETE ROI WIRING SYSTEM CURRENTLY BEING DEVELOPED FOR THE V-22
- ORGANIZED WIRING TO BE APPLIED IN FUTURE AIRCRAFT PLATFORMS AND REWIRE PROGRAMS
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NEMA WIRE AND CABLE STANDARDS DEVELOPMENT PROGRAMS

Robert W. Baird
National Electrical Manufacturers Association
Washington, DC

NEMA

National Electrical Manufacturers Association

WHAT IS NEMA?

"The National Electrical Manufacturers Association (NEMA) is the Nation's Largest Trade Association for Manufacturers of Electrical Equipment. Its Member Companies Produce Components, End-Use Equipment and Systems for the Generation, Transmission, Distribution, Control and Use of Electricity."
WHAT IS NEMA?

STRUCTURE

- 600 Member Corporations
- Approximately 100 Staff
- $10 Million Annual Budget
- 9 Divisions
- 68 Product Sections
- Affiliate Organizations:
  - Automation Forum (AF)
  - Joint Committee on Business Communications and Productivity (BCP)
  - National Lighting Bureau (NLB)

OUR MISSION

THROUGH NEMA, THESE COMPANIES COOPERATE IN STRIVING:

- To Meet Customer Needs and Public Interest With World Class Products and Services
- To Encourage the Innovative Application of Existing and Emerging Technology To Electrical Products
- To Accelerate the Growth and Enhance the Vitality of the Industry
OUR MISSION

Through The Cooperative Efforts of Its Members and Staff NEMA Pursues Its Mission by:

1. Engaging in the Development of Codes and Standards

2. Promoting Safety in the Manufacture and Use of Electrical Products

3. Communicating Appropriate Information About the Industry

4. Advocating its Views to Government Bodies and Other Interested Parties on Matters Affecting the Industry

5. Conducting Educational Forums

6. Promoting the Industry

WHAT IS NEMA?

PRODUCT ORIENTATION

• Industrial Automation

• Lighting Equipment

• Electronics

• Industrial Equipment

• Building Equipment

• Insulating Materials

• Wire and Cable

• Power Equipment

• Diagnostic Imaging and Therapy Systems
WHAT IS NEMA?

Activities

• National and International Standards

• Statistics

• Public Relations

• International Affairs

• Government Affairs

• Environmental Affairs

• Legal Affairs

• Market Relations

• Jointly Funded Research

• Education and Training
WIRE AND CABLE DIVISION

• 6 Sections
  - Building Wire and Cable
  - Fabricated Conductors
  - Flexible Cords
  - High Performance Wire and Cable
  - Magnet Wire
  - Power and Control Cable

• 60 Member Companies

• 5 Staff
WIRE AND CABLE DIVISION

Magnet Wire Section

Insulated conductors of the types generally used in the creation of an electromagnetic field.

*****

Alcatel Canada Wire, Inc.
American Wire Corporation
Bridgeport Insulated Wire Co.
Chicago Magnet Wire Corporation
Elektrisola, Inc.
Essex Group

Magnatek Lighting Products
Optec DD, USA, Inc.
Phelps Dodge Magnet Wire
Rea Magnet Wire Company
Southwire Specialty Products
Westinghouse Electric Corp.

WIRE AND CABLE DIVISION

Flexible Cords Section

Fixture and appliance wires and flexible cords including power supply cords, cord sets, and extension cords, with or without a molded on fitting or an attached wiring device.

*****

American Electric Cordsets
Belden
Carol Cable Company
Coleman Cable and Wire Company
Essex Group

General Cable Company
Leviton Mfg. Company
Pacific Electricord
Triangle Wire and Cable Company
Woods Wire Products
WIRE AND CABLE DIVISION

Building Wire and Cable Section

Building wire and cable including thermoplastic, thermoset, non-metallic, service entrance, armor and metal clad, underground feeder, machine tool, and branch circuit wire and cables.

*****

Alcan Cable
Carol Cable Company
Coleman Cable Corporation
Colonial Wire and Cable
General Cable Company
Okonite Company
Pacific Electricord Company
Pirelli Cable Corporation
Rome Cable Corporation
Royal Electric
Southwire Company
Triangle Wire and Cable

WIRE AND CABLE DIVISION

Power and Control Cable Section

Solid dielectric insulated wire and cables including thermosetting, thermoplastic, single and multiconductor, jacketed, sheathed or armored for power and control applications.

*****

Alcan Cable
Alcatel Chester Cable Corp.
Amercable
BICC Cables Corp.
Cablec Continental Cables Co.
Carol Cable Company
Furon Company
The Okonite Company
Pirelli Cable Corporation
The Rockbestos Company
Rome Cable Corporation
Royal Electric
Southwire Company
Triangle Wire and Cable
WIRE AND CABLE DIVISION

High Performance Wire and Cable Section

Insulated signal and communications cable, coaxial cable, hook-up wire, appliance wiring material, power-limited circuit cable, thermocouple wire, shipboard cables, airframe and automotive wire and cable.

American Electric Cable
Astro Industries
AT&T
Barcel Wire and Cable Corp.
Berk-Tek, Inc.
Brand-Rex
Cablec Continental Cables Corp.
Cable USA, Inc.
Cooper Industries/Belden
Delta Surprenant Wire and Cable
Furon Company
Harbor Industries
Helix/Hitemp Cables
Independent Cable, Inc.
Kris-Tech Wire Company
Champlain Cable Corp.

Micro-Tek Corporation
Mohawk Wire and Cable Company
Montrose Product Company
The Okonite Company
Pacific Electricord Company
Carol Cable Company
Philadelphia Insulated Wire
Prestolite Wire Corporation
Quirk Wire Company
Radix Wire Company
The Rockbestos Company
Siecor Corporation
Speciality Cables Corp.
Tensolite Company
Times Microwave Systems
Triangle Wire and Cable

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WIRE AND CABLE DIVISION

Activities

- National and International Standards
- Statistics
- Public Relations
- International Affairs
- Government Affairs
- Environmental Affairs
- Legal Affairs
- Market Relations
- Jointly Funded Research

WIRE AND CABLE DIVISION

Technical Liaisons

- UL
- CSA
- NFPA
- EEMAC
- EIA
- ICEA
- ASTM
- SPI
- DESC
- NAVSEA
- NAVAIR
- NASA
- Other Supplier and User Groups
WIRE AND CABLE DIVISION

NEMA Wire and Cable Standards

HP 3-1987 (R1992) Electrical and Electronic PTE (Polytetrafluoro-ethylene) Insulated High Temperature Hook-Up Wire (600 Volt), EE (1000 Volt), and ET (250 Volt)

HP 4-1988 Electrical and Electronic FEP Insulated High Temperature Hook-Up Wire, Type K, KK, and KT

HP 100-1991 High Temperature Instrumentation and Control Cables (Set)

HP 100.1-1991 High Temperature Instrumentation and Control Cables Insulated and Jacketed with FEP Fluorocarbons

HP 100.2-1991 High Temperature Instrumentation and Control Cables Insulated and Jacketed with EFTE Fluoropolymers

HP 100.3-1991 High Temperature Instrumentation and Control Cables Insulated and Jacketed with Cross-Linked (Thermoset) Polyolefin (XLPO)

HP 100.4-1991 High Temperature Instrumentation and Control Cables Insulated and Jacketed with ECTFE Fluoropolymers

MW 750-1984 (R1990) Dynamic Coefficient of Friction of Film Insulated Magnet Wire

MW 755-1991 Straight Flange Magnet Wire Plastic Spools/Reels

MW 760-1991 Tapered Flange Magnet Wire Plastic Spools/Reels

MW 765-1992 Reclaiming Magnet Wire Plastic Spools/Reels

MW 770-1993 Unified Customer Labeling for Magnet Wire Products

MW 800-1989 Guidelines for Precautionary Labeling of Magnet Wire
## WIRE AND CABLE DIVISION

### NEMA Wire and Cable Standards (Continued)

<table>
<thead>
<tr>
<th>No.</th>
<th>Standard Details</th>
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<tbody>
<tr>
<td>MW 1000-1993</td>
<td>Magnet Wire</td>
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<tr>
<td>WC 5-1992</td>
<td>Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy</td>
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<tr>
<td>WC 8-1988</td>
<td>Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-68-516)</td>
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<td>WC 26-1990</td>
<td>Wire and Cable Packaging</td>
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WIRE AND CABLE DIVISION

NEMA Wire and Cable Standards (Continued)

WC 52-1984 (R1991) High Temperature and Electronic Insulated Wire-Impulse Dielectric Testing


WC 55-1992 Instrumentation Cables and Thermocouple Wire (ICEA S-82-552)

WC 56-1986 3.0 kHz Insulation Continuity Proof Testing of Hook-Up Wire

WC 57-1990 Standard for Control Cables (ICEA S-73-532)

WC 58-1991 Standard for Portable and Power Feeder Cables for Use in Mines and Similar Applications

WC 61-1992 Transfer Impedence Testing

WIRE AND CABLE DIVISION

1993 Technical Activities

• UL/CSA Standards Harmonization
  - UL 62/CSA 49
  - UL 817/CSA 21
  - UL 758/CSA 210.2

• NEMA Standards Revisions
  - MW 1000
  - WC 3
  - WC 5
  - WC 7
  - WC 8
  - WC 53
  - WC 54
  - WC 56
  - WC 57
  - WC 58

• Participation/Support of ICEA Standards Development

• Development of Proposals for 1996 National Electrical Code

• Development of Input to UL PVC Compound Recognition Program

• Development of Proposed Revision to UL 719 Joint-pull Test

• Development of Proposed Updates to UL and ASTM Requirements for Compressed Strand Wire

• Development of Proposed Update to MIL-C-17
WIRE AND CABLE DIVISION

1993 Technical Activities
(Continued)

• Development of Proposed WC 63 on Premises Wiring Cables

• Consideration of Proposed NEMA Testing Methods for Dry Arc Tracking

• Consideration of Metrization Requirements

• Develop Input to ISO/TC 20 on Aircraft Wire and Cable

• Development of Proposed Bar Coding Standards for Wire and Cable Products

• Development of Proposed Commercial Item Description for Plenum Cable

• Development of Response on Military Prohibition of Silver Plated Conductors - MIL-STD-454

• Development of Proposed Revision to MIL-C-24640

• Round-robin Testing of Hybrid Wire Types

• Provide Input to MIL-C-27500

• Provide Input to MIL-W-22759 Polytetrafluoroethylene/Polymide Insulated Wire and Cable

• Provide Input to MIL-W-16878
WIRE AND CABLE DIVISION

- Diversity of Activity
- Changing to Reflect a Changing World
- Faster Paced
- Attuned to the Membership
- Attuned to Members' Markets
Page intentionally left blank
MSFC INSPECTIONS OF INSTALLED POLYIMIDE WIRE HARNESSES

• AN ALERT WAS ISSUED BECAUSE OF THE ARC-TRACKING POSSIBILITIES OF THIS TYPE OF WIRE

• MSFC UNDERTOOK A PROGRAM TO TRY TO ENHANCE THE SAFETY AND RELIABILITY OF THESE HARNESSES

• ONE ELEMENT OF THIS PROGRAM WAS INSPECTION OF INSTALLED WIRING HARNESSES

• PHOTOGRAPHS WILL BE PRESENTED SHOWING THE NEED FOR SUCH INSPECTIONS
WIRING HARNESS TOO NEAR THE EXHAUST PLUME OF HYPERGOLIC THRUSTER

SPLICES OF WIRING HARNESS UNDER HARNESS TIE
BACK SIDE OF HARNESS RUBBING AGAINST SHARP EDGE

HARNESS UNDERNEATH BRAIDED PROPELLANT LINE
SESSION III

WIRING TEST RESULTS
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INSULATION TESTING AND ANALYSIS

• IDENTIFY AND PRIORITIZE NASA WIRING REQUIREMENTS
• SELECT CANDIDATE WIRING CONSTRUCTIONS
• DEVELOP TEST MATRIX AND FORMULATE TEST PROGRAM
• MANAGE, COORDINATE, AND CONDUCT TESTS
• ANALYZE AND DOCUMENT DATA. ESTABLISH GUIDELINES AND RECOMMENDATIONS

TEST PROGRAM

CANDIDATE SYSTEMS:

• FILOTEX
• THERMATICS
• TENSOLITE
• GORE
• M 81381
• M 22759
• SILICONE RUBBER
• TEFLOM

CONFIGURATION:

• MIL-W-81381 & MIL-W-22759 CONSTRUCTIONS
• AWG: #12, #20
• SINGLE WIRE
• TWISTED PAIR
• BUNDLING
## WIRING CONSTRUCTIONS

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>INSULATION SYSTEM</th>
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<tbody>
<tr>
<td>FILOTEX</td>
<td>PTFE / PI / FEP</td>
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<tr>
<td>THERMATICS</td>
<td>PTFE / PI / PTFE</td>
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<tr>
<td>TENSOLITE</td>
<td>PTFE / PI / PTFE</td>
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<tr>
<td>GORE</td>
<td>PTFE / HS PTFE / PTFE</td>
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<tr>
<td>81381</td>
<td>FEP / PI</td>
</tr>
<tr>
<td>22759</td>
<td>XL - TEFZEL (ETFE)</td>
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<tr>
<td>SILICONE RUBBER</td>
<td>SILICONE RUBBER</td>
</tr>
<tr>
<td>TEFION</td>
<td>TFE</td>
</tr>
</tbody>
</table>

## PARTICIPATING ORGANIZATIONS

- McDonnell Aerospace Company
- NASA LDR: Electro-Physics Branch
- NASA JSC: Microgravity Combustion Branch
- NASA JSC: White Sands Test Facility
- NASA MSFC: Materials & Processes Laboratory
- NASA MSFC: Space Environmental Effects Laboratory
- NASA GSFC: Parts Project Office (NPPO)
- Naval Air Warfare Center (NAWC)
- University at Buffalo
TEST PLAN

McDONNELL AEROSPACE COMPANY
• AC CORONA
• TIME / CURRENT TO SMOKE
• WIRE FUSE TIME
• ABRASION & FLEX LIFE
• DYNAMIC CUT-THROUGH

NASA LeRC ELECTRO-PHYSICS BRANCH
• I & V LEVELS TO INITIATE & SUSTAIN ARC TRACKING
• DC & AC (400 Hz, 20 kHz)
• VACUUM (10^-6 TORR) AND TEMPERATURE (200° C)

NASA MICROGRAVITY COMBUSTION BRANCH
• IGNITION, FLAMING, SPREAD RATE
• OFFGASSING, SMOKING, TOXICITY
• NORMAL (1g) AND LOW GRAVITY (10^-2 g)
• OXYGEN, VACUUM, TEMPERATURE

NASA JSC WHITE SANDS TEST FACILITY
• FLAMMABILITY
• ODOR, OFFGASSING
• THERMAL VACUUM STABILITY
• RESISTANCE TO AEROSPACE FLUIDS

NASA MSFC MATERIALS AND PROCESSES LAB
• FLAMMABILITY & ARC TRACKING
• OXYGEN, HIGH TEMPERATURE, VACUUM

NASA MSFC SPACE ENVIRONMENTAL EFFECTS LAB
• THERMAL / ATOMIC OXYGEN EXPOSURE
• ULTRAVIOLET RADIATION, VACUUM
• COMBINED STRESSING (LEO)

UNIVERSITY AT BUFFALO
• DC & 400 Hz BREAKDOWN STRENGTH
• INSULATION RESISTANCE WITH TEMPERATURE
• MULTI-STRESS

NASA GSFC AND NAWC
• TEST COORDINATION
• QUALIFICATION & CERTIFICATION
PLANNED ACTIVITIES

• DOWN-SELECT WIRING CANDIDATES

• DEVELOP TEST MATRIX

• INVESTIGATE NEW CONSTRUCTION / MATERIALS:
  - TRW PFPI
  - 3M FPE FILM
  - FOSTER MILLER PBZT POLYMERS
  - ICI UPILEX
FLAMMABILITY, ODOR, OFFGASSING, THERMAL VACUUM STABILITY, AND
COMPATIBILITY WITH AEROSPACE FLUIDS OF WIRE INSULATIONS

David Hirsch
Lockheed
Las Cruces, New Mexico

and

Harry Johnson
NASA White Sands Test Facility
Las Cruces, New Mexico

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:
• PTFE Teflon, 12 AWG
• PTFE Teflon, 20 AWG
• Kapton, 12 AWG
• Kapton, 20 AWG
• Teflon/Kapton Hybrid, 12 AWG
• Teflon/Kapton Hybrid, 20 AWG

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:

<table>
<thead>
<tr>
<th>Materials</th>
<th>Burn Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample 1</td>
</tr>
<tr>
<td>PTFE Teflon, 12 AWG</td>
<td>0</td>
</tr>
<tr>
<td>PTFE Teflon, 20 AWG</td>
<td>8.1</td>
</tr>
<tr>
<td>Kapton, 12 AWG</td>
<td>0</td>
</tr>
<tr>
<td>Kapton, 20 AWG</td>
<td>0.3</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 12 AWG</td>
<td>0.3</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 20 AWG</td>
<td>1.0</td>
</tr>
</tbody>
</table>
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 Temperatures at 125 and 200 °C

Results:

<table>
<thead>
<tr>
<th>Materials</th>
<th>Single Wire Burn Length (cm)</th>
<th>Samples Tested at 125 °C</th>
<th>Samples Tested at 200 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE Teflon, 12 AWG</td>
<td></td>
<td>2.5 2.5 3.0</td>
<td>3.6 3.3 2.3</td>
</tr>
<tr>
<td>PTFE Teflon, 20 AWG</td>
<td></td>
<td>2.0 3.8 4.1</td>
<td>4.8 4.1 4.3</td>
</tr>
<tr>
<td>Kapton, 12 AWG</td>
<td></td>
<td>0 0 0</td>
<td>1.0 0.8 0.8</td>
</tr>
<tr>
<td>Kapton, 20 AWG</td>
<td></td>
<td>4.1 3.8 4.3</td>
<td>4.1 4.6 4.1</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 12 AWG</td>
<td></td>
<td>1.3 0 0</td>
<td>0 0 0</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 20 AWG</td>
<td></td>
<td>3.0 2.8 2.5</td>
<td>2.5 4.1 2.5</td>
</tr>
</tbody>
</table>
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


<table>
<thead>
<tr>
<th>Odor Scale Rating</th>
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<tbody>
<tr>
<td>Undetectable</td>
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<tr>
<td>Barely Detectable</td>
</tr>
<tr>
<td>Easily Detectable</td>
</tr>
<tr>
<td>Objectionable</td>
</tr>
<tr>
<td>Revolting</td>
</tr>
</tbody>
</table>

0 1 2 3 4

Results:

<table>
<thead>
<tr>
<th>Material</th>
<th>Odor Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE Teflon, 12 AWG</td>
<td>0.8</td>
</tr>
<tr>
<td>PTFE Teflon, 20 AWG</td>
<td>1.0</td>
</tr>
<tr>
<td>Kapton, 12 AWG</td>
<td>0.8</td>
</tr>
<tr>
<td>Kapton, 20 AWG</td>
<td>0.4</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 12 AWG</td>
<td>0.4</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 20 AWG</td>
<td>0.2</td>
</tr>
</tbody>
</table>

*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

Material: Teflon, 12 AWG

<table>
<thead>
<tr>
<th>Component</th>
<th>Toxic Limit (µg/g)</th>
<th>Quantity (µg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C10-C11 Saturated and Unsaturated Aliphatic Hydrocarbons</td>
<td>186.29</td>
<td>0.05</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>40.9</td>
<td>0.32</td>
</tr>
<tr>
<td>Fluoroaliphatic Hydrocarbons</td>
<td>0.14</td>
<td>0.007</td>
</tr>
<tr>
<td>Octamethylcyclotetrasiloxane</td>
<td>217.39</td>
<td>0.005</td>
</tr>
</tbody>
</table>
## Test 7
(Determination of Offgassed Products), Cont'd

### Material: Teflon, 20 AWG

<table>
<thead>
<tr>
<th>Component</th>
<th>Toxic Limit (μg/g)</th>
<th>Quantity (μg/g)</th>
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</thead>
<tbody>
<tr>
<td>C10-C11 Saturated and Unsaturated Aliphatic Hydrocarbons</td>
<td>186.29</td>
<td>0.07</td>
</tr>
<tr>
<td>C12 Saturated Aliphatic Hydrocarbon</td>
<td>7.17</td>
<td>0.005</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>40.9</td>
<td>0.23</td>
</tr>
<tr>
<td>Decamethylcyclopentasiloxane</td>
<td>248</td>
<td>0.005</td>
</tr>
<tr>
<td>Fluoroaliphatic Hydrocarbons</td>
<td>0.14</td>
<td>0.006</td>
</tr>
<tr>
<td>Hexamethylcyclotrisiloxane</td>
<td>324</td>
<td>0.005</td>
</tr>
<tr>
<td>Octamethylcyclotetrasiloxane</td>
<td>217.39</td>
<td>0.006</td>
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<tr>
<td>Xylenes</td>
<td>124</td>
<td>0.02</td>
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### Material: Kapton, 12 AWG

<table>
<thead>
<tr>
<th>Component</th>
<th>Toxic Limit (μg/g)</th>
<th>Quantity (μg/g)</th>
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</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>77.1</td>
<td>0.005</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>40.9</td>
<td>0.17</td>
</tr>
<tr>
<td>Hexamethylcyclotrisiloxane</td>
<td>324</td>
<td>0.009</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>15.05</td>
<td>0.005</td>
</tr>
<tr>
<td>Octamethylcyclotetrasiloxane</td>
<td>217.39</td>
<td>0.005</td>
</tr>
<tr>
<td>Toluene</td>
<td>108</td>
<td>0.005</td>
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<tr>
<td>Trimethyl silanol</td>
<td>2.58</td>
<td>0.005</td>
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</table>
Test 7  
(Determination of Offgassed Products), Cont'd

Material: Kapton, 20 AWG

<table>
<thead>
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<th>Component</th>
<th>Toxic Limit $(\mu g/g)$</th>
<th>Quantity $(\mu g/g)$</th>
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<tr>
<td>Acetaldehyde</td>
<td>77.1</td>
<td>0.01</td>
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<tr>
<td>Acetone</td>
<td>1018</td>
<td>0.02</td>
</tr>
<tr>
<td>C10 Aromatic Hydrocarbon</td>
<td>0.14</td>
<td>0.008</td>
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<tr>
<td>C8 Ether</td>
<td>167.03</td>
<td>0.005</td>
</tr>
<tr>
<td>C9 Saturated Aliphatic Hydrocarbon</td>
<td>7.17</td>
<td>0.005</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>40.9</td>
<td>0.17</td>
</tr>
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<td>Hexamethylcyclotrisiloxane</td>
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<td>0.009</td>
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<tr>
<td>Isopropyl Alcohol</td>
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<td>Methyl Alcohol</td>
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<td>217.39</td>
<td>0.006</td>
</tr>
<tr>
<td>Trimethyl silanol</td>
<td>2.58</td>
<td>0.01</td>
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Material: Teflon/Kapton, 12 AWG

<table>
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<th>Toxic Limit $(\mu g/g)$</th>
<th>Quantity $(\mu g/g)$</th>
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<tr>
<td>Acetaldehyde</td>
<td>77.1</td>
<td>0.007</td>
</tr>
<tr>
<td>C11 Saturated and Unsaturated Aliphatic Hydrocarbons</td>
<td>17.2</td>
<td>0.01</td>
</tr>
<tr>
<td>C9 Aromatic Hydrocarbon</td>
<td>21.5</td>
<td>0.005</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>40.9</td>
<td>0.05</td>
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<tr>
<td>Chlorobenzene</td>
<td>65.7</td>
<td>0.005</td>
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<tr>
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<td>324</td>
<td>0.005</td>
</tr>
<tr>
<td>Octamethylcyclotetrasiloxane</td>
<td>217.39</td>
<td>0.005</td>
</tr>
<tr>
<td>Toluene</td>
<td>108</td>
<td>0.007</td>
</tr>
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</table>
Test 7 (Determination of Offgassed Products), Cont'd

Material: Teflon/Kapton, 20 AWG

<table>
<thead>
<tr>
<th>Component</th>
<th>Toxic Limit (μg/g)</th>
<th>Quantity (μg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>77.1</td>
<td>0.04</td>
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<td>Acetone</td>
<td>1018</td>
<td>0.04</td>
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<tr>
<td>Acrolein</td>
<td>0.16</td>
<td>0.005</td>
</tr>
<tr>
<td>C10 Saturated Aliphatic Hydrocarbons</td>
<td>7.17</td>
<td>0.02</td>
</tr>
<tr>
<td>C11-C12 Saturated and Unsaturated Aliphatic Hydrocarbons</td>
<td>7.17</td>
<td>0.15</td>
</tr>
<tr>
<td>C6 Aldehyde</td>
<td>3.44</td>
<td>0.01</td>
</tr>
<tr>
<td>C7 Aldehyde</td>
<td>0.14</td>
<td>0.007</td>
</tr>
<tr>
<td>C9 Aldehyde</td>
<td>0.14</td>
<td>0.009</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>40.9</td>
<td>0.05</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>65.7</td>
<td>0.005</td>
</tr>
<tr>
<td>Decamethylcyclopentasiloxane</td>
<td>248</td>
<td>0.005</td>
</tr>
<tr>
<td>Ethyl Alcohol</td>
<td>134</td>
<td>0.005</td>
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<tr>
<td>Hexamethylcyclotrisiloxane</td>
<td>324</td>
<td>0.005</td>
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<tr>
<td>Methyl Alcohol</td>
<td>74.9</td>
<td>0.02</td>
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<tr>
<td>Methyl Ethyl Ketone</td>
<td>84.3</td>
<td>0.02</td>
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<tr>
<td>Nitromethane</td>
<td>71.5</td>
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<td>Tetrachloroethylene</td>
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<td>Trimethyl silanol</td>
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<tr>
<td>Unidentified Component</td>
<td>0.14</td>
<td>0.009</td>
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</tbody>
</table>
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

Immersion Data in Liquid Phase of Dinitrogen Tetroxide

<table>
<thead>
<tr>
<th>Material</th>
<th>Gas Pressure (psia)</th>
<th>Material Changes</th>
<th>Fluid Visual Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>PTFE Teflon, 12 AWG</td>
<td>133</td>
<td>132</td>
<td>None</td>
</tr>
<tr>
<td>PTFE Teflon, 20 AWG</td>
<td>135</td>
<td>133</td>
<td>None</td>
</tr>
<tr>
<td>Kapton, 12 AWG</td>
<td>141</td>
<td>131</td>
<td>Yellow to Brown</td>
</tr>
<tr>
<td>Kapton, 20 AWG</td>
<td>157</td>
<td>132</td>
<td>Rough, Friable</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 12 AWG</td>
<td>132</td>
<td>131</td>
<td>White to Light Pink</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 20 AWG</td>
<td>132</td>
<td>130</td>
<td>White to Light Pink</td>
</tr>
</tbody>
</table>
Immersion Data in Liquid Phase of Dinitrogen Tetroxide

<table>
<thead>
<tr>
<th>Material</th>
<th>Posttest Fluid Analysis (Non-volatile Residue), mg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample</td>
</tr>
<tr>
<td>PTFE Teflon, 12 AWG</td>
<td>2.1</td>
</tr>
<tr>
<td>PTFE Teflon, 20 AWG</td>
<td>2.0</td>
</tr>
<tr>
<td>Kapton, 12 AWG</td>
<td>1.4</td>
</tr>
<tr>
<td>Kapton, 20 AWG</td>
<td>2.1</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 12 AWG</td>
<td>1.5</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 20 AWG</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Immersion Data in Liquid Phase of Hydrazine

<table>
<thead>
<tr>
<th>Material</th>
<th>Gas Evolut. Rate (sccm/hr/cm² x 10E4)</th>
<th>Material Changes</th>
<th>Fluid Visual Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>PTFE Teflon, 12 AWG</td>
<td>EQ</td>
<td>EQ</td>
<td>None</td>
</tr>
<tr>
<td>PTFE Teflon, 20 AWG</td>
<td>EQ</td>
<td>EQ</td>
<td>None</td>
</tr>
<tr>
<td>Kapton, 12 AWG</td>
<td>7.1</td>
<td>3.7</td>
<td>Yellow to Brown Rough, Tacky</td>
</tr>
<tr>
<td>Kapton, 20 AWG</td>
<td>--</td>
<td>--</td>
<td>Gray to Yellow Rough, Tacky, Friable</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 12 AWG</td>
<td>EQ</td>
<td>EQ</td>
<td>White to Yellow</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 20 AWG</td>
<td>EQ</td>
<td>EQ</td>
<td>White to Yellow</td>
</tr>
</tbody>
</table>
Test 15
(Reactivity of Materials in Aerospace Fluids), Cont'd

Immersion Data in Liquid Phase of Hydrazine - Posttest Fluid Analysis

<table>
<thead>
<tr>
<th>Material</th>
<th>Purity (%)</th>
<th>CO₂ (ppm)</th>
<th>Non-Volatile Residue (mg)</th>
<th>Chloride (µg)</th>
<th>Fluoride</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE Teflon, 12 AWG</td>
<td>99.7</td>
<td>6</td>
<td>0.1</td>
<td>18.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Reference</td>
<td>99.7</td>
<td>6</td>
<td>ND</td>
<td>13.8</td>
<td>ND</td>
</tr>
<tr>
<td>PTFE Teflon, 20 AWG</td>
<td>99.6</td>
<td>3</td>
<td>0.6</td>
<td>9.2</td>
<td>ND</td>
</tr>
<tr>
<td>Reference</td>
<td>99.6</td>
<td>2</td>
<td>1.0</td>
<td>4.6</td>
<td>ND</td>
</tr>
<tr>
<td>Kapton, 12 AWG</td>
<td>99.8</td>
<td>1</td>
<td>110</td>
<td>18.4</td>
<td>6.9</td>
</tr>
<tr>
<td>Reference</td>
<td>99.8</td>
<td>6</td>
<td>0.5</td>
<td>9.2</td>
<td>ND</td>
</tr>
<tr>
<td>Kapton, 20 AWG</td>
<td>99.6</td>
<td>2</td>
<td>91</td>
<td>69</td>
<td>2.3</td>
</tr>
<tr>
<td>Reference</td>
<td>99.6</td>
<td>2</td>
<td>0.3</td>
<td>11.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 12 AWG</td>
<td>99.6</td>
<td>4</td>
<td>34</td>
<td>9.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Reference</td>
<td>99.6</td>
<td>1</td>
<td>0.1</td>
<td>6.9</td>
<td>ND</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 20 AWG</td>
<td>99.6</td>
<td>3</td>
<td>37</td>
<td>9.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Reference</td>
<td>99.6</td>
<td>1</td>
<td>0.1</td>
<td>9.2</td>
<td>ND</td>
</tr>
</tbody>
</table>
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

Results:

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight Loss (%)</th>
<th>VCM (%)</th>
<th>WVR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE Teflon, 12 AWG</td>
<td>0.06</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>PTFE Teflon, 20 AWG</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Kapton, 12 AWG</td>
<td>0.80</td>
<td>0.01</td>
<td>0.60</td>
</tr>
<tr>
<td>Kapton, 20 AWG</td>
<td>1.02</td>
<td>0.07;0</td>
<td>0.71</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 12 AWG</td>
<td>0.26</td>
<td>0</td>
<td>0.20</td>
</tr>
<tr>
<td>Teflon/Kapton Hybrid, 20 AWG</td>
<td>0.30</td>
<td>0.01</td>
<td>0.23</td>
</tr>
</tbody>
</table>
BACKGROUND

- PURPOSE

- HYBRID SAMPLES

- TESTING

TEST PROGRAM

M81381/7 VS. GORE HSCR™

20 AWG SPC

MULTI-LAYER FLUOROPOLYMER INSULATION (6 MIL NOM.)
TESTS PERFORMED

• CORONA INCEPTION & EXTINCTION
• TIME/CURRENT TO SMOKE
• WIRE FUSING TIME
• ABRASION
• FLEX LIFE
• DYNAMIC CUT THROUGH

CORONA INCEPTION & EXTINCTION VOLTAGES
-TEST PARAMETERS-

• 10X MANDREL, 10 TURNS
• 400 HZ POWER SUPPLY
• 50 VOLTS/SECOND
• SEA LEVEL, 60,000 FEET
CORONA INCEPTION & EXTINCTION VOLTAGES

-TEST RESULTS-

SEA LEVEL

CORONA INCEPTION & EXTINCTION VOLTAGES

-TEST RESULTS-

ALTITUDE

M81381 INCEPTION

GORE

INCEPTION

EXTINCTION

M81381 EXTINCTION
TIME/CURRENT TO SMOKE

-TEST PARAMETERS-

- SPECIMEN SUSPENDED HORIZONTALLY
- CONSTANT CURRENT DC POWER
- 5 AMP INCREMENTS
- 30 SECONDS AT AMPERAGE

-TIME/CURRENT TO SMOKE

-TEST RESULTS-

<table>
<thead>
<tr>
<th>CURRENT (AMPS)</th>
<th>AVERAGE TIME (SECONDS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>8</td>
</tr>
<tr>
<td>40</td>
<td>13</td>
</tr>
<tr>
<td>45</td>
<td>81</td>
</tr>
</tbody>
</table>

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WIRE FUSING TIME

-TEST PARAMETERS-

- SPECIMEN SUSPENDED HORIZONTALLY
- CONSTANT CURRENT DC POWER
- 2.5 X RATED CURRENT (60 A)

WIRE FUSING TIME

-TEST RESULTS-

<table>
<thead>
<tr>
<th>SPECIMEN NUMBER</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPECIMEN</td>
<td>M81381</td>
<td>GORE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIME TO INTERRUPT 60 AMPS (SECONDS)</td>
<td>30</td>
<td>27</td>
<td>24</td>
<td>27</td>
<td>24</td>
<td>27</td>
</tr>
</tbody>
</table>

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ABRASION

-TEST PARAMETERS-

• .020 INCH ROD
• 1 INCH PATH, 60 CYCLES PER MINUTE
• 1, 2, & 3 LB. WEIGHT
• AMBIENT & 150°C

ABRASION

-TEST RESULTS-

AMBIENT TEMPERATURE

<table>
<thead>
<tr>
<th>WEIGHT (LBS)</th>
<th>AMOUNT TO FAILURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>320</td>
</tr>
<tr>
<td>2</td>
<td>240</td>
</tr>
<tr>
<td>3</td>
<td>160</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>AMOUNT TO FAILURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>GORE</td>
<td>80</td>
</tr>
<tr>
<td>M81381</td>
<td>40</td>
</tr>
</tbody>
</table>
ABRASION
-TEST RESULTS-

150 DEGREES C

FLEX LIFE
-TEST PARAMETERS-

- 90° FLEX IN EACH DIRECTION
- 30 CYCLES PER MINUTE
- 6X MANDRELS
- 7 LB. WEIGHT
FLEX LIFE
-TEST RESULTS-

<table>
<thead>
<tr>
<th>Specimen</th>
<th>M81381 - Specimen Break</th>
<th>M81381 - Resistance Increase</th>
<th>GORE - Resistance Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DYNAMIC CUT-THRU

-TEST PARAMETERS-

- .020 INCH ROD
- 600 LB. LOAD CELL
- 0.2 INCH/MINUTE
- 23°C, 70°C, 150°C, & 200°C
CONCLUSIONS

- GORE NOT COMPARABLE TO M81381 IN PERFORMANCE AT ELEVATED TEMPERATURES

- MECHANICAL PROPERTIES FAIR BUT M81381 SUPERIOR

- CORONA, WIRE FUSING TIME EQUIVALENT
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EVALUATION OF PYROLYSIS AND ARC TRACKING ON CANDIDATE WIRE INSULATION DESIGNS FOR SPACE APPLICATIONS

Thomas J. Stueber
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio

and

Kenneth Hrovat
Cleveland State University
Cleveland, Ohio

* NHB 8060.1C Comparison
* Apparatus
* Sample Description
* Procedure
* Results
* Discussion
* Conclusions
* Future Plans

NHB 8060.1C (April 1991)

Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion.

Office of Safety and Mission Quality
Section 4.18 Arc Tracking (Test 18)
PURPOSE

* Determine ability of wire insulation materials and constructions to resist arc tracking.

* Assess damage caused by initial arcing and restrike events.

TEST CRITERIA

NHB 8060.1C:

- Arc propagation on either initial application of power or on reapplication of power is considered a test failure.

- Tests conducted on samples of worst-case use insulation thickness and wire gauge, and in the worst-case environment.

Wiring for Space Applications Program:

- All candidate space application insulation constructions arc track.

- Worst case insulation: prepyrolyzed polyimide wire insulation.

Results of Arc Tracking Initiation.

* Self Extinguish  (Best scenario).
  - No loss in wire bundle performance.
  - Charred insulation.

* Conductors Lose Insulation  (exposed conductors)
  - Safety hazard.
  - Short-circuit risks
  - No loss in wire bundle performance.

* Severed Conductor
  - Lost use of a wire pair within the bundle.
  - No loss in remainder of wire bundle performance.
  - No loss in wire bundle performance.

* Flashover Severs All Wires.  (Worst scenario)
Best and Worst Case Differences

* Voltage difference between two conductors.
  - High enough to break down the dielectric strength of the charred material.
  - Not high enough to break down the dielectric strength of the charred material (self ext.)

* Current Flow:
  - High enough, such that Joule heating will continue to pyrolyze neighboring insulation.
  - Not high enough, such that Joule heating will continue to pyrolyze neighboring insulation.
    - Self Extinguish
    - Glow like a carbon filament light bulb (Vacuum case)

Properly Insulated Wire.
(Rated for task requirements)

- Will not Arc Track due to voltage difference between conductors.
- Will not Arc Track due to typical Joule heating from current in conductors.

Defectively Insulated Wire.

- May momentarily short-circuit
  - Arc generated heat may char the insulation.
  - Charred insulation lowers the dielectric strength.
- n # of momentary short-circuits before sustaining an arc.
- Worst state of insulation.
  - Pyrolyzed to the point of sustained arc tracking.
  - Restrike possible, dielectric strength.
Necessary Restrike Min. Voltage and Min Current

= EQUALS =

Min. Voltage and Min. Current Necessary to Pyrolize the Insulation To The Point of Sustained Arc Tracking

Arc Tracking Circuit.

Diagram showing a circuit with a computer, DC power supply, arc voltage, arc current, and sample wire. 

Non-short-circuit potential between conductors.

R = controls the max short-circuit current available.

Twisted wire pair with space application candidate insulation.

Insulation ty-wraps.

2mm of insulation stripped.

Aluminum cup.

Platform: operator raise and lower.

Position A and Position B.
<table>
<thead>
<tr>
<th>Insulation Construction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Champlain #1</td>
<td>2919 Kapton (50% OL)/Extruded XL ETFE</td>
</tr>
<tr>
<td>Filotex</td>
<td>PTFE Extrusion/616 Kapton (50% Min OL)/PTFE Dispersion.</td>
</tr>
<tr>
<td>Thermatics #3</td>
<td>Modified PTFE Tape (50% min OL)/TPT Tape (50% min OL)/Mod PTFE Tape (50% min OL)/PTFE Dispersion.</td>
</tr>
</tbody>
</table>

**Abbreviations:**

- **2919 Kapton** => 0.5 mil Fluorocarbon (PTFE), 1 mil Polyimide, 0.5 mil Fluorocarbon (PTFE).
- **616 Kapton** => 0.1 mil Fluorocarbon (FEP), 1 mil Polyimide, 0.1 mil Fluorocarbon (FEP).
- **XL** => Crosslinked.
- **ETFE** => Ethylene Tetrafluoroethylene.
- **OL** => Overlap.
- **PTFE** => Poly Tetrafluoroethylene.
- **1 mil** => 25 micrometers.

**PROCEDURE:**

1) Sample Assembly and Installation.
2) Vacuum or Atmospheric Air Pressure.
3) Arc Tracking Initiation.
4) Arc Tracking Restrike.

**ARC TRACKING INITIATION:**

**Objective:** Manually initiate arc tracking on the wire sample.

**Procedure:** Raise and lower platform until arc tracking started.

**Next Step:** Terminate power. Reset power supplies to 0V. Test samples ready for restrike tests.
ARC TRACKING RESTRIKE

Objective: Ascertain minimum voltage to sustain an arc.

Procedure: Increment voltage from 0.

Results: Upon restrike, terminate arc by removing power.

Log Data: Open-Circuit-Voltage, and employed current limiter.

Calculations: Potential Short-Circuit-Current and, Volt * Amp product.

FUTURE INITIATION PLANS

Arc tracking did not initiate at onset of first momentary short-circuit.

Number of momentary arcs necessary to initiate arc tracking may be dependant on the intensity of the arc.

Quantify the energy necessary to initiate arc tracking by summing the energy in each arc during initiation exercises.

Use computer to log the data.

This information may determine which insulation type is least likely to start arc tracking.

FUTURE RESTRIKE PLANS

Monitor voltage and current characteristics of an arc.

Obtain necessary pyrolysis energy.

To determine which insulation type is least likely to restrike.
Champlain Arc Tracking Restrike
AWG 20, Vacuum

Filotex Arc Tracking Restrike
AWG 20, Vacuum
Teledyne Therm. Arc Tracking Restrike
AWG 20, Vacuum

Champlain Arc Tracking Restrike
AWG 20, Air
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Restrike Percentage vs. Volt*Amp Product Vacuum Tests

Volts * Amperes

- Champlain
- Filotex
- Thermatics
Page intentionally left blank
Restrike Percentage vs. Volt*Amp Product Air Tests
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DISCUSSION

- Remnants of hexagonal, graphitic carbon residue remained.
- Carbon residue, not necessarily a perfect conductor (gaps).
- Gaps prevent current flow, for low voltage.
- Higher electric field strengths may exceed carbon/gap median dielectric strength.
- Necessary breakdown voltage may be dependant on carbon trace positioning.
- Joule heating results from an arc breakdown.
- Restrike data describes breakdown voltage and necessary available current for Joule heating.

CONCLUSIONS

- Arc tracking tests conducted on Champlain, Filotex, and Teledyne Thermatics indicate the Filotex is least likely to arc track.
- Arc tracking occurs more readily in air than it does in vacuum.

PLANNED ACTIVITIES

- Further testing will be conducted to consider other space application candidate wire insulation constructions.
- Future testing will be done to determine ambient temperature influence on arc tracking.
- Future testing will be conducted to determine the level of Joule heating necessary for arc tracking initiation and propagation.
WIRE INSULATION DEGRADATION AND FLAMMABILITY IN LOW GRAVITY

Robert Friedman
NASA Lewis Research Center
Cleveland, Ohio

ORGANIZATION OF PRESENTATION

- INTRODUCTION TO SPACECRAFT FIRE SAFETY
- CONCERNS IN FIRE PREVENTION IN LOW GRAVITY
- SHUTTLE WIRE INSULATION FLAMMABILITY EXPERIMENT
- DROP TOWER RISK-BASED FIRE SAFETY EXPERIMENT
- EXPERIMENT RESULTS, CONCLUSIONS AND PROPOSED STUDIES

SPACECRAFT FIRE-SAFETY CHALLENGES

FIRE SAFETY ALWAYS RECEIVES PRIORITY ATTENTION IN NASA MISSION DESIGNS AND OPERATIONS—THE PRIMARY APPROACH IS THROUGH FIRE PREVENTION.

CONVENTIONAL FIRE-SAFETY TECHNIQUES ARE DIFFICULT TO APPLY TO SPACECRAFT, HOWEVER.

- THE SPACECRAFT INTERIOR IS A CONFINED ENVIRONMENT, WITH LIMITED RESOURCES AND ALMOST NO ESCAPE POTENTIAL.
- THERE IS LITTLE PAST EXPERIENCE TO FURNISH ACCURATE RISK PREDICTIONS FOR DESIGN OF SAFETY SYSTEMS.
- THE EXTREME HIGH VALUE OF SPACECRAFT AND MISSION OPERATIONS OFFERS NO OPTIONS OR SACRIFICES.
- THE LACK OF NATURAL CONVECTIVE STRONGLY INFLUENCES FIRE CHARACTERISTICS.
INFLUENCE OF LOW GRAVITY ON FIRES

BUOYANCY (UP) AND SEDIMENTATION (DOWN) FLOWS ARE GREATLY DIMINISHED, AFFECTING

MASS TRANSFER OF FUEL AND OXYGEN

HEAT TRANSFER TO AND FROM FLAME ZONE

FLAME CHARACTERISTICS OF TEMPERATURE, COMBUSTION PRODUCTS, AND SO ON

FIRES IN SPACE ARE NOT NECESSARILY "BETTER" OR "WORSE" BUT THEY ARE CERTAINLY "DIFFERENT"

WIRE-INSULATION BREAKDOWNS AND FIRE SAFETY

• BECAUSE OF THE LACK OF CONVECTIVE COOLING IN MICROGRAVITY, SURFACE TEMPERATURES RESULTING FROM BREAKDOWNS (OVERLOADS, ARC TRACKING) CAN EXCEED THOSE IN NORMAL GRAVITY.

• CONSEQUENTLY, IF NO REMEDIAL ACTION IS TAKEN, BREAKDOWNS MAY LEAD TO IGNITIONS AND FIRE SPREAD IN THE PRESSURIZED SPACECRAFT ATMOSPHERE.

• SHUTTLE MISSIONS HAVE EXPERIENCED A BREAKDOWN ON THE AVERAGE OF ONCE EACH 1600 HOURS OF OPERATION.

• NO IGNITION HAS RESULTED FROM THE SHUTTLE BREAKDOWNS, DUE TO THE MATERIAL CONTROLS AND THE IMMEDIATE RESPONSE OF THE CREW.

• THE SPACE STATION MAY HAVE A MORE SEVERE SAFETY PROBLEM IF BREAKDOWNS OCCUR DURING UNTENDED PERIODS.
SHUTTLE "BREAKDOWN" EXPERIENCE

FIVE REPORTED ELECTRICAL EVENTS

APRIL 1983  WIRES OVERHEATED AND FUSED AT MATERIAL PROCESSING UNIT
AUG. 1989  SHORT CIRCUIT FROM CABLE STRAIN AND INSULATION SPLIT AT TELEPRINTER
DEC. 1990  RESISTOR OVERHEATED FROM COOLING FAN FAILURE IN ELAPSED-TIME CIRCUIT OF DIGITAL DISPLAY UNIT
JUNE 1991  REFRIGERATOR-FREEZER FAN MOTOR FAILURE DUE TO COOLING FLOW LOSS
JULY 1992  BLOWN ELECTRICAL CAPACITOR IN MEDICAL APPARATUS

SIX REPORTED INTERMITTENT OR CONTINUOUS FALSE ALARMS

FIVE REPORTED FAILURES OF SMOKE DETECTOR SELF-TEST CONFIRMATIONS

NASA LEWIS
MICROGRAVITY WIRE-INSULATION FLAMMABILITY EXPERIMENTS

WIRE INSULATION FLAMMABILITY (NASA LEWIS, NIST):
SHUTTLE STS-50 GLOVEBOX, JUNE 1992

•  LONG-TERM OBSERVATIONS OF MICROGRAVITY FLAMMABILITY AND FLAME SPREAD OVER HEATED WIRES WITH PROMOTED IGNITION AND AIR FLOW OPPOSED TO AND CONCURRENT WITH THE FLAME SPREAD

RISK-BASED FIRE SAFETY EXPERIMENT (UCLA):
NASA LEWIS 2-SEC DROP TOWER, SEPT. TO DEC. 1992

•  VERY SHORT-TERM OBSERVATIONS OF MICROGRAVITY DEGRADATION AND IGNITION OF SELF-HEATED WIRES UNDER QUIESCENT CONDITIONS

WIRE-INSULATION BREAKDOWN EXPERIMENT (NASA)
NASA LEWIS AIRPLANE, PROPOSED

•  20-SEC OBSERVATIONS OF LOW-GRAVITY ARC-TRACKING AND IGGITIONS OF SELF-HEATED AND SHORTED WIRES WITH AIR FLOW AND ATMOSPHERIC OXYGEN AND PRESSURE VARIATIONS
WIRE INSULATION FLAMMABILITY EXPERIMENT
USML-1 GLOVEBOX ON SHUTTLE STS-50, JUNE 1992

OBJECTIVES:
- FLAMMABILITY AND FLAME-SPREAD RATES OF WIRE INSULATION IN QUIESCENT MICROGRAVITY ENVIRONMENT
- EFFECTS OF CONTROLLED AIR FLOW ON ABOVE
- TRANSIENT HEATING AND OFFGASSING BEHAVIOR IN MICROGRAVITY

APPARATUS:
- FOUR SEPARATE TEST MODULES WITH ONE SAMPLE EACH FOR TESTS AT FOUR CONDITIONS OF HEAT LEVELS AND AIR FLOWS OPPOSED AND CONCURRENT TO FLAME SPREAD

APPROACH:
- POLYETHYLENE-INSULATED NICHROME WIRE IS HEATED BY ELECTRIC CURRENT, THEN IGNITED BY EXTERNAL HOT WIRE IGNITER AT ONE END OF WIRE

GLOVEBOX WIRE INSULATION FLAMMABILITY EXPERIMENT (WIF) MODULE
WIRE INSULATION FLAMMABILITY EXPERIMENT
SET OF FOUR MODULES
Page intentionally left blank
WIRE INSULATION FLAMMABILITY EXPERIMENT
FLAME PROGRESSING FROM LEFT TO RIGHT - CONCURRENT AIR FLOW
Page intentionally left blank
WIRE INSULATION FLAMMABILITY EXPERIMENT
FLAME PROGRESSING FROM LEFT TO RIGHT - OPPOSED AIR FLOW
Page intentionally left blank
NOTE ➔ ASYMMETRIC INSULATION DROPLET ➔ GLOBULE EXPULSION
Page intentionally left blank
WIRE INSULATION FLAMMABILITY EXPERIMENT
SELECTED WIRE TEMPERATURE HISTORIES

WIRE INSULATION FLAMMABILITY EXPERIMENT
RESULTS AND CONCLUSIONS

BEHAVIOR IN MICROGRAVITY COMPARED TO NORMAL GRAVITY

- Transient heating rates and maximum wire temperatures are higher than in (normal-gravity) air but comparable to those under vacuum.
- Flame-spread rate is strongly affected by the forced air flow. Rates are higher for concurrent flow than for opposed flow. In fact, steady state was never achieved in concurrent flow.
- Melted fuel forms spherical drops adhering to wire.
- Fuel vapors from overheated wire can accumulate and ignite.
- Mean soot particle size is greater by factor of 2 for concurrent flow, by 3 for opposed flow; size range is also greater.
UCLA RISK-BASED FIRE-SAFETY EXPERIMENT
NASA LEWIS 2-sec DROP TOWER, SEPT.-DEC. 1992

OBJECTIVES: • QUANTITATIVE RISK ASSESSMENTS OF FIRE PROBABILITIES AND CONSEQUENCES IN ADVANCED SPACECRAFT
• SMALL-SCALE FIRE EXPERIMENTS TO FURNISH CHARACTERISTICS AND TIME CONSTANTS FOR ANALYSES
• EVENTUAL SPACE EXPERIMENT IN GASCAN

APPARATUS: • CHAMBER WITH WIRE SAMPLE MOUNTED IN FRAME FOR DROP TESTING IN FREE-FALL MICROGRAVITY

APPROACH: • TEFLON, TEFZEL (FLUORINATED ETHYLENE-PROPYLENE), AND KAPTON (POLYIMIDE)-INSULATED COPPER WIRES ARE OVERHEATED TO DEGRADATION OR IGNITION, TO REPRESENT A PROBABLE SPACECRAFT BREAKDOWN INCIDENT

APPARATUS FOR HEATED-WIRE SCENARIO VALIDATION
MICROGRAVITY TEST SERIES AT LeRC

Front View

Plan View
LOG-NORMAL CURVE FIT FOR PARTICLE DIAMETERS

<table>
<thead>
<tr>
<th>Microgravity</th>
<th>Normal Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation = 0.056 µm</td>
<td>Mean = 0.151 µm</td>
</tr>
<tr>
<td>Standard Deviation = 0.203 µm</td>
<td>Mean = 0.330 µm</td>
</tr>
</tbody>
</table>

GROUND-BASED TEST RESULTS ON INSULATION MASS LOSS

"Six Volt" Test Data

Mean = 31.54
Std. Dev. = 5.12
PARTICLE DIAMETER HISTOGRAM

UCLA RISK-BASED FIRE-SAFETY EXPERIMENT
RESULTS AND CONCLUSIONS

BEHAVIOR IN MICROGRAVITY COMPARED TO NORMAL GRAavity

• KAPTON AND TEFZEL INSULATION (CONSIDERED NON-FLAMMABLE IN NORMAL GRAVITY) FLAMED IN SOME INSTANCES.

• DAMAGE TO WIRE INSULATION IS MORE SEVERE.

• MASS CONSUMPTION RATE OF BURNING INSULATION IS GREATER; HENCE, MORE SMOKE AND GASES ARE PRODUCED.

• MEAN SMOKE PARTICLE SIZE IS GREATER BY FACTOR OF 2.

• SMOKE-PARTICLE SIZE DISTRIBUTION IS WIDER (GREATER STANDARD DEVIATION).
WIRE-INSULATION BREAKDOWN EXPERIMENT
PROPOSED FOR NASA LEWIS LOW-GRAVITY AIRPLANE FACILITY

OBJECTIVES: • ARC-TRACKING, DEGRADATION, AND IGNITION SUSCEPTIBILITY OF CURRENT AND ADVANCED WIRES INSULATIONS IN A LOW-GRAVITY ENVIRONMENT
• EFFECTS OF CONTROLLED AIR FLOW ON ABOVE
• EFFECTS OF ATMOSPHERIC PRESSURE AND OXYGEN

APPARATUS: • TEST CHAMBER, FLOW SYSTEM, AND DIAGNOSTICS EXISTING; TEST FIXTURE AND EXPERIMENT PLAN TO BE DEvised

APPROACH: • STILL UNDER DISCUSSION

IN ADDITION TO THE PROPOSED AIRPLANE ACCOMMODATION, THIS EXPERIMENT IS AN EXCELLENT CANDIDATE FOR A SHUTTLE GLOVEBOX PROJECT.

LOW-GRAVITY AIRPLANE FIRE SAFETY FACILITY
PROPOSED FOR WIRE-INSULATION BREAKDOWN EXPERIMENT

A—A
CONCLUSIONS

- There is a finite probability of a breakdown (arc tracking, for example) occurring in spacecraft (about once in 1600 mission hours).

- The lack of convective cooling can lead to higher surface temperatures following breakdowns. In the pressurized spacecraft cabin, this overheating can increase the probability of ignitions.

- The relative ranking of material resistance to degradation, off-gassing, or ignition may be different in microgravity compared to normal gravity.

- The automated detection of smoldering, degradation, or other breakdown "signatures" in spacecraft is very difficult.

- Additional experimental data and analyses are critically needed to support risk assessments, material acceptance standards, fire detection, and fire suppression in spacecraft.
BREAKDOWN TESTING OF WIRING INSULATION

J.R. Laghari
State University of New York at Buffalo
Buffalo, New York

BACKGROUND

M81381 (Polyimide) is widely used for wiring insulation in aerospace applications

Advantages

• Light Weight
• High Service Temperature
• High Breakdown Strength
• Availability

Disadvantages

• Resistive Heating
• Lossy at High Temperature
• Absorbs Moisture
• Arc Tracking
• Fire Hazard

TYPICAL OPERATING VOLTAGES

• 28 Volts dc (Space Shuttle)

• 120 Volts dc
  (Currently Proposed for Space Station Freedom)

• 28-270 Volts dc
  (Expendable Launch Vehicles)

• 115 V 3-ph 400 Hz (Aerospace Applications)
TASK

To evaluate dielectric strength at high temperature of potential wiring insulation recommended by NASA LeRC to replace existing M81381 (Polyimide)

Top Candidates Recommended by NASA LeRC for Dielectric Testing at UB

- Gore 12 AWG
- Gore 20 AWG
- Tensolite 12 AWG
- Tensolite 20 AWG
- Filotex 12 AWG
- Filotex 20 AWG
- Kapton (M81381) 12 AWG
- Kapton (M81381) 20 AWG
- Teledyne 12 AWG
- Teledyne 20 AWG
- Barcel 20 AWG
- Champlain 20 AWG
## Wiring Cable Specifications

<table>
<thead>
<tr>
<th>Sample</th>
<th>Insulation System</th>
<th>Insulation Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gore-12</td>
<td>PTFE/ High Strength PTFE/ PTFE</td>
<td>6 mil</td>
</tr>
<tr>
<td>Gore-20</td>
<td>PTFE/ High Strength PTFE/ PTFE</td>
<td>6 mil</td>
</tr>
<tr>
<td>Tensolite-12</td>
<td>PTFE/ Polyimide/ PTFE</td>
<td>7.15 mil</td>
</tr>
<tr>
<td>Tensolite-20</td>
<td>PTFE/ Polyimide/ PTFE</td>
<td>6.15 mil</td>
</tr>
<tr>
<td>Filotex-12</td>
<td>PTFE/ Polyimide/ FEP</td>
<td>6.9 mil</td>
</tr>
<tr>
<td>Filotex-20</td>
<td>PTFE/ Polyimide/ FEP</td>
<td>6.5 mil</td>
</tr>
<tr>
<td>M81381-12</td>
<td>Kapton with Polyimide top coat</td>
<td>8.6 mil</td>
</tr>
<tr>
<td>M81381-20</td>
<td>Kapton with Polyimide top coat</td>
<td>8.6 mil</td>
</tr>
<tr>
<td>Teledyne-12</td>
<td>PTFE/ Polyimide/ PTFE</td>
<td>~ 6 mil</td>
</tr>
<tr>
<td>Teledyne-20</td>
<td>PTFE/ Polyimide/ PTFE</td>
<td>~ 6 mil</td>
</tr>
<tr>
<td>Barcel-20</td>
<td>Kapton/ Unsintered PTFE, Buttrap</td>
<td>~ 6 mil</td>
</tr>
<tr>
<td>Champlain-20</td>
<td>Kapton/ Extruded XL ETFE</td>
<td>5.7 mil</td>
</tr>
</tbody>
</table>

### TEST FACILITY at UB

![Diagram of TEST FACILITY at UB](image-url)
FUTURE WORK

• Obtain breakdown strength of other constructions.

• Insulation resistance as a function of temperature.

• Multistress aging
  (Electrical, Thermal and Radiation)

CONCLUSION

• No dependence of breakdown strength on temperature for constructions tested.

• Little effect of frequency on the breakdown characteristics.
A NEW TEST METHOD FOR THE ASSESSMENT OF THE ARC TRACKING PROPERTIES OF WIRE INSULATION IN AIR, OXYGEN ENRICHED ATMOSPHERES AND VACUUM

Dieter König
Technical University of Darmstadt
Darmstadt, Germany

Published Information on the Activities of the Cooperating Group THD / ERNO / ESA-ESTEC

Survey of Arc Tracking on Aerospace Cables and Wires.

Principle of a New Arc Tracking Test of Cables and Wires for Spacecraft.
Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), October 18 – 21, 1992, Victoria, BC, Canada, pp. 363 – 369

[3] ESA/ESTEC

Presentation of Activities in the Field of Arc Tracking of Wire Insulations (ESA/ERNO) Materials And Processes Technical Interchange Meeting, Reston, VA, September 1 – 3, 1992

[5] ESA/ESTEC

6th Int. Symp. on the Flammability and Sensitivity of Materials in Oxygen Enriched Atmospheres, Noordwijk, May 11 – 13, 1993 (oral presentation)
### Tracking

A Phenomenon on the surface of the insulating materials
(Def. of G.A. Day)

### ARC

A kind of electric discharge mainly between two or more conductors
(Def. of Compton)

#### Arc Tracking

Interaction of different phenomena causing arcing and fault propagation in wire bundles

---

**A. G. DAY**

**Tracking**

Tracking is an untidy process; its incidence depends upon the insulation but its inception depends upon several other factors. By definition, tracking is the formation of a permanent conducting path across a surface of the insulation, and in most cases the conduction results from degradation of the insulation itself. It is therefore necessary for organic insulation to be present if tracking is to occur.

The three essentials of the tracking phenomenon are:

1. the presence of a conducting film across the surface of the insulation,
2. a mechanism whereby the leakage current through the conducting film is interrupted with the production of sparks,
3. degradation of the insulation must be caused by the sparks.
Definition of an Arc

Probably the best definition of an arc is that due to Compton; namely, the arc is a discharge in a gas or vapor with a voltage drop in the cathode region that is of the order of the lowest ionization potential of the gas or vapor in which it burns.

The voltage of short arcs is usually in the range 10 - 50 V. This arc drop is divided between anode and cathode drops (usually of the order of 10 V; often the anode drop is considerably higher than the cathode drop) and the balance in the column that depends on its length. Arc currents are usually from the order of one to many thousands amperes.

ARC TRACKING TESTS

Development of wet arc tracking test methods
Initiated by incidents of arcing recorded under wet conditions: e.g. a failure of a cable bundle on a Monarch Airlines aircraft caused by a leaking toilet.

Development of dry arc tracking test methods
Other incidents of arc ignitions recorded in dry conditions (mechanical damage of insulation, electrical sparks etc.)

Comparison of existing test methods
Conclusion: No appropriate arc tracking test for space application available

Aim:
Development of a new test method suitable for the assessment of the resistance of aerospace cables to arc tracking for different specific environmental and network conditions of spacecrafts.
### Table 1. Comparison of Test Methods (published at CEIDP, 1992)

<table>
<thead>
<tr>
<th>Test method comparison</th>
<th>Test methods:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Electric circuit</td>
<td></td>
</tr>
<tr>
<td>1.1. Power source</td>
<td></td>
</tr>
<tr>
<td>a) AC, 200/115V, 400Hz</td>
<td>- - - var - - -</td>
</tr>
<tr>
<td>b) DC</td>
<td>- - - var var - - -</td>
</tr>
<tr>
<td>c) Others</td>
<td>- 1) 2) - 3) 4)</td>
</tr>
<tr>
<td>1.2. Current</td>
<td></td>
</tr>
<tr>
<td>a) Same value for all cable sizes and types</td>
<td>+ + - - - + 1A 5)</td>
</tr>
<tr>
<td>b) Dependent from the nominal current of the tested cable</td>
<td>- - + * + - - -</td>
</tr>
<tr>
<td>c) Dependent from the protective device of the tested cable</td>
<td>- - + + - - -</td>
</tr>
<tr>
<td>1.3. Relation to recovery voltage</td>
<td>- - - - - - -</td>
</tr>
<tr>
<td>2. Arc ignition process</td>
<td></td>
</tr>
<tr>
<td>a) Wet ignition method</td>
<td>+ - - - - - -</td>
</tr>
<tr>
<td>b) Dry ignition method</td>
<td>- - - + + + -</td>
</tr>
<tr>
<td>3. Arc burning time limited by</td>
<td></td>
</tr>
<tr>
<td>a) Protective circuit breaker</td>
<td>+ + + + + + +</td>
</tr>
<tr>
<td>b) Self-extinction of the arc</td>
<td>+ + + + + + +</td>
</tr>
</tbody>
</table>

1) DC, 28 V, 2) DC+AC, 3) AC, 100V...800V, 4) DC, 220V, 5) Limited by $R = 20 \, \Omega$, 6) $< 10^6$, 7) Wet = L, Dry = S

(+ = yes; (-) = no; L = large ($\geq 8h$), S = short; 7 = no statement; var = variable)


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## Table 1. Comparison of Test Methods (continued)

<table>
<thead>
<tr>
<th>Test method companion</th>
<th>Test methods:</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Influence from environment conditions</td>
<td></td>
</tr>
<tr>
<td>a) Air under atmospheric pressure</td>
<td>+ + + + + + +</td>
</tr>
<tr>
<td>b) Air with enriched O₂</td>
<td></td>
</tr>
<tr>
<td>c) Vacuum</td>
<td></td>
</tr>
<tr>
<td>d) Mechanical vibration</td>
<td></td>
</tr>
<tr>
<td>5. Preparation and position of the sample</td>
<td></td>
</tr>
<tr>
<td>a) only insulation material used for the cable construction</td>
<td>- - - - - + +</td>
</tr>
<tr>
<td>b) a part of wire or cable bundle</td>
<td>+ + + + + + - -</td>
</tr>
<tr>
<td>c) insulation artificially damaged</td>
<td>+ + + + + - -</td>
</tr>
<tr>
<td>d) position</td>
<td></td>
</tr>
<tr>
<td>- vertical</td>
<td>- - - + + ? - -</td>
</tr>
<tr>
<td>- horizontal</td>
<td>+ - - - ? + -</td>
</tr>
<tr>
<td>- other</td>
<td>(6) - (6) - - ? - -</td>
</tr>
<tr>
<td>6. Test duration</td>
<td>L S 7) S S S S S</td>
</tr>
<tr>
<td>7. Evaluation criteria</td>
<td></td>
</tr>
<tr>
<td>a) Burning time of the arc</td>
<td>- - - + + - - +</td>
</tr>
<tr>
<td>b) Length of the arc path</td>
<td>+ + - - + + - +</td>
</tr>
<tr>
<td>c) Insulation resistance measurements</td>
<td>+ + - - - - - - +</td>
</tr>
<tr>
<td>d) Electric strength test</td>
<td>- - - - - - - - -</td>
</tr>
<tr>
<td>e) Continuity test of conductors</td>
<td>+ + - - - - - - -</td>
</tr>
<tr>
<td>f) Visual evaluation</td>
<td>+ + + + + + - -</td>
</tr>
</tbody>
</table>


PRINCIPLES OF A NEW ARC-TRACKING TEST

The following principles have been incorporated into the new test method.

a. Test equipment enables wires to be tested in vacuum, normal air (atmospheric pressure) and in an enriched oxygen atmosphere (at atmospheric and reduced pressure).

b. The supply voltage is adjustable. During test the current is initially set on the nominal current rating (including derating if applied) of the cable. Subsequent tests should be performed at different current values to assess the capability of the wire to withstand stress.

c. The arc is ignited by melting of an ignition wire (filament) ensuring that the influence of the ignition on the arc behaviour is minimised.

d. Switching cycles are applied to the test voltage (presently 10 sec. on, 3 min. off and a further 10 sec. on)

e. Damage is induced in the cable in a clearly defined location.

f. Evaluation criteria should be based on the test results and on any post test measurements such as:

- Remaining "conduction function" of the conductors
- Post test insulation state of damaged and/or undamaged cable bundles
- Arc duration and path length
- Measurement of electrical characteristics during test
- Visual records and post test inspection

Switching Cycle, Measurements and Evaluation Criteria

Accept/Reject Criteria: still under consideration

Basic ideas: Simple criteria based on selected post test measurements; support by electrical and optical records taken during test.
Scheme of the Arc Tracking Test Arrangement

Module I

Module II

Module III

Module IV

Explanation of Symbols: see [5]

Test sample configuration

marking of the cables

ties

table bunde

terminal board

View on arrow A

Cables Nr. 3 and 4: damaged
Cables Nr. 1, 2, 5, 6 and 7: undamaged

exploding wire igniter

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A NEW ARC-TRACKING TEST

Test Procedure (Draft)

a. Prepare test samples as described earlier and install in chamber.

b. Establish test atmosphere.

c. Adjust current to nominal rating for wire under test.

d. Activate test recording devices (video, transient recorder etc.)

e. Power to the test sample should be activated for 10 seconds to initiate the arc and then deactivated. After a period of 3 minutes power to the sample initiated for a further 10 seconds to test for arc tracking potential and damage.

f. During test the sample shall be observed and video recorded. Arc current and arc voltage are recorded by the transient recorder.

g. After test the following measurements are made:
   - Electrical resistance of the conductors of the sample,
   - Insulation resistance between damaged and / or undamaged wires. A value of at least 0.5 MΩ at 500 V DC is required.

h. If the test sample fails the test should be repeated on a new sample at a lower test current.

Typical Test Results:

*4 different arc extinction patterns*

The following four typical arc extinction patterns have been observed:

1. Self-extinguishing arc without reignitions (SE)

2. Arc extinction caused by metallic short circuiting of the conductors (M)

3. Arc extinction caused by low resistance short circuiting of the conductors (R)
   (Conductive material generated from molten insulating material and conductors bridging the conductors)

4. 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 10 sec. has to be expected)
Fig. 4 a/b. Typical records of test current $I(t)$ and voltage $U(t)$ between the conductors during the time $T_1$ of the switching cycle.

Fig. 4 c/d. Typical records of test current $I(t)$ and voltage $U(t)$ between the conductors during the time $T_1$ (c) and the time $T_2$ (d) of the switching cycle.
Arc Tracking Test of Wires
Experimental Results

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>Metallic short circuit</td>
</tr>
<tr>
<td>R</td>
<td>Low resistance short circuit</td>
</tr>
<tr>
<td>SE</td>
<td>Self-extinguishing arc</td>
</tr>
<tr>
<td>CI</td>
<td>Arc extinction after the current interruption by the contactor</td>
</tr>
<tr>
<td>NR</td>
<td>No arc reignition</td>
</tr>
<tr>
<td>A</td>
<td>Massive arcing</td>
</tr>
<tr>
<td>S</td>
<td>Short arcing</td>
</tr>
<tr>
<td>CF</td>
<td>Consuming fire</td>
</tr>
<tr>
<td>SF</td>
<td>Short duration fire</td>
</tr>
<tr>
<td>G</td>
<td>Glow if current flows</td>
</tr>
<tr>
<td>SS</td>
<td>Short spit</td>
</tr>
<tr>
<td>NA</td>
<td>No action</td>
</tr>
<tr>
<td>Y</td>
<td>Yes</td>
</tr>
<tr>
<td>N</td>
<td>No</td>
</tr>
</tbody>
</table>

Information
from recording of current and voltage with a transient recorder

Information
from video recording

After test electrical measurements

Table A. 8

<table>
<thead>
<tr>
<th>Sample No.: 1/20</th>
<th>Wire size: AWG 26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test voltage: 125 V</td>
<td>Test current: 10 A</td>
</tr>
<tr>
<td>Switching cycle</td>
<td>Time 1: 10 s</td>
</tr>
<tr>
<td>Time 2: 10 s</td>
<td></td>
</tr>
</tbody>
</table>

Environmental Conditions

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Normal atmosphere</th>
<th>Atmosphere with enriched oxygen</th>
<th>Vacuum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Post test measurements

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Arc duration (in s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( t_1 )</td>
<td>0.55</td>
<td>0.43</td>
<td>1.4</td>
<td>0.83</td>
<td>1.1</td>
<td>1.6</td>
</tr>
<tr>
<td>( t_2 )</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5. Total burn length (in mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>15</td>
<td>11</td>
<td>16</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>6. End to end wire continuity check.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wire No.:</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
</tr>
<tr>
<td>4. Ignitability resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lower than 0.5 MΩ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>measured for the following wires:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wire No.:</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1. Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Transient recorder:</td>
</tr>
<tr>
<td>Time 1</td>
</tr>
<tr>
<td>Time 2</td>
</tr>
<tr>
<td>B) Video recorder:</td>
</tr>
<tr>
<td>Time 1</td>
</tr>
<tr>
<td>Time 2</td>
</tr>
</tbody>
</table>
### Table A. 9

<table>
<thead>
<tr>
<th>Sample No.: 1/12</th>
<th>Wire type: AWG ‘12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test voltage: 125 V</td>
<td>Test current: 30 A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Switching cycle</th>
<th>Time 1: 10 s</th>
<th>Time 2: 10 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null period (Power off): 3 min.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environmental Conditions</th>
<th>Normal atmosphere</th>
<th>Atmosphere with enriched oxygen</th>
<th>Vacuum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post test measurements</td>
<td>Test No.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Arc duration (in s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_1$</td>
<td>1.2</td>
<td>1.4</td>
<td>2.2</td>
</tr>
<tr>
<td>$T_2$</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total burn length (in mm)</td>
<td>12</td>
<td>24</td>
<td>40</td>
</tr>
<tr>
<td>3. End to end wire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>continuity check.</td>
<td>Wire No.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation resistance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lower than 0.5 MΩ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>measured for the</td>
<td>Test No.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>following wires:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A) Transient recorder:</td>
<td>Time 1</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Time 2</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>B) Video recorder:</td>
<td>Time 1</td>
<td>A,CF</td>
<td>A,CF</td>
</tr>
<tr>
<td></td>
<td>Time 2</td>
<td>SF,G</td>
<td>CF,G</td>
</tr>
</tbody>
</table>

* — test current 10 A

---

**Average values of arc duration $t_a$, length of arc traces $L_a$, and arc propagation velocity $v_a$ for Cable 2/20 tested under different environmental conditions.**

Number of tests for each environmental condition $N=5$. 

---

**Cable Nr. 2/20**

**Conductor:** PI/PI/PTFE

<table>
<thead>
<tr>
<th>Vacuum</th>
<th>$24.5%O_2/24.5%\text{N}_2/30%\text{O}_2/\text{Air}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p=10^{-3}\text{Pa}$</td>
<td>75.5%\text{N}_2/70%\text{N}_2/p=1000\text{hPa}$</td>
</tr>
<tr>
<td></td>
<td>$p=1000\text{hPa}$</td>
</tr>
</tbody>
</table>
Average values of arc duration $t_a$, length of arc traces $i_a$ and arc propagation velocity $v_a$ for cable Nr. 3/20 tested under different environmental conditions.

Number of tests for each environmental condition $N=5$.

PRELIMINARY TEST RESULTS
ARC TRACKING TEST OF WIRES

TABLE 1. TEST SAMPLE 1/12 (Cable size AWG 12)

<table>
<thead>
<tr>
<th>Test-Nr.</th>
<th>Path length of damaged cable insulation in mm</th>
<th>Number of cables with insulation resistance $&lt; 0.5 \text{ M} \Omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 N</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>2 N</td>
<td>24</td>
<td>1</td>
</tr>
<tr>
<td>1 E</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>2 E</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>1 V</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>2 V</td>
<td>13</td>
<td>5</td>
</tr>
</tbody>
</table>

$N$ – Normal atmosphere, $E$ – Oxygen enriched atmosphere, $V$ – Vacuum

Conclusion: The path length of damaged cable insulation seems to be not correlated with the results of post-test measurements of the cable insulation resistance.
ANC TRACKING: CABLES SAMPLES FOR TESTING

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>ESA SCC-SPEC</th>
<th>No. of Cores</th>
<th>Wire Size AWG</th>
<th>Material Plating</th>
<th>Insulation Layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/20</td>
<td>3901 001</td>
<td>1</td>
<td>20</td>
<td>Co/Silver</td>
<td>PI PI PI (protective coating)</td>
</tr>
<tr>
<td>1/12</td>
<td></td>
<td>1</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 A/20</td>
<td>3901 002</td>
<td>1</td>
<td>20</td>
<td></td>
<td>PI PI (protective coating)</td>
</tr>
<tr>
<td>2/20</td>
<td>3901 007</td>
<td>1</td>
<td>20</td>
<td></td>
<td>PI PI PTFE</td>
</tr>
<tr>
<td>2/12</td>
<td></td>
<td>1</td>
<td>12</td>
<td></td>
<td>HR616 HR616</td>
</tr>
<tr>
<td>3/20</td>
<td>3901 009</td>
<td>1</td>
<td>20</td>
<td></td>
<td>PTFE PI PI</td>
</tr>
<tr>
<td>3/12</td>
<td></td>
<td>1</td>
<td>12</td>
<td></td>
<td>expanded HR616 HR616</td>
</tr>
<tr>
<td>4/20</td>
<td>3901 012</td>
<td>1</td>
<td>20</td>
<td></td>
<td>ETFE extruded</td>
</tr>
<tr>
<td>5/20</td>
<td></td>
<td>1</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/20</td>
<td></td>
<td>1</td>
<td>20</td>
<td>PTFE</td>
<td>PI PTFE tape 51 % overl. varnish</td>
</tr>
<tr>
<td>7/20</td>
<td>3901 013</td>
<td>1</td>
<td>20</td>
<td>PTFE</td>
<td>PI expanded coating</td>
</tr>
<tr>
<td>8/20</td>
<td></td>
<td>1</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ETFE = Ethylene Tetrafluoro-Ethylene  PI = Polymide  PTFE = Polytetrafluorethylene

TEST ACCEPTANCE CRITERIA (Draft)

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 and

2. All cables/wires of all five test specimens tested without the predamaged cables/wires have to fulfill the requirements of insulation resistance test, i.e. the insulation resistance between the cable/wire under test and the other cables/wires of a test specimen short-circuited must be higher than 0.5 MQ.

3. During the re-application of the power for 10 seconds following the three minutes pause no visible arc and/or glow activity is acceptable.

4. If only one cable/wire of all tested specimens fails, 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 as resistant to arc tracking for a given test voltage and currents below or equal to the test current with respect to this environmental condition.

5 TEST SPECIMENS OF 7 CABLES/WIRES EACH

IF ONLY ONE CABLE/WIRE FAILS — ADDITIONAL 3 TESTS
Table 2  Test Results and Acceptance Statement

<table>
<thead>
<tr>
<th>Test voltage: 125 V</th>
<th>Environmental conditions (E.C.):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Normal atmosphere (N)</td>
</tr>
<tr>
<td></td>
<td>2. Vacuum (V)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test criterion</th>
<th>E.C.</th>
<th>Test - Nr.</th>
<th>Criterion 1</th>
<th>Criterion 2</th>
<th>Criterion 3</th>
<th>Accepted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Number of cables that fell the continuity check of conductors (1...7)</td>
<td>Number* of cables with an insulation resistance ≤ 0,5 MΩ (1...5)</td>
<td>Visible arc or glow activity during re-application of the power (Yes/No)</td>
<td>Yes/No</td>
</tr>
<tr>
<td>10A</td>
<td>V</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>7,5A</td>
<td>V</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N</td>
<td>Y</td>
</tr>
</tbody>
</table>

Test Result:
The above specified cable is resistant to arc tracking for current values ≤ 7,5 A at the rated voltage of 125 V and for the environmental conditions defined as:
Normal atmosphere, $p = 0,1$ MPa

* without the pre-damaged cables Nr. 3 and Nr. 4
Procedure for an estimation of the arc tracking current limit

\[ I_a = 0.25 I_n \]

\[ I_a = 0.5 I_n \]

\[ I_a = 0.75 I_n \]

\[ I_a = I_n \]

\[ I_t / I_n \]

- 0
- 12.5%
- 25%
- 37.5%
- 50%
- 62.5%
- 75%
- 87.5%
- 100%

\[ I_i = \text{test current} \]

\[ I_n = \text{rated current of the tested cable / wires} \]

(see Table A.1)

1, 2, 3, ... \( N \) = Number of test steps
Conclusion

A brief summary of the results obtained is given below. However, it should be remembered that the conclusions drawn are based on limited series of tests and further work needs to be done to investigate the effects of different parameters. In addition, presently accept/reject criteria can be given only as a draft. Modifications may become necessary, if required by findings from a more extensive data base.

The results can therefore be summarised as follows:

a. The proposed test method appears to be a useful tool for the assessment of wire insulation systems under arc tracking stress.

b. The equipment can be easily adapted for tests at different realistic electrical network conditions incorporating circuit protection.

c. The test system works equally well whatever the test atmosphere.

d. Initial test results confirm published results of the available literature in that pure Kapton insulated wire has bad arcing characteristics and ETFE insulated wire is considerably better (in air).

e. Initial test results indicated that for certain wires arc tracking effects are increased at higher oxygen concentrations and significantly increased under vacuum. Although this letter point had been suggested from theoretical considerations it is believed that this is the first time this has been demonstrated in practice.

f. All tests on different cable insulation materials and performed in different environment including enriched oxygen atmospheres resulted in a more or less rapid extinguishing of all high temperature effects at the beginning of the post-test phase. In no case a self-maintained fire was initiated by the arc.
HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

Robert J. Jones
TRW
Redondo Beach, California

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

BACKGROUND

- DUAL USE SYSTEM DRIVERS FOR DEVELOPMENT, QUALIFICATION AND PRODUCTION OF NEXT GENERATION, VERY HIGH TEMPERATURE WIRE INSULATION
  - ENERGY RECOVERY/GENERATION/DISTRIBUTION AND TRANSPORTATION MARKETS (1990’s)
  - SUPER CAPACITY/RESPONSE ELECTRONIC COMPUTATION AND TELECOMMUNICATION EQUIPMENT (1990’s)
  - HIGH SPEED CIVIL TRANSPORT (NEXT CENTURY)
  - ALL ELECTRIC AIRPLANE (NEXT CENTURY)

- EXAMPLES OF SYSTEM RATIONALE FOR VERY HIGH TEMPERATURE WIRE INSULATION
  - SMALLER, MORE EFFICIENT ELECTRONIC SYSTEMS RUN HOTTER
  - OPERATING ENVIRONMENTS SUCH AS DOWNWELL ARE GETTING MORE THERMALLY SEVERE
  - ACTIVE COOLING SYSTEMS FOR GENERATORS/ALTERNATORS, STORAGE/TRANSMISSION/DISTRIBUTION SYSTEMS AND BLACK BOXES ARE COSTLY AND EQUATE TO SEVERE WEIGHT PENALTIES
  - SMALLER DIAMETER WIRES MAY BE SUFFICIENT TO CARRY EQUIVALENT POWER

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

BACKGROUND (CONTINUED)

- ASSESSMENT OF EMERGING REQUIREMENTS HAS DICTATED THAT 300°C PERFORMANCE IS THE GOAL FOR NEXT GENERATION WIRE INSULATION
  - VERY SIGNIFICANT INCREASE OVER CURRENTLY QUALIFIED POLYIMIDE AND FLUOROPOLYMERS RATED AT 200°C (OR SLIGHTLY ABOVE)
  - EMERGING HIGH TEMPERATURE POLYMER MATERIALS HAVE BEEN SHOWN TO HAVE POTENTIAL FOR PERFORMANCE AT ≥300°C
  - ≥300°C INSULATIONS SHOULD MEET NEW DUAL USE PERFORMANCE REQUIREMENTS WELL INTO NEXT CENTURY

- STATUS OF RECENT OR CURRENT 300°C POLYMERIC WIRE INSULATION ACTIVITY
  - UBE INDUSTRIES OFFERED UPILEX® S FILM, BUT WITHDREW IT FROM THE MARKET IN 1992
  - FOSTER MILLER IS STUDYING LIQUID CRYSTAL POLYMERS
  - 3M IS DEVELOPING FPE POLYMER MATERIAL
  - TRW HAS SHOWN HIGH PROMISE FOR ITS PPPI POLYMERS UNDER USAF SPONSORSHIP (FINAL REPORT WL-TR-91-2105); FURTHER WORK WILL BE CONDUCTED IN RECENTLY AWARDED USAF CONTRACT F33615-93-C-2367
HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION
TRW PFPI AS SUPERIOR 300°C POLYMER CANDIDATES

• REPRESENTATIVE CHEMISTRY

```
[CH3-CH2-C=O]3
```

US PATENT NUMBERS 4,111,906; 4,196,277; 4,203,922; 4,880,584
(PFPI POLYMERS WERE INVENTED UNDER NASA LEWIS RESEARCH CENTER SPONSORSHIP IN THE LATE 1970's)

• VERSATILITY
- FORMULATIONS CAN BE TAILORED TO MEET PRODUCT USE REQUIREMENTS
- COATING VARNISH, FILM AND POWDER PRODUCT FORMS CAN BE EMPLOYED TO ADAPT FORMULATIONS TO EXISTING PROCESSING EQUIPMENT FOR CONVERSION TO WIRE INSULATION
- POLYMERS POSSESS SUPERIOR COMBINATION OF THERMAL/ELECTRICAL/UV, MOISTURE & FLUID RESISTANCE/TRIBOLOGICAL PROPERTIES
- FILMS ARE AMENABLE TO CERAMIC COATING FOR LEO ATOMIC OXYGEN PROTECTION

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION
TRW PFPI AS SUPERIOR 300°C POLYMER CANDIDATES (CONTINUED)

• COMPARISON OF PROMISING PFPI FILM PROPERTIES WITH KAPTON® (FROM REPORT WL-TR-91-2105)

<table>
<thead>
<tr>
<th>PROPERTY MEASURED</th>
<th>KAPTON FILM</th>
<th>TRW PFPI FILM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRICAL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• DIELECTRIC CONSTANT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- AT 25°C</td>
<td>3.1</td>
<td>3.1</td>
</tr>
<tr>
<td>- AT 300°C</td>
<td>2.0</td>
<td>2.9</td>
</tr>
<tr>
<td>• DISSIPATION FACTOR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- AT 25°C</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>- AT 300°C</td>
<td>0.063</td>
<td>0.004</td>
</tr>
<tr>
<td>• BREAKDOWN VOLTAGE AT 25°C (V/MIL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- AC</td>
<td>7000</td>
<td>6000</td>
</tr>
<tr>
<td>- DC</td>
<td>11000</td>
<td>12000</td>
</tr>
<tr>
<td>LOW TEMPERATURE STABILITY (CRYOGENIC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• EXPOSURE IN LIQUID NITROGEN AND HELIUM</td>
<td>NO EFFECT</td>
<td>NO EFFECT</td>
</tr>
<tr>
<td>AIR AGING AT 300°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• WEIGHT LOSS AFTER 1000 HRS (%)</td>
<td>13.0</td>
<td>4.1</td>
</tr>
<tr>
<td>HUMIDITY AGING AT 90°C/100% RH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• WEIGHT LOSS AFTER 1200 HRS (%)</td>
<td>FAILED AFTER 500 HRS</td>
<td>0.4</td>
</tr>
<tr>
<td>BASIC SOLUTION (PH, 10) AGING AT 93°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• WEIGHT LOSS AFTER 96 HRS (%)</td>
<td>2.6</td>
<td>1.3</td>
</tr>
<tr>
<td>ULTRAVIOLET LIGHT AGING AT 25°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• WEIGHT LOSS AFTER 1000 HRS (%)</td>
<td>6.7</td>
<td>1.4</td>
</tr>
</tbody>
</table>

A) ALL PROPERTIES DETERMINED ON 0.001-INCH THICK FILMS
HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

TRW'S PFPI AS SUPERIOR 300°C POLYMER CANDIDATES (CONTINUED)

• PROMISING BULK POLYMER OR COATING PROPERTIES

<table>
<thead>
<tr>
<th>PROPERTY TYPE</th>
<th>PROPERTY MEASURED</th>
<th>TEST RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>THERMAL</td>
<td>• MELTING POINT</td>
<td>≥400°C</td>
</tr>
<tr>
<td></td>
<td>• GLASS TRANSITION</td>
<td>&gt;300°C</td>
</tr>
<tr>
<td></td>
<td>• TEMPERATURE</td>
<td></td>
</tr>
<tr>
<td>TRIBOLOGICAL</td>
<td>• FRICTION COEFFICIENT</td>
<td>0.3-0.6(RT); 0.1-0.2 (300°C)</td>
</tr>
<tr>
<td></td>
<td>• WEAR RATE</td>
<td>MUCH LOWER THAN TEFLOW</td>
</tr>
<tr>
<td>COATING</td>
<td>• COATING INTEGRITY</td>
<td></td>
</tr>
<tr>
<td>ENVIRONMENTAL RESISTANCE</td>
<td>AFTER EXPOSURE TO:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 500 HRS, 343°C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 21 DAYS, 71°C IN</td>
<td>NO BLISTERING OR</td>
</tr>
<tr>
<td></td>
<td>MIL-H-5606 HYDRAULIC FLUID</td>
<td>LOSS</td>
</tr>
<tr>
<td></td>
<td>• 21 DAYS, 71°C IN</td>
<td>OF ADHESION</td>
</tr>
<tr>
<td></td>
<td>MIL-L-7808 JET ENGINE OIL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 2000 HRS, 23°C IN 5% SALT SPRAY</td>
<td></td>
</tr>
</tbody>
</table>

HIGH TEMPERATURE POLYMER DIELECTRIC FILM INSULATION

TRW'S PFPI AS SUPERIOR 300°C POLYMER CANDIDATES (CONTINUED)

• DUAL USE CHALLENGES FOR 1994-1996 TIME FRAME

- CONTINUING USAF WORK
  • VERIFY PROMISING INITIAL FILM AND COATING PROPERTIES AS A WIRE INSULATION
  • DEMONSTRATE A SUPERIOR 300°C ADHESIVE FOR WRAPPED FILM
  • ACHIEVE HIGH INSULATION RESISTANCE TO Arcing & Tracking
  • ACHIEVE FACILE FILM WRAP PROCESSABILITY ON EXISTING PLANT EQUIPMENT AND PRODUCE HIGH QUALITY INSULATED WIRE

- COMMERCIAL PRODUCT DEVELOPMENT
  • QUALIFY AND INTRODUCE PFPI INTO MAGNET WIRE INSULATION, AUTOMOTIVE COMPONENT COATING AND MEDICAL DIAGNOSTIC PRODUCT APPLICATIONS
  • MAXIMIZE HIGH VOLUME USE APPLICATIONS TO MINIMIZE FUTURE POLYMER COSTS

• PROPOSED ADAPTATION OF PFPI TO MEET FUTURE NASA 200°C SPACE SYSTEM WIRE INSULATION REQUIREMENTS

- DETERMINE INITIAL BASELINE WIRE PROPERTIES SPECIFIC TO SPACE APPLICATION ON COATED OR WRAPPED WIRE
- TAILOR EXISTING 300°C POLYMER CANDIDATE TECHNOLOGY, AS REQUIRED, TO OFFER OPTIMUM 200°C PERFORMANCE; BUILD UPON EURECA SAMPLE TEST RESULTS
- PRODUCE OPTIMIZED INSULATED WIRE AND PERFORM QUALIFICATION TESTS FOR GENERAL AND MISSION SPECIFIC SPACE APPLICATIONS
HIGH TEMPERATURE ARC-TRACK RESISTANT AEROSPACE INSULATION

William Dorogy
Foster-Miller, Inc.
Waltham, Massachusetts

FOSTER-MILLER, INC.

• 37 year old independent technology development company
• Located in the Boston area
• About 270 employees
• Primary areas of business
  - Advanced polymers
  - Composites
  - Robotics
  - Special machinery

MATERIALS TECHNOLOGY GROUP

• Mission
  - Develop materials and processing technology to meet DoD and commercial needs
• Specific Areas of Research
  - High temperature dielectric materials
  - High performance dielectrics for capacitors
  - Electronics packaging
  - High performance structural materials
  - Microcomposite blends
  - NLO materials, devices
  - Smart processing
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 1994

• Contract monitors: Lt. Tim Townsend and Mr. Robert Andes

COMPARISON OF CURRENT MATERIALS AND MATERIALS UNDER DEVELOPMENT FOR AEROSPACE INSULATION

<table>
<thead>
<tr>
<th>Insulation Material</th>
<th>Max Use Temp. °C</th>
<th>Arc-Tracking</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetzel</td>
<td>150°C</td>
<td>No</td>
<td>Lower moisture absorption than Kapton. Non-combustible gases when fails.</td>
<td>Weight and volume penalty compared to Kapton. Poor mechanical properties.</td>
<td>Navy has been replacing Kapton with Tetzel.</td>
</tr>
<tr>
<td>PTFE/Polymide Hybrids</td>
<td>220°C</td>
<td>No</td>
<td>Good balance of properties compared to Kapton and Tetzel.</td>
<td>Maximum use temperature. 15 percent weight penalty compared to Kapton.</td>
<td>Identified by MacAir program. Teledyne Thermatics has been recommended for inclusion in QPL.</td>
</tr>
</tbody>
</table>
TARGET FOR NEW INSULATION

![Graph showing minimum life vs. hottest temperature.]

FOSTER-MILLER APPROACH TO DEVELOP A 300°C RATED, ARC-TRACK RESISTANT AEROSPACE INSULATION

Large Classes of High Performance Polymers

Evaluation Based on
- Structure
- Thermal Stability
- Electrical Properties

Phase I Program
- 6 Materials

Phase II
- Step I
- 2 Materials
  - Experimental Characterization
  - Rank According to Performance

Phase II
- Step II
  - Experimental Evaluations in Wire Configuration
  - Selection Based on Performance and Commercialization Potential

One Material System for Consideration to Include in QPL
## PHASE I PROGRAM

### ADVANTAGES AND THE DISADVANTAGES OF KEY STRUCTURAL FEATURES

<table>
<thead>
<tr>
<th>STRUCTURAL FEATURE</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorine content</td>
<td>For low dielectric constant, low loss factor, high volume resistivity, uniform electrical properties over a wide range of temperatures and resistance to arc-tracking.</td>
<td>Allphatic fluoropolymers, such as Tetzel, have poor mechanical properties at high temperatures. To overcome this limitation, must incorporate other features.</td>
</tr>
<tr>
<td>Liquid crystalline</td>
<td>Solvent resistance, high thermal stability, excellent electrical properties and possible improved resistance to arc-tracking.</td>
<td>Liquid crystalline polymers are difficult to process, need to incorporate additional features, e.g., polyimide.</td>
</tr>
<tr>
<td>Polyimide</td>
<td>High thermal stability, abrasion resistance, good electrical properties and good processability.</td>
<td>Poor resistance to arc-tracking. Improved through introduction of additional features, e.g., fluorinated groups, crystallinity.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STRUCTURAL FEATURE</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aromatic</td>
<td>High thermal stability.</td>
<td>Highly aromatic polymers yield conducting char upon pyrolysis.</td>
</tr>
<tr>
<td>Rigidity/ stiffness</td>
<td>Rigidly increases thermal and mechanical capability, and reduces susceptibility to solvents.</td>
<td>Highly rigid polymers can be intractable, difficult to process, and low elongation to break. Some degrees of flexibility desired.</td>
</tr>
<tr>
<td>Cross-linking</td>
<td>X-linking significantly increases thermal stability. This process is widely used in the development of 371°C-rated composites.</td>
<td>X-linking greatly reduces flexibility, reduces elongation to break, and embrittles.</td>
</tr>
<tr>
<td>Carbon to hydrogen ratio</td>
<td>High carbon to hydrogen ratio increases thermal capability of polymers.</td>
<td>High carbon to hydrogen ratio may cause the formation of conductive char and susceptibility to arc-tracking.</td>
</tr>
</tbody>
</table>
CLASSES OF MATERIALS EVALUATED

- Organic Polymers
  - Polyimides
    - Thermoset polyimides
    - Thermoplastic polyimides
    - Fluorinated polyimides
    - Liquid crystalline polyimides
    - Fluorinated liquid crystalline polyimides
    - Siloxane imides
  - Liquid crystalline polymers
  - Lyotropic liquid crystalline polymers
  - Thermotropic liquid crystalline polymers
  - Polyquinolines
  - Polyphenylquinoxalines
  - Polyketones
  - Polyether ketones
  - Polyarylates
  - Polysulfones
  - Aromatic polyimides
  - Polyamide-imides
  - Polybenzimidazoles
  - Aliphatic fluoropolymers

- Blends of Organic Polymers
  - Polyimide blends with thermotropic liquid crystalline polymers
  - Polyimide blends with polyether sulfones

- Inorganic Materials
  - Polysilsesquioxanes
  - Polycarbosilane

SUMMARY GOALS AND ACHIEVEMENTS OF THE PHASE I PROGRAM

<table>
<thead>
<tr>
<th>GOAL</th>
<th>ACHIEVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establish insulation</td>
<td>Thermal, electrical, mechanical and physical requirements established</td>
</tr>
<tr>
<td>requirements</td>
<td></td>
</tr>
<tr>
<td>Prepare an evaluation matrix</td>
<td>Selection criteria to screen polymers developed:</td>
</tr>
<tr>
<td>to rank materials</td>
<td>- Key structural features that contribute desired performance</td>
</tr>
<tr>
<td></td>
<td>- Key electrical properties</td>
</tr>
<tr>
<td></td>
<td>- Key thermal properties</td>
</tr>
<tr>
<td>Conduct screening tests</td>
<td>Eleven candidate materials were acquired and prepared for testing</td>
</tr>
<tr>
<td></td>
<td>- Dielectric measurements (25°C to 300°C, and 20 Hz to 1 MHz) on all</td>
</tr>
<tr>
<td></td>
<td>- available polymers with potential for 300°C were conducted</td>
</tr>
<tr>
<td>Select most promising</td>
<td>Six polymers have been identified with the potential for:</td>
</tr>
<tr>
<td>materials</td>
<td>- No arc-tracking</td>
</tr>
<tr>
<td></td>
<td>- 300°C rating</td>
</tr>
<tr>
<td></td>
<td>- Better hydrolytic stability than Kapton</td>
</tr>
<tr>
<td></td>
<td>- Better mechanical properties and solvent resistance than Tefzel</td>
</tr>
<tr>
<td>Proposed strategy for</td>
<td>A two step program to develop an insulation system for consideration to</td>
</tr>
<tr>
<td>implementation</td>
<td>- include in GPL:</td>
</tr>
<tr>
<td></td>
<td>- Experimental investigation and ranking of performance to narrow the</td>
</tr>
<tr>
<td></td>
<td>- performance to two</td>
</tr>
<tr>
<td></td>
<td>- Evaluation in wire construction to select one material system on the</td>
</tr>
<tr>
<td></td>
<td>- basis of performance, cost and manufacturability</td>
</tr>
<tr>
<td>Conduct cost/benefit analysis</td>
<td>Deferred to Phase II</td>
</tr>
</tbody>
</table>
PHASE II
PROGRAM DETAILS

PERFORMANCE GOALS FOR SELECTED MATERIALS

• Arc-track resistance
  - >300 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

MATERIALS UNDER EVALUATION IN PHASE II

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3F-PBO-PE</td>
<td>Fluorinated benzoxazole polyether</td>
</tr>
<tr>
<td>6F-PBO-PE</td>
<td>Thermoplastic fluorinated benzoxazole polyether</td>
</tr>
<tr>
<td>6F-PBO-PI</td>
<td>Fluorinated benzoxazole polyimide</td>
</tr>
<tr>
<td>36FDA-PDA</td>
<td>Fluorinated copolyimide</td>
</tr>
<tr>
<td>6FDA-PMDA-4BDAF</td>
<td>Fluorinated copolyimide</td>
</tr>
<tr>
<td>Low char polyimide</td>
<td>DuPont proprietary polyimide</td>
</tr>
<tr>
<td>Siloxane-polyimide</td>
<td>Polydimethylsiloxane polyimide</td>
</tr>
<tr>
<td>Phosphine oxide polymer</td>
<td>Poly(arylene ether phosphine oxide)</td>
</tr>
<tr>
<td>Xydar blends</td>
<td>Liquid crystal polyester</td>
</tr>
</tbody>
</table>
MOLECULAR STRUCTURES OF CANDIDATE POLYMERS

[Chemical structures are shown here representing different polymers, including symbols for molecular bonds and elements such as carbon (C), oxygen (O), and fluorine (F).]

MOLECULAR STRUCTURES OF CANDIDATE POLYMERS

Siloxane Polyimide

Phosphine Oxide Polymer

Xydar
## CANDIDATE POLYMER PROPERTIES

<table>
<thead>
<tr>
<th>POLYMER</th>
<th>SOURCE</th>
<th>Tg (°C)</th>
<th>PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>3F-PBO-PE</td>
<td>Prof. J.E. McGrath VPI &amp; SU Blacksburg, VA</td>
<td>299</td>
<td>5% wt loss at 547°C in air. Inherent viscosity (THF) = 0.80. Able to form 12 wt% solution in THF.</td>
</tr>
<tr>
<td>6F-PBO-PE</td>
<td>Daychem Laboratories Dayton, OH</td>
<td>290</td>
<td>Degradation onset in N₂ at 521°C. Able to form 18 wt% solution in THF.</td>
</tr>
<tr>
<td>6F-PBO-PI</td>
<td>Foster-Miller, Inc. Hoechst-Celanese</td>
<td>367</td>
<td>3% wt loss at 350°C after 64 hr. Dielectric constant (1MHz) = 2.82. Dissipation factor (1MHz) = 0.0004. Excellent solvent resistance.</td>
</tr>
<tr>
<td>36FDA-PDA</td>
<td>Foster-Miller, Inc. United Technologies</td>
<td>406</td>
<td>2% wt loss at 371°C after 100 hr in air. Films tend to be brittle with all p-PDA.</td>
</tr>
</tbody>
</table>

---

## CANDIDATE POLYMER PROPERTIES

<table>
<thead>
<tr>
<th>POLYMER</th>
<th>SOURCE</th>
<th>Tg (°C)</th>
<th>PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>6FDA-PMDA-4BDAF</td>
<td>Prof. J.E. McGrath VPI &amp; SU Blacksburg, VA</td>
<td>299</td>
<td>Using 30% 6FDA/70% PMDA ratio. 5% wt loss at 540°C in air. Mₙ = 30,000. Able to form 25 wt% PAA solution in DMAc.</td>
</tr>
<tr>
<td>Low char polyimide</td>
<td>DuPont</td>
<td>-</td>
<td>Able to form 14 wt% PAA solution in DMAc.</td>
</tr>
<tr>
<td>Siloxane - polyimide</td>
<td>Prof. J.E. McGrath VPI &amp; SU Blacksburg, VA</td>
<td>-</td>
<td>34% PDMS (Mₙ = 4.5K) -66% polyimide (Mₙ = 11K) Able to form 20 wt% solution in CHCl₃, 52% PDMS (Mₙ = 4.5K) -48% polyimide (Mₙ = 4K) Able to form 25 wt% solution in CHCl₃.</td>
</tr>
<tr>
<td>Phosphine oxide polymer</td>
<td>Prof. J.E. McGrath VPI &amp; SU Blacksburg, VA</td>
<td>245</td>
<td>R = σ and Ar = biphenyl 5% wt loss at 520°C in air.</td>
</tr>
<tr>
<td>Xydar</td>
<td>Amoco Performance Products</td>
<td>150</td>
<td>300 sec arc-track resistance. Tₘ = 348°C Dielectric constant (1MHz) = 2.8 Dissipation factor (1MHz) = 0.06.</td>
</tr>
</tbody>
</table>
**FILM PROPERTIES**

- Measure properties of candidate polymers and Kapton using Air Force approved test plan
- Arc-track resistance tester built by Foster-Miller
- Proposed properties to be measured

<table>
<thead>
<tr>
<th>THERMAL</th>
<th>ELECTRICAL</th>
<th>MECHANICAL</th>
<th>PHYSICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_g$</td>
<td>Dielectric constant</td>
<td>Tensile strength, break</td>
<td>Humidity resistance</td>
</tr>
<tr>
<td>$T_m$</td>
<td>Dissipation factor</td>
<td>Tensile strength, yield</td>
<td>Water absorption after 24 hr</td>
</tr>
<tr>
<td>5% weight loss</td>
<td>Dielectric strength</td>
<td>Tensile elong., break</td>
<td>Fluid immersion</td>
</tr>
<tr>
<td>Volume resistivity</td>
<td>Tensile elong., yield</td>
<td>Flexural modulus</td>
<td>Aging stability</td>
</tr>
<tr>
<td>Surface resistivity</td>
<td>Arc resistance*</td>
<td>C.T.E.</td>
<td></td>
</tr>
</tbody>
</table>

*Use ASTM D495 or alternative arc resistance test

**DETAILED PROGRAM PLAN**

![Program Plan Diagram]

1. **Air Force**
2. **Foster-Miller**, experience in synthesis
3. **Dowchem**, VPI, UTC, Dupont
4. **Foster-Miller**, Film Processing Experience
5. **Dolts**, Surprserant
6. **Delta Surprserant**, Teledyne
7. **TRW, FMI**
8. **Rexham**
9. **Delta Surprserant**
10. **Teledyne Thermatics**

**Tasks:**

- Task 1: Test Plan to Evaluate Polymers
- Task 2: Acquire/Synthesize Polymers
- Task 3: Cast into Films
- Task 4: Produce Xydar Blends
- Task 5: Measure Film Properties
- Task 6: Rank and Select Two Materials
- Task 7: Identify Key Tests to Evaluate Wires
- Task 8: Scale-Up Synthesis
- Task 9: Convert into Continuous Films
- Task 10: Fabricate into Aerospace Wire
- Task 11: Measure Performance Characteristics
- Task 12: Evaluate and Recommend One System
- Task 13: Evaluate Commercialization Potential
- Task 14: Reports and Program Management

201
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3M High Temperature Dielectric Film

Summary

* A high performance film product to over 200 °C
* Excellent electrical properties to over 200 °C
* Good mechanical properties
* Intriguing optical properties
* Excellent environmental & chemical properties
  - Low shrinkage to 300 °C
  - Moisture insensitive
  - Low outgassing under vacuum
  - Excellent surface qualities - easy metallization of film
  - Flame retardant
  - Low smoke generation

3M FPE High Temperature Dielectric Film

General Comments

- High molecular weight polymer - 400,000 to 700,000
- Experimentally prepared film - caliper 5 μ to 400 μ
- Density - 1.22 g/cc
- Radiation stability measured to 400 megrads
- Easily metallized
3M FPE High Temperature Dielectric Film

Thermal Properties

- High $T_g$ - 335°C (DSC measurement)
- Thermal stability to 500°C (TGA measurement in air)
- Thermal conductivity - 0.13-0.15 watts/m K° (23°-150°C)
- Flame retardant - high limiting oxygen index, low smoke generation, high ignition temperature, high char yield, no drip and/or ignition when exposed to flame
- Low shrinkage - <0.2% at 200°C/24 hours
  - 1% at 200°C/2000 hours
  - <0.3% at 250°C/10 hours

---

FPE High Temperature Dielectric Film

![Graph showing weight loss vs. temperature]

Wt: 5.2001
Rate: 20 deg./min.
Dielectric Constant as a Function of Frequency - 3M FPE Film
(25°C - 3M Data)

Dielectric Constant as a Function of Temperature - 3M FPE Film
(1 KHz - 3M Data)
3M FPE Film Dissipation Factor as a Function of Temperature
(100 Hz to 1 KHz)
3M FPE Film Breakdown Voltage (D.C.) as a Function of Thickness

Test Conditions:
- Measurement in air at ambient conditions
- Voltage rise 250 V/sec.
- Each data point is average of 36 measurements
- Electrodes: 0.25 inch diameter brass deadweight, rounded edges

Volume Resistivity as a Function of Temperature 3M FPE and DuPont Kapton Film
Comparative DC Dielectric Strength of Insulation Films

<table>
<thead>
<tr>
<th>Film</th>
<th>DC dielectric strength @ 1 mil, 25°C, air (KV/mil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3M FPE</td>
<td>12.3</td>
</tr>
<tr>
<td>PET</td>
<td>7.5</td>
</tr>
<tr>
<td>Polyimide</td>
<td>7.0</td>
</tr>
<tr>
<td>PTFE</td>
<td>4.2</td>
</tr>
</tbody>
</table>

3M FPE High Temperature Dielectric Film

Mechanical Properties
(Measurements to 300°C)

- Tensile strength - 20,000 psi (22°C)
- Elongation - 70% (22°C)
- Modulus of elasticity - 500,000 psi (22°C)
- High heat distortion temperature - <1% (21°C - 300°C; 50 psi load), 1% (21°C - 300°C; 300 psi load)
- Coefficient of expansion $C(\alpha)$ - $4 \times 10^{-5}$ m/m/°C
3M FPE High Temperature Dielectric Film

Chemical Properties

- Humidity coefficient $C(\beta) = 0.4 \times 10^{-5} \text{m/m/}%\text{RH}$
- Moisture absorption <0.6% (50% RH, 23°C, 24 hrs)
- Very low outgassing under high vacuum - insignificant at $10^{-7}$ torr, at least a factor of 10 lower than polyimide
- Non-toxic by 3M testing
- Low toxic gas generation - no N, S, or X in chemical structure
- Compatible with common impregnants, weak acids, and weak bases - Fluorochemicals, Silicone oil, Castor oil, Monoisopropyl biphenyl, Ditolyl ether, Tricresyl phosphate, Phenyl xylyl ethane

Thermal Aging and Hydrolytic Stability Test Results
(WPAFB Contract F44615-88-C2913)

<table>
<thead>
<tr>
<th>Aging Environment</th>
<th>Meas. Temp. (°C)</th>
<th>100 Hz</th>
<th>400 Hz</th>
<th>1 kHz</th>
<th>10 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>25</td>
<td>0.0020</td>
<td>0.0021</td>
<td>0.0026</td>
<td>0.0053</td>
</tr>
<tr>
<td>Air, 7 days, 300°C</td>
<td>25</td>
<td>0.0025</td>
<td>0.0024</td>
<td>0.0029</td>
<td>0.0046</td>
</tr>
<tr>
<td>N₂, 7 days, 300°C</td>
<td>25</td>
<td>0.0022</td>
<td>0.0021</td>
<td>0.0026</td>
<td>0.0046</td>
</tr>
<tr>
<td>H₂O, 2 days, 100°C</td>
<td>25</td>
<td>0.0018</td>
<td>0.0019</td>
<td>0.0025</td>
<td>0.0045</td>
</tr>
<tr>
<td>Ambient</td>
<td>225</td>
<td>0.0014</td>
<td>0.0006</td>
<td>0.0006</td>
<td>0.0004</td>
</tr>
<tr>
<td>Air, 7 days, 300°C</td>
<td>225</td>
<td>0.0012</td>
<td>0.0007</td>
<td>0.0008</td>
<td>0.0008</td>
</tr>
<tr>
<td>N₂, 7 days, 300°C</td>
<td>225</td>
<td>0.0008</td>
<td>0.0003</td>
<td>0.0004</td>
<td>0.0005</td>
</tr>
<tr>
<td>H₂O, 2 days, 100°C</td>
<td>225</td>
<td>0.0009</td>
<td>0.0003</td>
<td>0.0004</td>
<td>0.0003</td>
</tr>
</tbody>
</table>
3M FPE High Temperature
Dielectric Film
Optical Properties

- Optically transparent; colorless, water white, haze 0.1%
- High index of refraction polymers - 1.656
- Very low coefficient of birefringence - 0.0003
- Good U.V. stability - self-stabilizing mechanism
- Transmissions 90-95% from 350 nanometers through 2 μm

Suggested Applications

- Electrical insulation - class F/H/C
- Capacitor film high temperature, high energy density, pulse power, surface mount
- Wire and cable insulation
  - Electrical power and signal wire film wrap
  - Fiber optic cable wrap
  - Magnet wire film wrap
  - Magnetic filament cable wrap
- Conformal coatings
- Substrate
  - Electronic packaging
  - ThIn film depositions for opto-electronic and magnetic product applications
<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
<th>Address</th>
<th>City, State, Zip</th>
</tr>
</thead>
<tbody>
<tr>
<td>John Andrasik</td>
<td>NASA Lewis Research Center</td>
<td>MS 501-4</td>
<td>21000 Brookpark Rd., Cleveland, OH 44135</td>
</tr>
<tr>
<td>Robert Baird</td>
<td>NEMA</td>
<td>2101 L. St. N.W. Suite 300</td>
<td>Washington, DC 20037</td>
</tr>
<tr>
<td>Donald Bellinger</td>
<td>NASA AD Indianapolis</td>
<td>6000 E. 21st. street</td>
<td>Indianapolis, IN 46219-2189</td>
</tr>
<tr>
<td>Robert W. Bergsaw</td>
<td>NASA Lewis Research Center</td>
<td>MS 301-2</td>
<td>21000 Brookpark Rd., Cleveland, OH 44135</td>
</tr>
<tr>
<td>Ned Bryant</td>
<td>Lawrence Technology</td>
<td>2400 Packer Rd.</td>
<td>Lawrence, KS 66044</td>
</tr>
<tr>
<td>Linda Burkhardt</td>
<td>McDonnell Douglas Aerospace</td>
<td>PO Box 516</td>
<td>Mail Code 1066157, St. Louis, MO 63166</td>
</tr>
<tr>
<td>Patricia Cahill</td>
<td>FAA</td>
<td>ACD-240, Bldg. 203</td>
<td>Atlantic City Airport, NJ 08405</td>
</tr>
<tr>
<td>Gidget Cantrell</td>
<td>NASA Lewis Research Center</td>
<td>MS 302-1/CSU</td>
<td>21000 Brookpark Rd., Cleveland, OH 44135</td>
</tr>
<tr>
<td>Frank Despain</td>
<td>Martin Marietta Space Systems</td>
<td>PO Box 173 MS 4015</td>
<td>Denver, CO 80201</td>
</tr>
<tr>
<td>John E. Dickman</td>
<td>NASA Lewis Research Center</td>
<td>MS 301-2</td>
<td>21000 Brookpark Rd., Cleveland, OH 44135</td>
</tr>
<tr>
<td>Stan Domitz</td>
<td>NASA Lewis Research Center</td>
<td>MS 301-2</td>
<td>21000 Brookpark Rd., Cleveland, OH 44135</td>
</tr>
<tr>
<td>Bob Frazier</td>
<td>Rockwell International</td>
<td>555 Gemini Avenue, ZC 01</td>
<td>Houston, TX 77058</td>
</tr>
<tr>
<td>Lawrence Kelly</td>
<td>General Research</td>
<td>2940 Presidential Dr.</td>
<td>Fairborn, OH 45324-6223</td>
</tr>
<tr>
<td>Wasim Khachat</td>
<td>University of Buffalo</td>
<td>312 W. Bonner Hall</td>
<td>Buffalo, NY 14260</td>
</tr>
<tr>
<td>Patrick Kirov</td>
<td>NASA-ERNO</td>
<td>Goddard Space Flight Center</td>
<td>MS 310A</td>
</tr>
<tr>
<td>Dietmar König</td>
<td>Technical University Darmstadt</td>
<td>D-6100 Darmstadt</td>
<td>Germany</td>
</tr>
<tr>
<td>Javad Lahgar</td>
<td>University of Buffalo</td>
<td>Bonner Hall, Room 316</td>
<td>Buffalo, NY 14260</td>
</tr>
<tr>
<td>Joe Landers</td>
<td>NASA Marshall Space Flight Center</td>
<td>MS CP 21</td>
<td>Huntsville, AL 35812</td>
</tr>
<tr>
<td>Stan Levin</td>
<td>Allied-Apalco</td>
<td>26306 Lombardy Rd.</td>
<td>Mission Viejo, CA 92692</td>
</tr>
<tr>
<td>Larry Linel</td>
<td>NASA WSTF</td>
<td>PO Drawer MM</td>
<td>Las Cruces, NM 88004</td>
</tr>
<tr>
<td>Dave McDermott</td>
<td>Tennolite Company</td>
<td>6340 Chesham N.E.</td>
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**List of Attendees**

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# REPORT DOCUMENTATION PAGE

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<td>This document contains the proceedings of the Second NASA Workshop on Wiring for Space Applications held at NASA Lewis Research Center in Cleveland, Ohio, October 6–7, 1993. The workshop was sponsored by NASA Headquarters Code QW Office of Safety and Mission Quality, Technical Standards Division and hosted by 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. Speakers from government, industry and academia presented and discussed topics on arc tracking phenomena, wiring system design, insulation constructions, and system protection. Presentation materials provided by the various speakers are included in this document.</td>
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