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Wiring for Aerospace Applications

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Abstract: *In this paper the authors summarize the current state of knowledge of arc propagation in aerospace power wiring and efforts by the National Aeronautics and Space Administration (NASA) towards the understanding of the arc tracking phenomena in space environment. Recommendations will be made for additional testing. A database of the performance of commonly used insulating materials will be developed to support the design of advanced high power missions, such as Space Station Freedom and Lunar/ Mars Exploration.*

INTRODUCTION

Failures in aerospace vehicles have been reported both on the ground and inflight due to persistent arcs in the wiring harnesses. The arc typically propagates along the wire and causes the loss of the entire wire harness along with all associated functions. Such failure mechanisms, which are not accounted for in the present engineering design practices, represent a serious problem for advanced aerospace vehicles. In this paper, a summary will be given of the current understanding in the area of arc propagation in commonly used wiring insulation materials. The potential hazards associated with arc propagation and state-of-the-art development of new arc resistant materials for aerospace applications will be presented. A description will be given of the NASA program to assure the safety and reliability of space wiring systems.

ARC PROPAGATION

In aerospace applications, the effects of insulation failure can be very costly in terms of loss of expensive equipment, imperilment of missions, and loss of lives. Since the mid sixties, MIL-W-81381 (polyimide insulated wire) has been the material of choice for most aerospace applications due to its high dielectric strength, excellent thermal properties, non flammability, low weight, and high abrasion resistance. However, insulation failures became unexpectedly common in a number of applications. This prompted some US Federal Agencies to launch studies to characterize the problem and to search for substitutes for polyimide¹ insulation. It resulted in the United States Navy banning the use of polyimide as a wiring insulator in their ships and planes.

The studies found that there are two steps in the failure process. Damage, cracking, or deterioration of the insulation can occur due to exposure to water or certain other liquids, or when the material is subject to mechanical stresses (such as sharp bending). These conditions provide a path from the live wire to ground through which an arc may be initiated. The extreme heat from the electrical arc causes pyrolysis of the polyimide film and forms a conductive path

of carbon residue that is referred to as a carbon arc track. This carbon arc track frequently has a sufficiently high electrical resistance to limit the currents to values that do not trip the circuit breaker. When this is the case, nothing prevents the arc from propagating along the entire wire. Even if the circuit breaker is tripped, resetting it will restart the arc and cause further damage to the harness. Arc tracking can result in flashover in which the arc jumps to adjacent wires within the same bundle and damages them as well. The rate and extent of arc propagation depends on the following: (a) type of insulation material, (b) applied voltage (magnitude and frequency), (c) wire gauge, and (d) environmental factors (moisture, temperature, proximity, etc...).

NASA'S INVOLVEMENT

NASA will engage in manned and unmanned space missions that will demand greater amounts of electrical power than today's spacecraft, increasing the likelihood of arc-induced failures. Some of the systems to be developed are Space Station Freedom (75 kWe), Mars Cargo and Piloted Vehicles (2 MWe - 10 MWe), and the First Lunar Outpost (12 kWe).

Because little is known about the phenomenon of arc tracking in space, NASA held a workshop² to assess issues and concerns on electrical wiring for space applications. The attendees included representatives of several US Federal Agencies, National Laboratories, academia, and private industry having particular expertise in the field. The workshop covered: operational experience with polyimide insulation, results of several test programs, wiring requirements for a variety of space missions, and properties of alternate materials.

Operational difficulties were reported with: 1) the Space Transportation System (STS), in which six incidents were reported; 2) numerous arcing incidents and fires in U.S. military aircraft; and 3) a variety of isolated incidents, such as an expensive electrical fire in the Magellan spacecraft ground support equipment.

Two of the most comprehensive studies were: the Wright Research Development Center / McDonnell Aircraft Company evaluations on new insulation constructions for aeronautical applications, and the NASA's White Sands Test Facility in White Sands, New Mexico, on power requirements for arc propagation under STS conditions. Some important test results reported at the workshop include: 1) arc propagation in polyimide-insulated wires was demonstrated at very low power levels (4 - 8 Watts) [1]; 2) arc tracking and propagation in polyimide was found to occur in the Space Station Freedom (SSF) solar array flexible current carriers[2]; and 3) at voltages as low as 270 Vdc, all types of insulation tested to date exhibited arc propagation[3].

1. Polyimide insulation is frequently referred to as Kapton®, which is a popular brand manufactured by DuPont.

2. "Workshop on Wiring for Aerospace Applications", held at NASA Lewis Research Center, Cleveland, Ohio, on the 23-24 of July, 1991

A number of papers discussed the complexities of the space environments and how insulation may be affected by environmental factors such as: vacuum, radiation, wide temperature swings, space plasma, zero gravity, and atomic oxygen. Finally, there were discussions of a number of alternate materials and wire / insulation constructions. While there was a number of attractive candidates, it was emphasized by several speakers that wiring must be considered as a system in which careful tradeoffs must be made between various properties and requirements.

A major conclusion of the workshop was that the testing to date was inadequate to determine the performance of insulation in the complex environment of space; the tests were not conclusive because they only addressed the limited range of operational conditions for aircrafts and STS. Therefore, it was concluded that there is a need for the establishment of a broader test matrix and for additional experimental work which emphasize those test parameters that reflect the environmental stresses expected to be encountered in current and future NASA space missions.

PROGRAM OVERVIEW

The NASA's Office of Safety and Mission Quality has initiated a three year effort at the Lewis Research Center to address some of these issues. The goal of this program is to provide the information and guidance needed to develop and qualify lightweight, safe and reliable wiring systems that are both resistant to arc tracking and suitable in all ways for use in space applications. The eventual goal of this program is the construction of a database containing the performances of commonly used insulating materials that could be utilized in the design of advanced missions, such as SSF and Lunar/ Mars exploration.

To accomplish this mission, this program was divided into three major tasks: 1) define space wiring application requirements; 2) define and perform the additional testing and analysis needed to assess available materials and constructions; and 3) review issues in the design of complete wiring systems. The next three sections provide an interim report on the results of these tasks.

Space Missions Environments

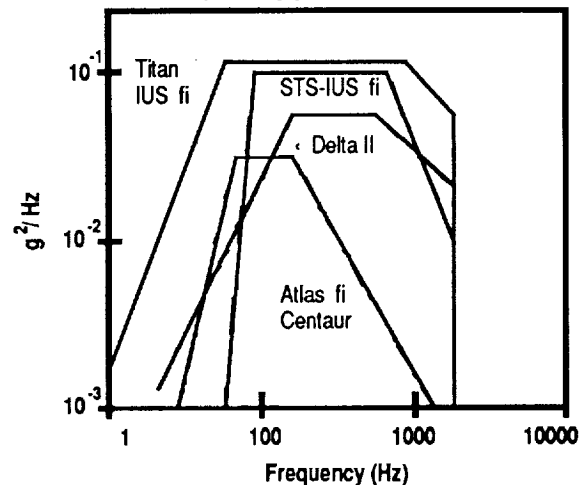
The objective of this task is to identify typical requirements and environments (as relevant to electrical power wiring) for NASA space missions and systems, and to evaluate the adequacy of the findings of previous test programs in assessing wiring systems for NASA missions. A survey of NASA missions was made to identify environmental characteristics that would impose particular requirements on insulation for electrical wiring systems. From the results, five typical environments were identified as being characteristic of those in present and future NASA missions with respect to their operational requirements for the wiring systems. These environments are characteristic of: 1) pressurized modules (characteristic of SSF, and other manned missions), 2) LEO/GEO³ applications, 3) trans-atmospheric vehicles, 4) Lunar surface, and 5) Mars surface. A brief description of each of these environments follows.

Pressurized module: Since the purpose of a pressurized module, such as those found in the STS orbiter and the Space Station Freedom, is to protect the crew, the wiring experiences a comparatively narrow temperature range and benign environment [4].

Inside the pressurized modules, the potential exists for high humidity because of the presence of humans, however, the actual level of humidity is expected to be regulated. For the pressurized modules

3. LEO = Low Earth Orbit, about 300 km of altitude, and GEO = Geo stationary Orbit, which is about 32,000 km equatorial orbit.

Figure 1. Vibration Environment of Payloads for Launch Systems [8]



a 30% oxygen environment increases the danger in the case of a fire. The fires on board the Apollo 1 and 13 were fueled by high oxygen concentration environments (Apollo 1 was 100% oxygen) [5,6]. However, the moisture environment itself is insufficient to cause cracking and is reversed when power is applied [4,7].

Because of the vibration during the launch phase, all wires and cables must be restrained from movement. The vibration to which the pressurized module wiring is exposed is intense but short-lived (roughly 2 minutes of vibration during launch) [4,7]. This is clearly described in figures 1 and 2, and in table 1. The enclosed manned environment requires that if outgassing were to occur, no significant amounts of toxic compounds may be released.

The function of the pressurized modules is for the habitation of the astronauts and for laboratory experiments. These types of operations may increase the possibility of fluids coming in contact with wiring insulation. In the case of the pressurized modules for Space Station Freedom, there will be voltages as high as 120 V DC inside of the modules.

Figure 2. Acoustic Environment of Payloads for Launch System SPL (dB)

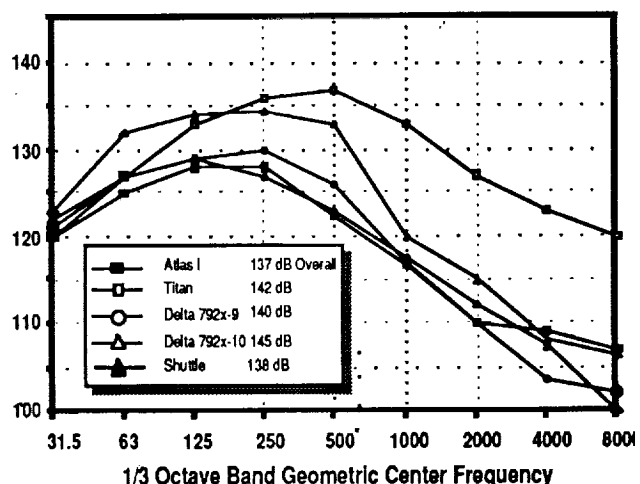


Table 1. Acceleration Environment of Payloads for Launch Systems [8]

Vehicle	Condition	Lift-off		Maximum Airloads		Stage 1 Shutdown (Booster)		Stage 2 Shutdown (Booster)	
		axial	lateral	axial	lateral	axial	lateral	axial	lateral
T34D/IUS	steady state	+1.5	—	+2.0	—	+4.5	—	+2.5	—
	dynamic	±1.5	±5.0	±1.0	±2.5	±4.0	±2.0	±4.0	±2.0
Atlas II	steady state	±1.3	—	+2.2	+0.4	±5.5	—	+4.0	—
	dynamic	±1.5	±1.0	±0.3	±0.4	±0.5	±0.5	±2.0	±0.5
Delta Max* All Series	steady state	±2.4	—	—	—	—	—	±7.7	—
	dynamic	±1.0	±2.0	—	—	—	—	+4.0	—
H-II	steady state	—	—	—	—	—	—	—	—
	dynamic	±3.2	±2.0	—	—	—	—	±5.0	±1.0
Shuttle	steady state	±3.2	±2.5	+1.1	+0.25	—	—	+3.2	+0.59
	dynamic	±3.5	±3.4	—	—	—	—	—	—

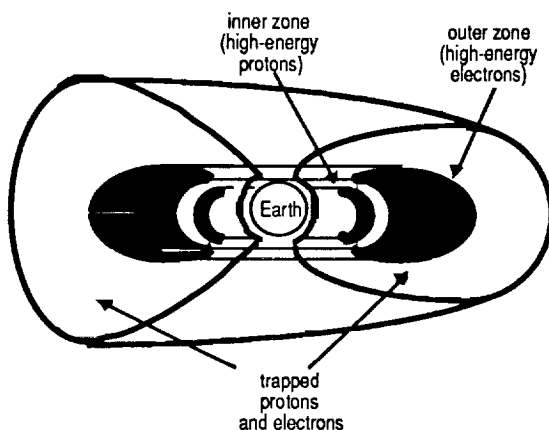
*2 Sigma Values

LEO/GEO applications: A key element in LEO/GEO applications is long lifetime which places more stress on the wiring systems. The electrical wiring for LEO/GEO satellites is protected by the spacecraft structure from most space environment effects such as uv radiation, atomic oxygen, and micrometeoroids.

This is also true for the SSF power and control cabling that are outside of the pressurized modules because the cables will be protected by utility or cable trays. Any exposed wiring can receive damage from atomic oxygen (AO) because of the high relative velocity impacts and chemical reactions between the ions and the insulation. The potential for damage from meteoroid and debris, is not totally eliminated by the cable trays.

The electrical wiring inside unmanned LEO/GEO spacecraft is temperature regulated by radiative cooling designed to keep the electronics and battery systems in a reasonable operating temperature range. Heat generated by ohmic (I^2R) losses in the cabling can add to external heat sources such as the Sun and raise tempera-

Figure 3. Toroidal Section of the Earth Radiation Zone



tures to approximately 200°C [4].

Once in orbit, the wiring will expand and contract with the orbital temperature variations. The frequency in GEO of the spacecraft passing through the Earth Shadow (see figure 3) is once per day, while in LEO this cycle occurs approximately once every 45 minutes, depending upon orbit altitude and inclination [8]. Therefore, thermal cycling for a GEO spacecraft will not be as severe as for a LEO spacecraft

Although the majority of satellite power systems have been 28 Vdc, systems are now planned with voltages as high as 120 Vdc. In the case of the Space Station Freedom, there will be voltages as high as 160 Vdc. Therefore, arc tracking effects at these voltages must be evaluated.

Radiation is a key issue for missions which either cross or travel within the Van Allen belts. These missions are typically either in polar orbits which cross the Van Allen belts over the Earth's poles, or highly elliptical orbits (Molniya orbits) used for communications and reconnaissance satellites. Because charged radiation is trapped and "concentrated" in the magnetic field of the Earth, such a spacecraft receives a radiation dose significantly higher than that experienced by a GEO spacecraft.

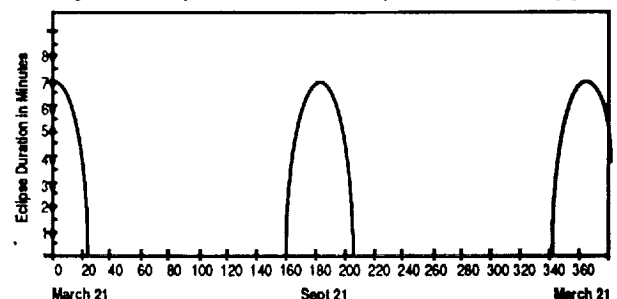
When a spacecraft encounters a charged plasma environment, a potential may be produced between the spacecraft surfaces. When the potential voltage exceeds the breakdown threshold of the insulation, an electrostatic discharge can occur. Discharges can cause long-term degradation of exterior surface coatings and enhance contamination of surfaces [9].

The charged radiation trapped by the Earth's magnetic field is a product of the solar wind and consists primarily of protons and electrons and form the charged plasma regions shown in figure 4. The inner belt consists primarily of low energy electrons (20 keV - 1 MeV) and high energy protons (≥ 600 MeV), and extends from about 480 km to 6400 km above the Earth. The outerbelt consisting mostly of very high energy electrons (20 keV - 5MeV) with few low energy protons (~ 60 MeV) extends from 16,000 km to 58,000 km [9,10].

Transatmospheric Vehicles: In addition to the LEO / GEO environments, the wiring systems for transatmospheric vehicles experience additional environmental conditions: high humidity, vibration, temperature cycling, and fluids. For the STS, the conditions which lead to hydrolytic degradation, such as high humidity, have been eliminated by storing the orbiter in a controlled environment, and continuously purging the shuttle with conditioned air while on the launch pad [7].

The vibration to which the trans-atmospheric wiring system is exposed is intense but short-lived. The space shuttle must endure

Figure 4. Eclipse Seasons in Geosynchronous Orbit [8]



roughly 2 minutes of vibration during launch three to four times a year. An expendable launch vehicle (ELV) must function for only one launch, therefore ELV requirements are not as strict. All wiring must be protected from chafing against sharp edges which would damage the insulation during operational vibration or maintenance abrasion [7,11].

The interactions of the trans-atmospheric wiring systems, particularly reusable launch vehicles such as the space shuttle, with chemical and cryogenic fluids may be important. Transatmospheric vehicles experience a wide range of temperatures from cryogenic temperatures of fuels to high temperatures from rocket engines or atmospheric reentry. Cables in reusable vehicles such as the space shuttle experience a large number of temperature cycles during their operational lifetimes which can lead to cracking, arcing, and arc-propagation.

Lunar surface: The power system for a permanently manned lunar base may have to be at a distance from the habitat modules. Cables may lie exposed on the lunar surface. In general, almost all the same environmental conditions experienced in LEO / GEO will be seen by the exposed lunar base cables. In addition, problems related to temperature extremes and cycling, radiation, micrometeoroids, abrasion, and lunar dust will be unique for this application. An example of a lunar base specific problem is the effect of lunar dust on initiation and propagation of an arc.

Martian Surface: Atomic oxygen in the Martian atmosphere can damage cables as a result of high relative velocity impacts of the ions on the insulation, and subsequent degradation and chemical reactions. The Mars atmosphere contains water vapor, however, it makes up only 0.03% of the air, and therefore, probably will not result in degradation. The Mars surface base will operate in a 95.3% carbon dioxide and 0.13% oxygen environment. Insulation material must not react with this atmosphere [12].

A database on arc tracking, wiring systems, and wiring constructions is also being established from which promising candidate insulation systems will be identified based on results of related studies. The work performed by the U.S Air Force on new wiring constructions for aerospace applications was analyzed. This database was compared to the requirements resulting from the survey. Preliminary results of this task are depicted on table 2.

Supplemental Insulation Tests and Analysis

The objective of this task is to provide missing information needed to evaluate potential insulation systems and to determine their suitability for use in NASA aerospace environments. The supplemental testing and characterization efforts for the identification of arc-track-resistant aerospace wiring system are being coordinated with the ongoing programs at other NASA and government laboratories. The database established in previous task, will be used to prioritize the environmental and operational tests to be performed.

Results from these tests will be combined with the results from the database to define safe operating ranges for various insulation systems. Conditions which contribute to arc generation and propagation will be identified. The test results will be used to develop a better understanding of the life cycle of wiring insulation systems. The following are some of the preliminary tests to be performed under this effort:

Atmospheric tests: These tests concentrates on five (5) new wiring constructions (size 20 AWG, single wire) and the two (2) military standard wiring constructions. The new insulation constructions, include the Filotex, Thermatics, Nema #3, Tensolite, and Gore configurations. The following is a list of the tests to be performed:

- Verification that the wiring construction meets the specifications.
- Full performance tests (as shown in table 3) on the Gore construction.
- 160 VDC and 400 Hz, 208 VAC dry arc resistance.
- Flammability, offgassing, and fluid compatibility.
- Cold flow resistance measurements.

Vacuum tests: Vacuum constitutes one of the stresses to which wiring systems are exposed to in the space environment. In general, most insulating materials undergo some changes in their properties under such environmental conditions. These changes, which may be profound in polymeric dielectrics, include offgassing, brittleness and reduction in the material's breakdown or corona inception voltages.

Partial gravity and micro-gravity tests: Standard vertical flammability tests have been performed on polyimide, showing no burning. These tests, however, did not take into consideration the carbon arc tracking phenomena. Arc tracking is not a true burning mechanism that can occur in vacuum. All previous arc-tracking tests have been performed in a 1 gravity (g) environment. Without the heat convection process present at 1 g, hot gasses produced by an arc in zero-g stagnate within the vicinity raising the temperature of the insulation. This is potentially a significant problem.

Previous tests performed at 1 atmosphere may not be relevant to an environment with lower pressure and higher oxygen concentration such as the case in a habitat module. Other effluents of interest are waste gas from the life support system and propellant from the attitude control thrusters. Effects of these effluents on the arc tracking phenomena in zero-g will be investigated. Therefore, the effects of a zero-g environment, temperature, atmospheric pressure, and atmospheric composition on the arc tracking phenomena must be investigated.

A low cost, short duration experiment is being designed taking advantage of the in-house μ g laboratory at the Lewis Research Center. Available for carrying out the partial g experiments is the Lewis Research Center Lear Jet and the NASA-Johnson Space Center KC-135 aircraft. These airplanes by flying in a parabolic trajectory can provide about 15 to 25 seconds of low gravity conditions. Features of the μ g testing facility are described in table 4.

Results of the study phase will be used to design the experimental procedures and specifications for the fabrication/ procurement of required hardware (breadboard, test subjects, support equipment and instrumentation). A database will be compiled containing the results of this battery of experiments.

As a result of this effort, techniques will be developed for evaluating and testing electrical wiring insulation materials for space applications. Physical models will be developed for use by missions planners to select of competing wire insulation materials based on mission requirements.

Wiring Systems Technology

This task identifies issues related to safety and reliability for the complete wiring systems. Related technologies will be identified which have an impact on prevention, detection, and isolation of wiring failures and system reconfiguration following a failure.

Included in the topic of prevention techniques are evaluation techniques such as total quality management (TQM) which spans from

Table 2. Air Force and NASA Mission Environmental Requirements

Mission/ Reqs	Air Force	Press. Modules	LEO/ GEO	Trans- atmospheric	Lunar Surface	Mars Surface
Electrical						
Voltage	8 kV Impulse/ 1000 hrs @ 200°C, 60 Hz 500 V/s, $I_{Leak} < 5\text{mA}$ [3]	28 - 120 V [12]	28 - 160 V [22]	28 - 270 V [14,18,23]	28 - 160 V [22]	28 - 160 V [22]
Frequency	corona: dc & 400 Hz voltage withstand: 60 Hz arc: dc & 400 Hz [3]	dc [22]	dc [22]	dc [14,18,23]	dc \Rightarrow ac [22,24]	dc \Rightarrow ac [22,24]
Power	N/A	75 kW [14]	10's W \Rightarrow 10's kW [22,25,26]	≤ 7 kW [27]	50 kW [28,29]	20 kW [28,29]
Thermal						
Temperature/ Thermal Cycling (°C)	-65 \Rightarrow 230 4 cycles: 200°C, 30 min - 55°C, 30 min [3]	15 \Rightarrow 25 [13]	LEO: -65 \Rightarrow 120 6000/yr GEO: -196 \Rightarrow 128: 90/yr [4,5,16,39]	-200 \Rightarrow 260 6000/yr in orbit [14,16]	-171 \Rightarrow 111 13/yr [12]	-143 \Rightarrow 27 356/yr [12]
Flammability	Afterflame 3 sec. max Flame travel 3 in max [3]	30% Oxygen [5]:	N/A	0 \Rightarrow 30% Oxygen [5]:	N/A	0.13% Oxygen [17]:
Mechanical						
Vibration/ Acoustic (Abrasion)	Unconditioned or Aged 200°C for 1000 hrs Test: 23°C & 150°C [3]	launch: 1 - 10 g SPL: 137 - 145 dB [8,13]	launch: 1 - 10 g SPL: 137 - 145 dB [8,13]	launch: 200g SPL: 137 - 145 dB [8,13,14]	launch: 1 - 10 g SPL: 137 - 145 dB [8,13]	launch: 1 - 10 g SPL: 137 - 145 dB [8,13]
Meteoroids /Debris	N/A	N/A	11 - 26 impact/m ² /yr (impacts ≥ 0.05 mm) [16]	0 - 26 impact/m ² /yr (impacts ≥ 0.05 mm) [16]	1 - 50 impacts/cm ² / 10 ⁶ yrs (d=500µm) 70 - 150 impacts/yr (100's g) [12]	very low probability [17]
Chemical						
Humidity	15 Cycles of 6 hrs, 70°C @ 95%, 16 hrs, 38°C @ 95%: IR ≥ 5 MW/1000ft [3]	$\leq 50\%$ inside payload fairing [13]	$\leq 50\%$ inside payload fairing [13]	$\leq 50\%$ in payload fairing $\leq 100\%$ external [13]	$\leq 50\%$ inside payload fairing [13]	0.03% H ₂ O 100% RH at night [12]
Outgassing/ Toxicity	38°C, 72 hrs, 5 -96% RH, 384 hrs, 200°C, 36 Torr, weight loss $\leq 1.5 - 2\%$, no specific toxicity [3]	TBD	N/A	N/A	N/A	N/A
Gas/Fluid Compatibility	Various Chemicals Hydrolysis: 8 hrs @ 200°C, 672 hrs of 5% salt water, 2.5 kV, 60 Hz, 1 min. $I_{Leak} < 5\text{mA}$ [3]	TBD	AO: 10 ⁷ - 10 ⁸ cm ⁻³ 4.3 - 4.4 eV [16,30]	Water/Salt Water/ Humidity/Chemicals /LO/LH/Hydrazine [14,15]	Electrostatically Charged Dust Particles liquids TBD [12]	95.3% CO ₂ liquids TBD [12]
Environmental/Operational						
Radiation	uv: 120 cycles of 8 hrs uv, 70°C, 4 hrs condensation, 40°C [3]	N/A	LEO uv: 2220 \Rightarrow 5844 GEO uv: 8760 (ESH/yr) [16]	uv: 2220 \Rightarrow 8760 ESH/yr [16]	solar: 1371 W/m ² uv: 8760 ESH/yr [12]	Solar: 590 - 650 W/m ² uv: 1656 ESH/yr [12]
Gravity	1 g [3]	10 ⁻⁶ \Rightarrow 10 ⁻³ g [18]	10 ⁻⁶ \Rightarrow 10 ⁻³ g [18]	10 ⁻⁶ \Rightarrow 1 g [18]	0.165 g [12]	0.38 g [12]
Pressure (Torr)	36 \Rightarrow 760 [3]	530 \Rightarrow 760 [5]	LEO: 10 ⁻¹⁰ - 5x10 ⁻⁸ GEO: 7.5 x 10 ⁻¹⁴ [12,19]	7.5 x 10 ⁻¹⁴ \Rightarrow 760 [19,20]	10 ⁻¹² \Rightarrow 10 ⁻⁸ [12,21]	3 \Rightarrow 7.5 [12]
Plasma	N/A	N/A	LEO: 0.3 - 45 x 10 ⁴ cm ⁻³ 0.1 - 0.2 eV GEO: 0.24 - 1.12 cm ⁻³ 120 - 295 keV [5,9,19]	0 - 9 x 10 ⁵ cm ⁻³ 0.1 - 0.2 eV [5,9,19]	Solar Wind (H & He) Solar & Galactic Cosmic Rays [12]	10 ³ - 10 ⁵ cm ⁻³ O ⁺ , O ₂ ⁺ , CO ₂ ⁺ [12]
Lifetime (yrs)	1.7 [3]	30 [22]	LEO: 30 GEO: 20 [22]	30	30 [28,29]	30 [28,29]

TBD: To Be Determined

SPL: Acoustic Sound Pressure Level

N/A: Not Applicable

[]: Reference

Table 3. Full Performance Tests

**SAE
AS 4373
METHOD**

TEST NAME

(1)	Jacket Wall Thickness
(2)	Dry arc resistance and arc propagation
501	Dielectric constant
502	Corona inception and extinction
506	Surface resistance
507	Time current to smoke
509	Wet arc tracking
511	Wiring fusing time
602	Forced hydrolysis
603	Humidity resistance
604	Weight loss under vacuum & temperature
606	Weathering resistance
607	Wicking
701	Abrasion
702	Cold bend
(3)	Crush resistance
703	Dynamic cut through
704	Flex life
705	Insulation impact resistance
706	Insulation tensile strength and elongation
707	Notch propagation
(4)	Wire to wire rub test
(5)	Aging stability
803	Smoke quantity
804	Thermal index
805	Thermal shock
807	Property retention after thermal aging
712	Wire surface markability

- (1) Perform according to Federal Test Standard 228, Method 1018.
- (2) Perform according to British standard Institute 90/76828 and 90/80606.
- (3) Perform according to ASTM D3032, Section 20.
- (4) Perform according to a procedure developed at DAC.
- (5) Perform according to MIL-C-27500G, Paragraph 4.5.10.

the manufacturing of the wiring to the installation and maintenance. Various approaches are being explored for circuit protection by industry. This task will identify those approaches which may be applicable to arc tracking detection and isolation. Candidate system reconfiguration techniques which may be applicable to the restoration of the system following a failure detection and isolation will also be identified.

Current practices in the manufacturing, handling, maintenance, and operational specifications for electric wiring systems in the aeronautics and space community are being studied. Particular emphasis is being given to changes in recommendations resulting from recent wiring system failures in aircraft / spacecraft. These findings will be compared to the knowledge acquired during the testing phase to determine areas requiring improvement for safety and reliability.

Methodologies will be developed and recommended which enable the verification of device and systems performance upon design completion and quality conformance to the design upon manufacture. These techniques would include in-situ techniques to verify wiring integrity. These methodologies will have to cover the entire power transmission system, i.e., wire bundles, interconnections with components, circuit protection, and integration with the mission / ve-

Table 4. μ g and partial-g testing capability at LeRC

Features of shared facility:

- Sealed test chamber capable of vacuum to about 1.5 atms.
- Operation at quiescent or blowdown flow conditions.
- Gas handling system for atmospheric mixing to 30% O₂.
- Vacuum system for low pressure atmosphere and purging.
- Flow and back pressure regulation.
- Color motion-picture and video photography.
- Standard thermocouple system and signal conditioners.
- Standard data acquisition system and software.
- Provision for smoke sampling and combustion-product collection.

Specific objectives of wire-flammability tests:

- Arc tracking at low gravity.
- Ignition of adjacent fuel materials.
- Off-gassing, smoke evolution, combustion products, etc

Specific variables for wire-flammability tests:

- Wire and bundle configurations.
- Insulation materials.
- Ambient-temperature and preheated samples.
- Atmospheric pressure and O₂ content.

hicle structure, in order to account for synergistic effects which may differ from those of separate individual wiring components.

A survey of emerging technologies and techniques will be conducted to assess potential applications of these technologies in the area of risk reduction and system maintainability. Those promising candidates technologies and techniques will be considered for future development, such as: fire detection and suppression systems, sensors that could alert of impending failures in the system, and system reconfiguration schemes following a failure.

CONCLUSIONS

NASA's future in manned and unmanned space activities will place increasing demands on electrical wiring and thus, increase the likelihood of an arc-induced failure. Little is known at this point of the effects of the various space environments on arc tracking phenomena.

It is anticipated that a better understanding of arc propagation in commonly used wiring insulation materials will result from the Wiring Program for Space Applications at NASA in conjunction with the other efforts currently underway at other U.S. government laboratories, industry, and academia.

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