Comparison of Arc Tracking Tests in Various Aerospace Environments

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March 1996

Prepared for
Lewis Research Center
Under Contract NAS3-27186
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In Various Aerospace Environments

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Abstract: Momentary short-circuit arcs between a polyimide insulated wire with defective insulation and another conductor may cause pyrolization of the insulation resulting in a conductive path capable of sustaining the arc. These sustained arcs may propagate along the wire or to neighboring wires leading to complete failure of the wire bundle. Wire insulation susceptibility to arc tracking may be dependent on its environment. Because all wire insulation types tested to date arc track, a test procedure has been developed to compare different insulation types with respect to their arc tracking susceptibility. This test procedure is presented along with a comparison of arc tracking in the following three environments: 1) Air at atmospheric pressure and 1 gravitational (g) force, 2) Vacuum (2.67 x 10⁻³ Pa) and 1g, and 3) Air at atmospheric pressure and microgravity (<0.04g).

INTRODUCTION

Momentary short-circuit arcs between a defective polyimide insulated wire and another conductor may thermally char (pyrolize) the insulating material. The charred polyimide, being conductive, is capable of sustaining the short-circuit arc. The sustained arc may propagate along the wire through continuous pyrolization of the polyimide insulation (arc tracking). If the arcing wire is part of a multiple wire bundle, the polyimide insulation of other wires within the bundle may become thermally charred and start to arc track (flash over). Therefore, arc tracking may lead to complete failure of an entire wire bundle or harness. Due to the popular use of polyimide insulated wires, such as MIL-W-81381, for use in aerospace vehicles, the NASA Office of Safety and Mission Assurance (Code Q) has initiated a program to identify candidate wire insulation types for aerospace applications that are not susceptible to arc tracking. Arc tracking tests conducted by the Electro-Physics Branch, Power Technology Division, at the NASA Lewis Research Center (LeRC) were initiated to evaluate candidate wire insulation tests for susceptibility to arc tracking.

This report defines a test procedure to aid in the selection of the candidate insulation type least susceptible to arc tracking. Furthermore, this report gives some preliminary information concerning test results conducted in the following three environments: 1) air at atmospheric pressure and 1 gravitational (g) force, 2) vacuum (2.67 x 10⁻³ Pa) and 1g, and 3) air at atmospheric pressure and microgravity (<0.04g).

TEST THEORY

Arc tracking can be described as an arc between two conductors that pyrolizes surrounding insulation leading to propagation of the arc along the wire as a result of charred insulation growth. Safety risks associated with the phenomena are: 1) probability of arc tracking initiation, 2) probability of reinitiation (restrike), and 3) extent of arc tracking damage (propagation rate). Item 2 is an issue if power is capable of being terminated from and reapplied to (switch, fuse, resettable circuit breaker) the arcing wire. Item 3 refers to how easily the arc chars nearby insulation and propagates along the wire pair. Ease of nearby insulation charring can be determined by measuring the rate of arc propagation. An insulation that chars easily will propagate the arc faster than one that does not char very easily.

This report covers measurements of the arc tracking propagation rates for three candidate insulation construction types (MIL-W-81381/7-20, Filotex Filar tex® T8C 1G20, and Tensolite TLT-200-20S) in the following three environments: • Air at atmospheric pressure and 1 gravitational (g) force. • Vacuum (2.67 x 10⁻³ Pa) and 1g. • Air at atmospheric pressure and microgravity (μg < 0.04g).

APPARATUS

Ground based (1g) tests were conducted in a helium cryo-pumped vacuum bell-jar (capable of obtaining 2.67 x 10⁻³ Pa). The bell-jar was left open when conducting tests at atmospheric pressure and 1g. The μg tests used the Spacecraft Fire Safety Facility (SF²) to provide an atmospheric pressure environment onboard NASA LeRC’s DC-9 Reduced-Gravity Aircraft. To obtain ground level atmospheric pressure (1.013 x 10⁵ Pa) within the (SF²) chamber while flying at varying altitudes (cabin pressure may range from 1.013 x 10⁵ to 7.51 x 10⁴ Pa), a regulated air bottle (less than 1 ppm total water contamination) was connected to the (SF²) test chamber. The oxygen content of the air bottle, measured with a Matheson Gas Products oxygen deficiency monitor (model number 8060) with a diffusion type sensor, was 19.7%.

The circuit configuration used to supply power to the test specimen, for both ground-based (1g) and μg tests, is described in Figure 1. The power supply voltage level was adjusted to a predefined non-short-circuit potential of 90 volts between the test specimen conductors. A current limiting resistor, set at 25Ω, restricted the maximum short-circuit current available during an arcing event.
**SAMPLE DESCRIPTION**

The following three AWG 20 (American Wiring Gauge 20) samples were tested:

- MIL-W-81381/7-20 (baseline).
  - 6 mil wall polyimide insulation, silver coated copper [1].
- Filotex Filartex® T8C1G20.
  - PTFE Extrusion/616 Kapton (50% Min OL)/PTFE Dispersion [1].
- Tensolite TLT-200-20S.
  - 200AJ919 (50% Min OL)/PTFE Tape (50% Min OL) [1].

Where:

- 616 Kapton = 0.1 mil Fluorocarbon (FEP), 1 mil Polyimide, 0.1 mil Fluorocarbon (FEP) [1].
- 200AJ919 = 0.5 mil Fluorocarbon (PTFE), 1 mil Polyimide, 0.5 mil Fluorocarbon (PTFE).

These insulations were hybrid constructions comprised of different combinations of the materials PTFE (Poly Tetrafluoroethylene) and polyimide [3]. Filotex and Tensolite were the top two wire insulation constructions identified by an Air Force wiring program [3].

Sample preparation for all arc tracking environments were identical. Each sample consisted of two wires with the same insulation type (a supply line and a return line). To maintain the wires within close proximity to each other throughout a test, as they will be when bundled, a floating stainless steel wire (AWG 28) was wrapped around the wire pair. A defect was introduced to each test wire by cutting a notch in the insulation, exposing approximately 1 mm lengthwise by 1 mm widthwise of the conductor, at the midpoint of the wire length.

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**PROCEDURE**

With power applied to the test wire pair (60V), a conductive wand was used to short-circuit the wires, at the defect site in the insulation, until unassisted arc tracking evolved. Power was then removed from the wires to terminate the arcing event. These arc damaged wires were then mounted in the designated environment chamber. Once mounted in the chamber, a photograph was taken to obtain a picture of the sample prior to testing. At this point the samples were ready for testing.

A typical test would consist of applying a voltage (90V) between the predamaged test wires (restrike), by means of a controlled relay contactor for 16 seconds in the desired environment. After the 16 seconds have expired, the voltage was removed and the samples were again photographed. The pre- and post-restrike photographs were compared to determine the distance of arc propagation. The reason for the 16 second parameter for these

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**Table 1. Statistical Restrike Test Results.**

<table>
<thead>
<tr>
<th>Mil-W-81381</th>
<th>Filotex Filartex® T8C1G20</th>
<th>Tensolite TLT-200-20S</th>
</tr>
</thead>
<tbody>
<tr>
<td>µg, latm</td>
<td>µg, latm</td>
<td>µg, latm</td>
</tr>
<tr>
<td># of Tests</td>
<td>78</td>
<td>40</td>
</tr>
<tr>
<td>Mean (µm)</td>
<td>2.9017</td>
<td>7.6290</td>
</tr>
<tr>
<td>σ (µm)</td>
<td>1.9899</td>
<td>7.4482</td>
</tr>
<tr>
<td>Maximum Length (µm)</td>
<td>9.0043</td>
<td>27.6485</td>
</tr>
<tr>
<td>1g, latm</td>
<td>12.9309</td>
<td>8.0060</td>
</tr>
<tr>
<td>1g, vac</td>
<td>0.2620</td>
<td>6.4292</td>
</tr>
<tr>
<td>2.5706</td>
<td>7.3337</td>
<td>7.3337</td>
</tr>
<tr>
<td>22.9826</td>
<td>5.3607</td>
<td>5.3607</td>
</tr>
<tr>
<td>27.1577</td>
<td>4.3274</td>
<td>4.3274</td>
</tr>
<tr>
<td>22.9826</td>
<td>22.5592</td>
<td>24.8387</td>
</tr>
</tbody>
</table>

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![Figure 1. Typical circuit configuration for arc tracking tests.](image)

![Figure 2. Comparison of the three wire insulation construction types, in each environment of interest, with respect to their arc propagation distance of travel within a 16 second time frame. The error bars represent one standard deviation.](image)
tests was to ensure execution of arc tracking only while the desired
environment existed. The microgravity tests were conducted on
LeRC's DC-9 reduced-gravity aircraft. The microgravity window
created with each parabola was approximately 25 ± 5 seconds.
Therefore, the test duration was limited to 16 seconds so that a
completed test run could be conducted with each microgravity
parabola.

If the restrike test resulted in a direct conductor to conductor
short-circuit or an open-circuit, the test specimen was replaced
with a new sample.

RESULTS
Figure 2 is a comparison of arc propagation distance of travel
within a 16 second time frame for the baseline, Filotex, and
tensolite, in each of the three environments. The error bars in
Figure 2 are ± standard of deviation (σ). The statistical data
displayed in Figure 2 is given in Table 1.

DISCUSSION

Environmental Comparison
The results of the baseline (Mil-W-81381) displayed in Figure
2 indicate the means of the μg, 1 atm case and the 1 g, 1 atm case
are similar. To validate this premise, the following hypothesis test
is in order to determine if there is a statistical difference between
two of these two environments. For this hypothesis test, let the NULL
hypotheses (H0) and the Alternate hypotheses (H1) be described as
follows:

\[ H_0: \mu_{\text{μg}} = \mu_{1 \text{ atm}} \]
\[ H_1: \mu_{\text{μg}} \neq \mu_{1 \text{ atm}} \]

\[ \mu \Rightarrow \text{Mean value (Table 1) for either the \( \mu \text{g} \), 1 atm or the 1g, 1 atm environments.} \]

H0 is two sided since \( \mu_{\text{μg}} \) may be > or < \( \mu_{1 \text{ atm}} \); therefore, a two-tailed
test is appropriate. The equation for the test statistic 'Z' is given
in equation 1, where σ is the standard deviation from Table 1 and

\[ Z = \frac{\bar{X}_{\text{μg}} - \bar{X}_{1 \text{ atm}} - (\mu_{\text{μg}} - \mu_{1 \text{ atm}})}{\sqrt{\frac{\sigma^2_{\text{μg}}}{n_{\text{μg}}} + \frac{\sigma^2_{1 \text{ atm}}}{n_{1 \text{ atm}}}}} \quad (1) \]

\( n \) is the number of data points. Setting the desired level of
probability that H0 is rejected when H1 is true (Type I error) \( \alpha =
0.05 \), then H0 is rejected if either Z ≥ 1.96 or Z ≤ -1.96. The
calculated value of Z as described in equation 2 is 2.378. Since
2.378 > 1.96, H1 is rejected in favor of the conclusion that \( \mu_{\text{μg}} \neq \mu_{1 \text{ atm}} \)
(the μg, 1 atm test is not similar to the 1g, 1 atm test). Therefore,
the μg, 1 atm test is considered a harsher environment than the 1g,
1 atm environment. Visual inspection of the chart in Figure 2,
and similar calculations for Z (Z=16.16), indicates that the 1g, 1 atm
environment is harsher than the vacuum environment. Similar
hypothesis testing on the tensolite data reveal both the μg, 1 atm
tests (Z=6.45) and the 1g, 1 atm tests (Z=8.85) were harsher than
the vacuum tests. When Comparing the tensolite data obtained
from the μg, 1 atm environment with those from the 1g, 1 atm
environment the NULL hypothesis cannot be rejected due to a low
Z (Z=0.87) indicating a potential Type I error. The hypothesis test
for the probability (p) of a Type II error (accepting H0 when H1 is
false) is calculated using equation 3, where zα was defined above
to be 1.96 and \( \Phi \) is the standard normal cumulative distribution
function. The calculated value for p as described in equation 5 is
0.8597. Therefore, the NULL hypothesis cannot be accepted
without a high risk of a Type II error. Hence, no statistical
conclusion can be derived between the tensolite's μg, 1 atm tests
and the 1g, 1 atm tests. Filotex results were independent from
environment.

For two of the three samples, the vacuum tests resulted in the
smallest arc propagation distance. There is a statistical difference
between the baseline's μg and ground based tests. This difference
is not evident with the other two sample types.

Sample Type Comparison
Using similar hypothesis testing as described in the
Environmental Comparison section, Table 2 below displays the
calculated Z values for comparing the baseline Mil-W-81381 with
the Filotex and the tensolite samples. Both the Filotex and the
tensolite samples statistically had arcs propagate further than the
baseline over the 16 second duration.

Using the hypothesis test to compare the Filotex sample against the
Furthermore, but for conductor, to seconds. For one of the few times length values for susceptible to two environments, no Tensolite three environments tested. two candidates with the least amount of r_e arc tracking in all in this value of p=0.8701 for the lg, latin results in values of p=0.9499 for the Tensolite samples. Accordingly, the Filotex and Tensolite samples are indistinguishable and would be the choice over the baseline Mil-W-81381 in environments that have air at atmospheric pressure. However, in the vacuum environment, the baseline sample would perform similar to the Tensolite’s sample, and both outperformed the Filotex sample.

**CONCLUSION**

For an actual application using one of these candidate wire insulation types, the 16 second parameter is insignificant, because the arc, if undetected, would have a long period of time (>120 seconds) to do its damage. Therefore, the data displayed in Table 3 for the baseline Mil-W-81381 should be used to compare against the data mean (mm) row data of Table 1 for the Filotex and Tensolite samples. Accordingly, the Filotex and Tensolite samples are indistinguishable and would be the choice over the baseline Mil-W-81381 in environments that have air at atmospheric pressure. However, in the vacuum environment, the baseline and the Tensolite samples results are indistinguishable, and both outperformed the Filotex sample.

**REFERENCES**


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Prepared for the 1996 International Symposium on Electrical Insulations co-sponsored by the Institute of Electrical and Electronics Engineers and the Dielectrics and Electrical Insulation Society, Montreal, Canada, June 16-19, 1996. Thomas J. Stueber and Ahmad Hammoud, NYMA Inc., 2001 Aerospace Parkway, Brook Park, Ohio 44142 (work funded by NASA Contract NAS3–27186); David McCall, Cleveland State University, Cleveland, Ohio. Project Manager, Ronald Call, Space Power Technology Division, organization code 5430, (216) 433-3948.

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