NASA White Sands Test Facility

Electrical Arc Ignition Testing of Spacesuit Materials

October 2006

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**Background**

- Testing in response to frayed cable discovered during spacewalk
- Reliance on Apollo-era arc testing
  - Limited applicability to current materials
  - Significant changes in voltage and circuitry
  - Poor understanding of test configuration
Test Objectives

• Gain better understanding of Apollo-era data
• Investigate new test methods
• Characterize minimum current levels necessary for combustion of EMU materials (at a given voltage)
Test Sample Materials

- LCVG liner (tricot)
- LCVG outer layer (nylon/spandex)
- LCVG water transport tubing
- Pressure garment bladder (urethene coated nylon)
- Pressure garment cover-restraint (dacron)
- TMG liner (neoprene coated nylon ripstop)
- TMG insulation layers (aluminized mylar)
- TMG cover (ortho-fabric)
Test Methods

- Multiple location intermittent arcing (scratch) test
- Single location intermittent arcing (poke) test
- Single location wire-break arcing test
Scratch Test Objectives

- Simulate Apollo-era testing
- Determine configurational effects
- Test materials currently used in the EMU
Cotton Scratch Test Video
Scratch Test Results

• Testing yielded results similar to Apollo-era testing
• Frayed materials more reactive
• No distinguishable difference between horizontal samples and vertical samples
• Tests performed at 23.5 psia 100% O2, 22.5 V
  – 7 materials tested
  – Current required for ignition ranged from 0.8 A to 1.4 A
Entire Data Plot

BTAMOL12.dat: Voltage/0 – Current/1 (905)

- Volts
- Amps
- Time (milliseconds)
BTAMOL12.dat: Voltage/0 – Current/1

Current

Voltage

Time (milliseconds)

Volts

Amps
Scratch Test Problems

- Not possible to determine which arc ignited material
- Arc energies vary widely from test to test and arc to arc
- Difficult to ensure that test sample material is in intimate contact with arcing event
- Configuration not realistic for inside spacesuit because of size of stylus
Poke Test Objectives

• Determine whether more severe to arc with wires or stylus
• Determine whether more severe to arc in single location (poke test) or multiple locations (scratch test)
Poke Test Results

• Poke test results consistent with scratch test results
  – No detectable difference between arcing in one location or multiple locations

• Tests showed that it is more severe to arc with a wire than a stylus
  – Wires are flammable and can burn in oxygen
  – Burning wires easily ignite test materials
Poke Test Problems

- Not possible to determine which arc ignited material
- Arc energies vary widely from test to test and arc to arc
- Difficult to ensure that test sample material is in intimate contact with arcing event
Wire-break Test Objectives

• Reduce variability in tests
• Test all materials
• Determine whether ignition is dependent on voltage or current
<table>
<thead>
<tr>
<th>AWG Size</th>
<th>34</th>
<th>38</th>
<th>39</th>
<th>40</th>
<th>41</th>
<th>42</th>
<th>43</th>
<th>44</th>
<th>45</th>
<th>46</th>
<th>47</th>
<th>48</th>
<th>49</th>
<th>50</th>
<th>51</th>
<th>52</th>
<th>54</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (in.)</td>
<td>0.0063</td>
<td>0.004</td>
<td>0.0035</td>
<td>0.0031</td>
<td>0.0028</td>
<td>0.0025</td>
<td>0.0022</td>
<td>0.002</td>
<td>0.0018</td>
<td>0.0016</td>
<td>0.0014</td>
<td>0.0012</td>
<td>0.0011</td>
<td>0.00088</td>
<td>0.00078</td>
<td>0.00062</td>
<td></td>
</tr>
<tr>
<td>% of Flight Wire Cross Sectional Area</td>
<td>1550</td>
<td>625</td>
<td>479</td>
<td>375</td>
<td>306</td>
<td>244</td>
<td>189</td>
<td>156</td>
<td>127</td>
<td>100</td>
<td>77</td>
<td>56</td>
<td>47</td>
<td>39</td>
<td>30</td>
<td>24</td>
<td>15</td>
</tr>
<tr>
<td>Approximate Current Required to Break Wire (A)</td>
<td>9.00</td>
<td>5.00</td>
<td>3.80</td>
<td>3.00</td>
<td>2.60</td>
<td>2.30</td>
<td>1.80</td>
<td>1.50</td>
<td>1.30</td>
<td>1.10</td>
<td>0.90</td>
<td>0.83</td>
<td>0.70</td>
<td>0.63</td>
<td>0.50</td>
<td>0.45</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Cotton Wire-Break Test Video
High Speed Cotton Wire-break Test Video
Closeup Data Plot

c3.dat: Voltage/0 - Current/1

Voltage vs Time (milliseconds)

Volts

Amps

Time (milliseconds)
Wire-break Test Results

• Much more severe than scratch and poke tests
• Test conditions
  – 23.5 psia 100% O2, 22.5 V
  – 50 psia 50% O2 and 50% N2, 15 V
• Several materials failed testing at the lowest possible current, ~0.3 A
• Current required for ignition for most materials ranged from <0.3 A to 0.97 A
Wire-Break Test Results (cont.)

- Gore-Tex only ignited under much more severe conditions
  - 100% O2, 54 psia
  - Zigzag wire configuration
**Wire-break Tests vs. Scratch Tests**

23.5 psia 100% O2, 22.5 V

<table>
<thead>
<tr>
<th>Material</th>
<th>Wire Test Available Current at Ignition (A)</th>
<th>Scratch Test Available Current at Ignition (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic cotton</td>
<td>0.36</td>
<td>0.95</td>
</tr>
<tr>
<td>Moleskin</td>
<td>0.3</td>
<td>0.8</td>
</tr>
<tr>
<td>UCN (shiny side)</td>
<td>0.70</td>
<td>1.4</td>
</tr>
<tr>
<td>Nylon/Lycra Comm Cap</td>
<td>0.59</td>
<td>1.3</td>
</tr>
<tr>
<td>Astronaut undergarment</td>
<td>0.64</td>
<td>1.4</td>
</tr>
<tr>
<td>LCVG spandex</td>
<td>0.53</td>
<td>1.4</td>
</tr>
<tr>
<td>LCVG tricot</td>
<td>0.49</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Urethane-coated Nylon

Current (A) vs. Voltage (V) graph showing ignition behavior:
- No Ignition (blue dots)
- Ignition (red triangles)

21.8 Watt Power Curve

2.5 V, 4.99 A

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Moleskin

6.8 Watt Power Curve
Ignition
No Ignition

1.3V, 0.25A
<table>
<thead>
<tr>
<th>Surface Characteristics</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth</td>
<td>Interface cable Gore-Tex® sleeve</td>
</tr>
<tr>
<td>Smooth</td>
<td>Urethane-coated nylon suit bladder (fabric side)</td>
</tr>
<tr>
<td>Smooth</td>
<td>PVC</td>
</tr>
<tr>
<td>Smooth</td>
<td>Interface cable polyurethane jacket</td>
</tr>
<tr>
<td>Smooth</td>
<td>Urethane-coated nylon suit bladder (shiny side)</td>
</tr>
<tr>
<td>Smooth</td>
<td>Astronaut longhandle undergarment</td>
</tr>
<tr>
<td>Smooth</td>
<td>CCA cap spandex (nylon &amp; Lycra® knit fabric)</td>
</tr>
<tr>
<td>Smooth</td>
<td>LCVG garment (multifilament nylon / spandex knit 1106 treated with 3% TCHDE solution)</td>
</tr>
<tr>
<td>Smooth</td>
<td>LCVG garment inner liner (nylon tricot treated with 3% TCHDE solution)</td>
</tr>
<tr>
<td>Fuzzy</td>
<td>Cotton flocked Rucothane® glove bladder</td>
</tr>
<tr>
<td>Fuzzy</td>
<td>TCU assembly (Capilene® – hollow fiber polyester treated with 3% TCHDE solution) (gray)</td>
</tr>
<tr>
<td>Fuzzy</td>
<td>Kerlix dressing</td>
</tr>
<tr>
<td>Fuzzy</td>
<td>Generic cotton</td>
</tr>
<tr>
<td>Fuzzy</td>
<td>Moleskin</td>
</tr>
</tbody>
</table>
Conclusions

• Wire-break test is worst-case
• Fuzzy materials generally easier to ignite
• Current appears to have greater effect than voltage
• Controlling risk must include both
  – Physical isolation of easy to ignite materials
  – Limiting current and voltage