CFRP Flammability Tests

Test Configuration Influence on Flame Propagation

Presented to: IAMFTWG Atlantic City NJ
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Introduction

• Tests were performed to determine the influence of a variety of configurational factors on inboard flame propagation of composite fuselage panels
  – Insulation-panel spacing
  – Heat retention near panel surface
  – Outboard surface heat loss

• The original foam block fire source and test rig were used

• CFRP panels were procured for this testing
  – 0.1” thickness
  – Quasi-isotropic tape layup, single outer ply of woven fabric
  – 350°F cure toughened epoxy
Test Series

- **Flat Panel Tests**
  - Baseline
  - Thermal-Acoustic insulation blanket between inboard face of test panel and test rig shroud
    - Vary gap from tightly pressed up to panel → 1” gap
  - If significant flame propagation is found,
    - Determine if increasing the rate of heat transfer from the outboard surface influences inboard flame propagation

- **Simulated Structure and Panel Tests**
  - Determine if both the structure and panel will propagate flames under conditions found previously
  - Determine if increasing the rate of heat transfer from the outboard surface influences inboard flame propagation

- **Simulated Primary Lithium Battery Powered Electronic Locator Transmitter (ELT) failure adjacent to CFRP panel**
  - Higher intensity fire source
  - Determine if this fire source will cause CFRP panel to propagate flames similar to foam block
  - Will more intense fire source overcome increased rate of heat transfer from the outboard surface?
Foam Block Test Configuration

- Insulation Blanket
- Foam Block Fire Source
## Test Matrix: Foam Block Ignition Source

<table>
<thead>
<tr>
<th>Date</th>
<th>Test Name</th>
<th>Configuration</th>
<th>Insul. Dist.</th>
<th>Burn Length</th>
<th>Burn Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/22/2015</td>
<td>Baseline</td>
<td>Std. Config.</td>
<td>n/a</td>
<td>6.5625</td>
<td>6.6875</td>
</tr>
<tr>
<td>1/22/2015</td>
<td>Insulation 1</td>
<td>Insul Pressed Tightly to Skin</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1/26/2015</td>
<td>Insulation 2</td>
<td>Insul Pressed Tightly to Skin</td>
<td>0</td>
<td>7.5</td>
<td>15.25</td>
</tr>
<tr>
<td>1/27/2015</td>
<td>Insulation 3</td>
<td>Insul slightly further from skin</td>
<td>0.5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>1/27/2015</td>
<td>Insulation 4</td>
<td>Insul further from skin</td>
<td>1</td>
<td>9.25</td>
<td>6.25</td>
</tr>
<tr>
<td>1/28/2015</td>
<td>Insulation 5</td>
<td>Insul closer, added gasket</td>
<td>0.5</td>
<td>46</td>
<td>12</td>
</tr>
<tr>
<td>3/4/2015</td>
<td>Insulation 6</td>
<td>Insulation 5 w/water cooling</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3/9/2015</td>
<td>Insulation 7</td>
<td>repeat of insulation 6</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3/17/2015</td>
<td>Insulation 8</td>
<td>CFRP with frames</td>
<td>0.5</td>
<td>46</td>
<td>12</td>
</tr>
<tr>
<td>3/19/2015</td>
<td>Insulation 9</td>
<td>CFRP with frames &amp; water cooling</td>
<td>0.5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3/24/2015</td>
<td>Insulation 10</td>
<td>CFRP frames &amp; stringers</td>
<td>0.5</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>3/27/2015</td>
<td>Insulation 11</td>
<td>CFRP frames &amp; stringers (flipped panel)</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>4/2/2015</td>
<td>Insulation 12</td>
<td>CFRP frames &amp; stringers</td>
<td>1</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>4/2/2015</td>
<td>Insulation 13</td>
<td>CFRP frames &amp; stringers (flipped panel)</td>
<td>1</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>4/2/2015</td>
<td>Insulation 14</td>
<td>CFRP frames &amp; stringers (sealed w/RTV)</td>
<td>1</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>4/30/2015</td>
<td>Insulation 15</td>
<td>CFRP frames &amp; stringers (flipped panel+RTV)</td>
<td>0.5</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>4/30/2015</td>
<td>Insulation 16</td>
<td>CFRP frames &amp; stringers (sealed w/RTV)</td>
<td>0.5</td>
<td>33.5</td>
<td>14</td>
</tr>
<tr>
<td>5/28/2015</td>
<td>Insulation 17</td>
<td>Insulation 16 w/water cooling</td>
<td>0.5</td>
<td>9</td>
<td>9.75</td>
</tr>
</tbody>
</table>
Lithium Battery Ignition Source Test Configuration

- Lithium Battery Test Configuration
  - 5 D-Cell Lithium batteries (non-rechargeable)
  - Battery box insulated w/ 1/2” ceramic fiberboard
  - Battery box surface within 1/2” of CFRP inboard panel surface
  - Insulation blanket placed between shroud and inboard face of CFRP panel
  - Thermocouples penetrate through insulation blanket, within 1/4” of CFRP panel surface
  - Thermocouples on each battery cell and on cartridge heater
Gas Analyzers

- Non-dispersive IR Measurement of CO and CO$_2$
- Paramagnetic Measurement of O$_2$
- Single stream sample plumbed in series
- Filtered and dried to 1 micron & 5°C dew point
- 6 Lpm flowrate
- Approx 20’ of ¼” sample line
10 Ply CFRP, Battery Ignition Source

Inboard Panel Temperatures

- Temperatures measured over time for different panels labeled 1R, 1L, 2R, 2L, 3R, 3L, 4R, 4L.

Measured Gas Concentrations

- Gas concentrations over time with distinct peaks and troughs.
Repeat with water spray cooling on outboard surface
Comparison: Static Ambient vs. Cooled Backside Heater and Battery Cell Temperatures

Static Ambient

Cooled Backside

13.5 min

12.7 min
Comparison: Static Ambient vs. Cooled Backside
Measured Exit Gas Concentrations

Static Ambient

Cooled Backside
Comparison: Static Ambient vs. Cooled Backside
Inboard Panel Temperatures
### Test Matrix: Lithium Battery Ignition Source

<table>
<thead>
<tr>
<th>Date</th>
<th>Test Name</th>
<th>Configuration</th>
<th>Panel Thickness (in.)</th>
<th>Insul. Dist. (in.)</th>
<th>Burn Length (in.)</th>
<th>Burn Width (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/9/2015</td>
<td>ELT 1</td>
<td>Simulated ELT, insulation, no cooling</td>
<td>0.098</td>
<td>0.5</td>
<td>46</td>
<td>15</td>
</tr>
<tr>
<td>7/16/2015</td>
<td>ELT 2</td>
<td>Simulated ELT, insulation, w/cooling</td>
<td>0.098</td>
<td>0.5</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>8/6/2015</td>
<td>ELT 3</td>
<td>Simulated ELT, insulation, no cooling, 32 Ply</td>
<td>0.366</td>
<td>0.5</td>
<td>17</td>
<td>10.5</td>
</tr>
<tr>
<td>8/13/2015</td>
<td>ELT 4</td>
<td>Simulated ELT, insulation, no cooling, 24 Ply</td>
<td>0.275</td>
<td>0.5</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>8/25/2015</td>
<td>ELT 5</td>
<td>Simulated ELT, insulation, no cooling, 16 Ply</td>
<td>0.13</td>
<td>0.5</td>
<td>43.5</td>
<td>15.5</td>
</tr>
</tbody>
</table>
24 Ply CFRP, Battery Ignition Source

Inboard Panel Temperatures

Measured Gas Concentrations
ThermaKin set-up: Perform 1D simulations, mass loss rate (MLR) as output

Model Input Parameters:

- **Composite** description
  Density, thermal conductivity, heat capacity, etc. Can be obtained from lab tests

- **Ignition source** (foam block, battery set). External flux, duration. Can be obtained from literature, thermocouples.

- **Boundary conditions**
  - *Outside* (ambient, external cooling)
  - *Inside* (open composite, channel)

- **Heat generation process**
  (e.g. smoldering, carbon fiber oxidation) can be obtained from CO/CO$_2$/O$_2$ analyzes
Gas CO/CO\textsubscript{2}/O\textsubscript{2} analyzers data

Main goal for the gas analyzers data is to determine the driving force behind heat generation process

Cone calorimetry | Over-ventilated, excess O\textsubscript{2}

Inaccessible Area Fire Tests | O\textsubscript{2} starved

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{chart.png}
\caption{Graph showing the gas concentration over time for different conditions.}
\end{figure}

Fuel Oxidation Kinetics

\[
\text{Fuel} + \frac{1}{2} \text{O}_2 \xrightarrow{k_{CO}} \text{CO} \quad \Delta H_1 \text{ C} \rightarrow \text{CO} 110 \text{ kJ/mole}
\]

\[
\text{CO} + \frac{1}{2} \text{O}_2 \xrightarrow{k_{CO_2}} \text{CO}_2 \quad \Delta H_2 \text{ CO} \rightarrow \text{CO}_2 283 \text{ kJ/mole}
\]

Heat generation process inside of the channel is probably smoldering, according to CO\textsubscript{2}/CO ratio

- Flaming combustion 30/1
- After flame out (smoldering) 15/1
- Inaccessible area fire test 9/1 (1100-1300 sec, after main battery event)
Painted Panel Tests

• .1” CFRP panels painted with aircraft exterior paint (white)
  – Eclipse® High Solids Polyurethane Topcoat
  – Primer + 3 coats sprayed
• Foam block ignition source
• Nearly full-length propagation
  – Inflation of insulation bag created restriction in channel
  – Buoyant products not able to escape freely
  – Fresh air not able to be drawn in
  – Self-extinguished due to lack of available oxygen
Next Steps

- Increase measurement range of CO analyzer to 30%
  - Re-test CFRP 10 ply w/foam block
- Quantify cooling efficiency
  - Compare to calculated and/or measured in-flight heat loss rates for CFRP airplanes
- Once cooling rate is fixed, re-test foam block and Lithium battery configurations w/new cooling rate
Large Scale CFRP Skin & Structure Tests

• Large scale CFRP skin and structure test fixture
• Study propagation of fire from bay-to-bay with and without cooling
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