Testing of Advanced Conformal Ablative TPS

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Outline

• Technology Description
• SPRITE Test Design and Results
• Summary
Technology description: Conformal TPS

- **Reinforcement on low density carbon or polymer felts**
  - High strain to failure eliminates need for strain isolation during attachment to rigid aeroshell (required for PICA)
  - Allows for large area ablators
  - Eliminates gaps and gap filler issues present with standard PICA

- **Impregnation with advanced polymer resins to improve properties**
  - Reduce thermal conductivity
  - Endothermic energy absorption due to decomposition of the resin
  - Increased char strength
• Conformal TPS Materials Development to TRL 5
• Develop and demonstrate (via ground testing) a conformal ablator capable at 250 W/cm² and beyond
  – Based on felt reinforcements that come in very large sizes
  – Reduced part counts (compared to PICA)
  – High strain-to-failure eliminates/reduces gap and gap filler issues common with PICA
• Our assumptions are:
  – Commercially available felt systems such as carbon felt, and simpler steps in making conformal TPS will lower the cost
  – Conformal is going to be less complex to integrate across a variety of carrier structure – lower design complexity
  – Conformal is going to be cheaper to manufacture and install
Test Campaigns

• **Test 1: 2012 Arcjet test series**
  – Assess the thermal performance of proposed materials over a broad range of conditions
  – Develop TPS-C instrumentation for developing and validating thermal response models from TPS materials testing in the arcjet
  – Down-select one conformal material for further testing.

• **Test 2: 2013 Arcjet test series**
  – Develop mid-fidelity material response models that can predict recession and in-depth temp response in support of mission design and analysis
  – Address attachment of conformal TPS to a rigid carrier structure and seam design between gore panels
SPRITE Configuration

SPRITE\(^1\) – Small Probe Reentry Investigation for TPS Engineering

Advantages

• Enables the testing in relevant environment
  – It is possible to obtain a flight like pressure, shear and heatflux distribution

• Can test standard TPS against conformal material within the same model resulting in cost savings.

• Enables testing of seams in relevant test conditions

SPRITE Test Article Detail

- 8-inch diameter
- 55° sphere cone
# MSL Peak Aerothermal Environment

<table>
<thead>
<tr>
<th>Location</th>
<th>Peak Heat Rate (W/cm²)</th>
<th>Peak Shear (Pa)</th>
<th>Peak Pressure (atm)</th>
<th>Peak Heat Load (J/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS Leeside Flank</td>
<td>220.1</td>
<td>393.4</td>
<td>0.246</td>
<td>6103.5</td>
</tr>
<tr>
<td>HS Leeside Shoulder</td>
<td>225.7</td>
<td>465.4</td>
<td>0.242</td>
<td>6402.4</td>
</tr>
<tr>
<td>HS Leeside Shoulder</td>
<td>203.2</td>
<td>490.2</td>
<td>0.208</td>
<td>5895.3</td>
</tr>
<tr>
<td>Stagnation Point</td>
<td>59</td>
<td>5.4</td>
<td>0.332</td>
<td>2604.5</td>
</tr>
<tr>
<td>HS Nose Apex</td>
<td>119.2</td>
<td>127.4</td>
<td>0.239</td>
<td>4113.2</td>
</tr>
<tr>
<td>HS Windside Shoulder</td>
<td>114.4</td>
<td>216.7</td>
<td>0.242</td>
<td>4136.8</td>
</tr>
<tr>
<td>HS Windside Shoulder</td>
<td>103.8</td>
<td>240.5</td>
<td>0.172</td>
<td>3749.7</td>
</tr>
</tbody>
</table>

250 W/cm², 0.33 Atm, 490 Pa Shear
CFD Analysis: High Condition

High Condition “MSL”
~ 400 W/cm², ~ 24 kPa
Press. ~ 200 Pa shear on Flank and ~ 500 Pa shear
On 0.8” Rₐ corner

CFD by Dinesh Prabhu
Medium Condition “MSL”

~ 180 W/cm², ~ 13 kPa
Press. ~ 150 Pa shear on Flank and ~ 300 Pa shear On 0.8” R_b corner

CFD by Dinesh Prabhu
Test 1: Test Matrix and Instrumentation

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Model</th>
<th>Heat-flux at the flank (W/cm²)</th>
<th>Exposure Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>C-PICA</td>
<td>~180</td>
<td>60</td>
</tr>
<tr>
<td>Medium</td>
<td>C-SICA</td>
<td>~180</td>
<td>60</td>
</tr>
<tr>
<td>High</td>
<td>C-PICA</td>
<td>~400</td>
<td>30</td>
</tr>
<tr>
<td>High</td>
<td>C-SICA</td>
<td>~400</td>
<td>30</td>
</tr>
</tbody>
</table>

- 4 inch hemi calorimeters to characterize the flow
- Each model was instrumented with 4 TC-plugs with 3 TCs in each plug. The data from all the 12 TCs was collected during the test.
- Infrared camera and pyrometer were mounted to obtain surface temperature.
- Laser scans were obtained pre- and post- arcjet to measure recession.
• The conformal TC plugs worked well and we were able to obtain reasonable measurements from these tests to develop thermal response models.
Test 1- recession

Summary Table

<table>
<thead>
<tr>
<th>Model</th>
<th>Test condition</th>
<th>Recession (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-PICA</td>
<td>High</td>
<td>3.5~4.2</td>
</tr>
<tr>
<td>C-PICA</td>
<td>Medium</td>
<td>5.8~6.3</td>
</tr>
<tr>
<td>C-SICA</td>
<td>High</td>
<td>3.1~4.0</td>
</tr>
<tr>
<td>C-SICA</td>
<td>Medium</td>
<td>2.5~4.0</td>
</tr>
</tbody>
</table>

C-PICA model in high condition
Test 1 – Conclusions

• The tests proved that conformal ablator technology is a viable option.
• C-PICA was down-selected to be advanced to a higher TRL based on ease of processing, machining.
• The next step was to test gaps and seams for conformal ablator.
Test 2: Seam Model

- 45° Joint Annular Cut
- 45° Joint 45° Radial Cut
- 45° Lap Joint Radial Cut
- Standard PICA

Flow Arrows indicate the direction of flow at different points in the model.
Test 2: Pre-Test Images

Thermal Response Model

Seam Model
Test 2: Test Matrix and Instrumentation

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Pressure (atm)</th>
<th>Heat-flux at the flank (W/cm²)</th>
<th>Shear (Pa)</th>
<th>Exposure Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (High)</td>
<td>0.25</td>
<td>~400</td>
<td>230</td>
<td>30</td>
</tr>
<tr>
<td>2 (Medium)</td>
<td>0.14</td>
<td>~180</td>
<td>143</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>0.07</td>
<td>~130</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>4</td>
<td>0.09</td>
<td>~40</td>
<td>80</td>
<td>100</td>
</tr>
</tbody>
</table>

- Test Details:
  - Articles tested at 4 conditions: 40, 130, 180 & 400 W/cm²
  - 4-inch hemispherical calorimeters were used to characterize the flow
  - 4 TC plugs (0.15, 0.30 & 0.50-inch depth) – 1 in each TPS segment
  - IR and Pyrometer data were obtained for surface temperature
  - Pre and post- arcjet laser scans were obtained.
Model During Testing @ 400 W/cm²
Model During Testing @ 400 W/cm²
Test 2: Video of Seam Model
Test 2: Post test laser scan

- Recession comparable to PICA
The thermocouple data consistently showed significantly lower bondline temperature for conformal PICA.
Post-Test – 400 W/cm$^2$, 30 sec
SPRITE Test Summary

• Objectives of the test were met:
  – Demonstrated applicability of conformable ablator on a curved structure at range of conditions from $40-400\text{W/cm}^2$
    • MSL-heat flux and COTS LEO shear conditions
  – Demonstrated advanced instrumentation of conformable ablators and gathered in-situ temperature data
  – Gathered recession and back-face temperature data on conformable ablators in a representative shear environment
  – Evaluated 5 seam designs. All the seams performed very well in the arcjet environments. No widening of gaps, redeposit etc were observed during the test.

The two tests proved that Conformal PICA is a viable technology solution that addresses the issues of gap fillers and seams with standard PICA, while proving a lower bondline temperature.