Development of Low Density, Flexible Carbon Phenolic Ablators

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Outline

Background

Motivation

Applications

Testing

Summary
State-of-the-Art (SoA) Low Density Carbon Phenolic Ablators

- Phenolic Impregnated Carbon Ablator (PICA), an enabling TPS material for the Stardust mission used as a single piece heatshield

- PICA is low-density (~0.27g/cm^3) and efficient at high heat fluxes

- PICA is the primary heat shield material for Mars Science Lab (MSL) and the Space-X Dragon as a tiled configuration
Challenges with PICA

- Low strain to failure
- May require use of strain isolation pad
- Relatively large part count in tiled configuration
- Brittle char
- Needs a compatible gap filler
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Advantages of Flexible Ablators

Flexible Ablator Advantages Compared to Rigid TPS

- Less complex design
- More straightforward system integration
- Easier to manufacture
- Requires fewer segments (larger tiles can be made)
- Easier to assemble
- Enables larger diameter aeroshells
- Reduces gap and seam issues

Orion Heat Shield
(5 m diameter)

MSL Heat Shield
(4.5 m diameter)
Making PICA Flexible

- PICA is a low density carbon phenolic thermal protection material
- Composition works well up to 1000 W/cm²
- Goal = retain the composition but change the architecture

Substrate
- Carbon Fiberform
- Carbon Felt

Matrix
- Phenolic Resin
- Modified Resins

heat →
cure

PICA

PICA FLEX
Making PICA Flexible

Flexible PICA from a Felt Substrate

- Comparable in composition to PICA
- Remains flexible after charring
- Can be processed as large pieces
- Parameters such as thickness, density, etc can be tailored
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Summary
Potential Conformable Applications

Lunar Return Missions

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Location</th>
<th>q (W/cm²)</th>
<th>Margin q?</th>
<th>Pressure (kPa)</th>
<th>Shear (Pa)</th>
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</thead>
<tbody>
<tr>
<td>Orion, LEO</td>
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<td>433</td>
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Flexible ablators can mitigate PICA integration issues

Mars Missions

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Location</th>
<th>q (W/cm²)</th>
<th>Margin q?</th>
<th>Pressure (kPa)</th>
<th>Shear (Pa)</th>
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<td>19.7</td>
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<td>98</td>
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<td>19</td>
<td>137</td>
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<tr>
<td>Mars 2018</td>
<td>Dish</td>
<td>69</td>
<td>no</td>
<td>24</td>
<td>43</td>
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Flexible ablators are an attractive alternative to rigid PICA for future MSL class rigid aeroshells
Potential Flexible Applications

Mars Vehicle Concepts

<table>
<thead>
<tr>
<th>Entry Vehicle Concept</th>
<th>Location</th>
<th>q (W/cm²)</th>
<th>Margin q?</th>
<th>Pressure (kPa)</th>
<th>Shear (Pa)</th>
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<tbody>
<tr>
<td>EDL SA (23 m)</td>
<td>Peak Forebody</td>
<td>106 / 32</td>
<td>YES</td>
<td>11 / 8</td>
<td>42 / 25</td>
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<tr>
<td>EDL SA (23 m)</td>
<td>Peak Forebody</td>
<td>67 / 21</td>
<td>no</td>
<td>9 / 6</td>
<td>27 / 16</td>
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A/E = Aerocapture/Entry

Venus / Saturn Vehicle Concepts

<table>
<thead>
<tr>
<th>Entry Vehicle Concept</th>
<th>Location</th>
<th>q (W/cm²)</th>
<th>Margin q?</th>
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<th>Shear (Pa)</th>
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</table>

1 Hypersonic Inflatable Aerodynamic Decelerator
2 Adaptive Deployable Entry-system Project
Outline

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**Testing**

Summary
• 4 candidate PICA FLEX systems evaluated

• Preliminary Results:
  – Tensile tests
  – Thermal Conductivity
  – Microstructure
  – LHMEI Testing
  – Arc Jet testing
Mechanical Properties (Tensile)

- Samples were tested to evaluate strength and strain to failure. (8” x 1”)

- PICA flex failed gracefully and showed necking behavior

- PICA flex could withstand approx. 8%-12% strain before onset of necking
• PICA thermal conductivity values taken from Orion Database
• Laser flash method used for PICA FLEX
• Data is an average of 3 samples
• PICA and PICA flex samples have comparable densities, however, the thermal conductivity of PICA flex is approximately one-third of rigid PICA
Microstructure

- Microstructure influences properties
- PICA flex microstructure resembles PICA in many aspects; distributed phenolic phase in a carbon matrix
• Exposure 450 W/cm² for 25 seconds
• Comparable areal mass for all materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Max. Backface Temperature (°C)</th>
<th>Time to Reach Max. Backface Temperature (sec)</th>
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<tr>
<td>PICA</td>
<td>240</td>
<td>93</td>
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<tr>
<td>PICA Flex Variant 1</td>
<td>118</td>
<td>213</td>
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<tr>
<td>PICA Flex Variant 2</td>
<td>75.5</td>
<td>246</td>
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<tr>
<td>PICA Flex Variant 3</td>
<td>133</td>
<td>143</td>
</tr>
</tbody>
</table>

*LHMEL - Laser Hardened Materials Evaluation Laboratory, Air Force Research Laboratory, Wright-Patterson AFB, OH

Courtesy S. White NASA ARC
Arc-Jet Screening Tests

- Initial testing completed at Johnson Space Center
- Samples were:
  - 3.5” diameter by ~ 1” thick
  - bonded to an LI 2200 tile holder with collar
  - instrumented with a backface thermocouple
- 2 conditions evaluated
  - Heat Flux: 250 W/cm², Pressure: 0.2 atm and Duration: 30 seconds
  - Heat Flux: 540 W/cm², Pressure: 0.3 atm and Duration: 20 seconds
- PICA flex performed well up 540 W/cm²
- Performance limits for flexible ablators TBD
Pre- and Post-Test Comparisons

Heat Flux: 250 W/cm²
Pressure: 0.2 atm
Duration: 30 sec

<table>
<thead>
<tr>
<th>Description</th>
<th>Peak Surface Temperature °C</th>
<th>Backface Temperature Delta °C</th>
<th>Recession cm</th>
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<tr>
<td>PICA</td>
<td>2041</td>
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<td>PICA FLEX M1</td>
<td>2027</td>
<td>52</td>
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<tr>
<td>PICA FLEX M2</td>
<td>1967</td>
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<td>1996</td>
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<td>PICA FLEX M4</td>
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</table>
Pre- and Post-Test Comparisons

Heat Flux: 540 W/cm²
Pressure: 0.3 atm
Duration: 20 sec

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<thead>
<tr>
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<th>Description</th>
<th>Peak Surface Temperature °C</th>
<th>Backface Temperature Delta °C</th>
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<td>3247</td>
<td>PICA FLEX M4</td>
<td>2474</td>
<td>102</td>
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Summary

Currently evaluating alternative architectures for flexible and more conformal carbon phenolic materials with comparable performance to PICA.

Flexible TPS concepts address some of the design issues faced in the use of a tiled PICA heat shield.

Initial testing of flexible PICA concepts has shown:
  - Substantially higher strain to failure than PICA
  - Lower thermal conductivity than PICA
  - Survived a 540 W/cm², arc jet exposure

Flexible ablator technology is applicable for upcoming NASA missions needing either rigid or flexible TPS, e.g., HIAD and ADEPT deployable decelerators.

PICA FLEX evaluation ongoing under OCT funded CFA TPS program
Families of Ablators Under Development at NASA ARC

**Rigid Ablators**
- Advanced PICA-like ablators
- Graded Ablators

**Conformable Ablators**
- Conformable PICA

**Flexible Ablators**
- Flexible PICA
- Flexible SIRCA

**Woven TPS**
- Mid density TPS
- Carbon phenolic replacement
Acknowledgement

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  – Entry, Descent, and Landing Technology Development Project

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