Sustaining PICA for future NASA Robotic Science Missions including NF-4 and Discovery

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Outline

• **Background**
  – Heritage PICA
  – PICA Sustainability Challenge
  – Lyocell – an alternative precursor to rayon
  – PICA Manufacturing

• **Establishment of PICA-D as a Replacement for Heritage PICA**
  – Lyocell Fiberform/PICA Billet and Near Net Shape Cast Processing
  – PICA-D Property Testing
  – PICA-D Arc Jet Testing

• **CY18/19 work**
  – Establish PICA-D as a drop-in replacement for Heritage PICA
  – Establish the Expanded Capability (Extensibility) of PICA-D
  – PICA-D CY18/19 Schedule

• **Summary**
• **Acknowledgements**
Background – PICA

State of the Art Low Density Carbon Phenolic Ablators

- Phenolic Impregnated Carbon Ablator (PICA)
  - first used as forebody single piece heatshield for Stardust

- Low density coupled with efficient ablative capability at medium-high heat fluxes

- Since Stardust,
  - PICA used on Mars Science Lab (MSL) in a tiled configuration,
  - OSIRIS-REx sample return capsule as a single piece
  - slated for Mars 2020

- Based on successful mission use across destinations ranging from earth return to Mars, PICA has been proposed as the TPS option for numerous New Frontier and Discovery missions.
Challenges with PICA Sustainability

- In 2016 NASA learned that the heritage rayon used in PICA was ceasing production, leading to a flight-qualified PICA sustainability concern
  - The carbon fiber precursor for PICA has become obsolete twice since the material was developed and used on Stardust, so a secure source is essential to maintain PICA capabilities for future missions
- In FY16/17, NASA ARC was funded by the Planetary Science Division of the Science Mission Directorate to address PICA rayon sustainability
- Lyocell Based PICA (PICA-D) was manufactured and limited testing performed – initial results indicate Lyocell is a good candidate as a potential replacement for heritage rayon
Lyocell – A Sustainable Precursor

- Traditional rayon manufactured from wood pulp involves many steps and the conversion of wood pulp into rayon or regenerated cellulose results in toxic byproducts
  - rayon manufacturing was discontinued and is no longer a viable process in the US and Europe
- Lyocell - solvent spinning technique is simpler and more environmentally sound
  - uses a non-toxic solvent chemical that is 99% recycled in the manufacturing process
- Lenzing – sister factories in US and UK able to provide the same Lyocell precursor – dual supply routes alleviate future sustainability concern

Refer to below links if interested in information on how fibers are made from wood pulp:
https://www.youtube.com/watch?v=tHdJGFv99fE
https://www.youtube.com/watch?v=14PZNgRoEUM
PICA Manufacturing Overview
Role of Rayon/Lyocell in PICA Manufacturing

• Chopped, graphitized rayon or Lyocell-based carbon fiber slurry-cast into either block (billet) or single piece heatshield preforms
• Single piece cast heatshields have fiber oriented to optimize through-thickness thermal conductivity
• Lightweight phenolic sol-gel matrix is infiltrated into preform
Establishment of PICA-D as a Replacement for Heritage PICA

- FY17 - SMD-PSD funded NASA Ames to manufacture & perform limited property/aerothermal characterization of Lyocell-based PICA (PICA-D)
  - Fiber Processing, billet fabrication, single piece heatshield preform fabrication, conversion to PICA (billets and single piece preform)
  - PICA property testing and arc jet testing
- FY17 task successfully completed - limited testing indicates PICA-D has the potential to be a drop-in replacement for heritage PICA
- FY18/FY19 - NASA Ames leading an effort to further characterize and extend the capability of PICA-D and establish Lyocell PICA as a drop-in replacement for heritage PICA
  - Establishing PICA-D as a “drop in replacement” will allow missions to depend on and design with PICA-D without having to address further sustainability risks.
  - Establishing extended capability of PICA-D will allow Sample Return Missions with higher entry speed that were not considered before.
    - Extended operational capability
    - Extended single piece heatshield manufacturing
Lyocell Fiberform/PICA Billet and Near Net Shape Cast Processing

- 9 FiberForm billets manufactured in FY17 to optimize process (Lyocell).
- Fabricated 3 net-shaped Fiberform heatshield blanks (OSIRIS REx scale) in FY17.
  - Density targets in all 3 net cast blanks were achieved.
  - Process refinements and lessons learned have been documented.
  - Limited Non Destructive Evaluation (NDE) on the near net shape FiberForm unit to evaluate fiber alignment.
- FY18/19 demonstrate repeatability and increase single piece net cast >1.2-m.
PICA-D Property Testing

- 3 billets of PICA-D were manufactured to support testing
  - Limited In-plane (IP) tension, through-thickness (TT) tension, and through thickness thermal conductivity at 100°F and 350°F were conducted and compared to heritage rayon PICA
- Overall these results are in family with production rayon PICA – however additional testing is needed as only a few coupons were evaluated
  - Limited property data had substantial scatter – detailed testing planned for FY18/19

### Mechanical Property Comparison

<table>
<thead>
<tr>
<th>Density (g/cc)</th>
<th>Average Failure Stress (psi)</th>
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</thead>
<tbody>
<tr>
<td><strong>Average Lyocell PICA</strong></td>
<td></td>
</tr>
<tr>
<td>IP properties</td>
<td>0.28</td>
</tr>
<tr>
<td>160 - 255 for rayon PICA</td>
<td></td>
</tr>
<tr>
<td><strong>Average Lyocell PICA</strong></td>
<td></td>
</tr>
<tr>
<td>TTT properties</td>
<td>0.28</td>
</tr>
<tr>
<td>43 to 54 for rayon PICA</td>
<td></td>
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</table>

### Thermal Property Comparison

<table>
<thead>
<tr>
<th>Thermal Conductivity (BTU-in/hr-ft²-°F)</th>
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<tbody>
<tr>
<td><strong>at 100°F</strong></td>
</tr>
<tr>
<td><strong>Average Lyocell PICA</strong></td>
</tr>
<tr>
<td>TTT properties</td>
</tr>
<tr>
<td><strong>Rayon PICA</strong></td>
</tr>
<tr>
<td>TTT properties</td>
</tr>
</tbody>
</table>
**PICA-D Arc Jet Testing**

- **Primary test objectives**
  - compare the thermal response and recession behavior of Lyocell derived PICA to rayon derived PICA
  - initial look at any performance differences or off-nominal behavior in PICA-D

- **3 conditions – testing completed in Oct 2017**
- **NF proposers provided guidance on target test conditions**

### Arc Jet Test Matrix

<table>
<thead>
<tr>
<th>Target Conditions</th>
<th>Objective</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>~220W/cm² and 0.08 atm (4” iso-q)</td>
<td>thermal response, recession</td>
<td>Instrumented coupon, calibration included Testing in Oct 2017</td>
</tr>
<tr>
<td>~400W/cm² and 0.3 atm (4” iso-q)</td>
<td>thermal response, recession</td>
<td>Instrumented coupon, Testing complete Aug 2017</td>
</tr>
<tr>
<td>~1550W/cm² and 1.3 atm (4” iso-q)</td>
<td>Failure mode evolution, thermal response, recession</td>
<td>Instrumented coupon, Testing complete Aug 2017</td>
</tr>
</tbody>
</table>

### Coupon Geometry
- 4” iso-q coupons
- Each coupon instrumented with a plug containing 5 in-depth thermocouples consisting of 2 type-R and 3 type-K
PICA-D Arc Jet Testing - Results

Limited # of models of each version of PICA tested at each condition

- Initial tests gives confidence that PICA-D will be a drop in replacement for heritage PICA
- Comparable recession and thermal response observed between PICA-D and heritage PICA
  - all coupons at a given condition had the same exposure time
- Run condition very relevant for NF proposers considering PICA as a forebody or backshell material
- Presence of dulling agent in PICA-D resulted in a slight decrease in char emissivity – future PICA-D precursor (Lyocell) will not use a dulling agent

Recession Comparison

<table>
<thead>
<tr>
<th>Material</th>
<th>Average centerline recession (1550W/cm² and 1.3 atm)</th>
<th>Average centerline recession (400W/cm² and 0.3atm)</th>
<th>Average centerline recession (220W/cm² and 0.08atm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyocell PICA</td>
<td>4.0mm</td>
<td>6.02mm</td>
<td>3.79mm</td>
</tr>
<tr>
<td>Rayon PICA</td>
<td>4.2mm</td>
<td>5.97mm</td>
<td>3.89mm</td>
</tr>
</tbody>
</table>

Pre/ Post Test Model Comparison
(1550W/cm² condition)

- **Rayon Derived PICA**
  - Pre test
  - Post test

- **Lyocell Derived PICA**
  - Pre test
  - Post test
- Develop comprehensive material property database
  - Perform comprehensive material property testing (range of temperatures) for thermal and mechanical properties

- Perform comprehensive arcjet test campaign
  - Test at multiple conditions, including different material lots
  - Testing to include thermal response, instrumented stagnation and wedge shear coupons

- Develop PICA-D thermal response model utilizing arcjet test data and new material property database
Entry Systems and Technology Division

**CY18/19 work - Establish the Expanded Capability (Extensibility) of PICA-D**

- Demonstrate Manufacturing and Scale-Up of a Single Piece Heatshield at > 1.2m Diameter
  - Perform comprehensive characterization and evaluation of single piece Fiberform casting
  - Characterize fiber alignment, mechanical properties and non-destructive evaluation (NDE)

- Establish Expanded Design Space of PICA-D
  - Perform arcjet testing at heat flux / pressure conditions beyond which PICA has previously been tested and / or flown (> 2000 W/cm², > 0.5 atm, TBD shear)

- Increased single piece heatshield size - currently return speed limited to 12.9 km/s vs future potential of 13.5 – 14.5 km/s for entry bodies of diameter 1.5 X that of Stardust
# PICA-D FY18/19 Schedule

## Entry Systems and Technology Division

<table>
<thead>
<tr>
<th></th>
<th>CY18</th>
<th>CY19</th>
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<tbody>
<tr>
<td></td>
<td>Q1</td>
<td>Q2</td>
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<tr>
<td><strong>Drop-In Replacement for Heritage PICA (Task 1)</strong></td>
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<td>Lyocel Procurement (Tasks 1 &amp; 2)</td>
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<td>Fiber form Manufacturing</td>
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<td>PICA-D Infusion</td>
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<td>Mission Design Studies</td>
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<td>Material Property Testing Complete</td>
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<td>Arcjet CFD</td>
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<tr>
<td>Arcjet Model Build Complete</td>
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<tr>
<td><strong>PICA Extensibility (Task 2)</strong></td>
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<td>Fiber form Manufacturing for Scaled-up Single Piece</td>
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<td>Single Piece MDU Vessle Run</td>
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<tr>
<td>NDE of MDU</td>
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<tr>
<td>Property Testing of Scaled-up PICA-D Casting</td>
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<tr>
<td>Arcjet CFD</td>
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<tr>
<td>Arcjet Model Build Complete</td>
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<tr>
<td><strong>Final Report</strong></td>
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- **AHF & IHF Arcjet Testing**
- **PICA-D Thermal Response Model**
- **Mission Design Studies**
- **Final Report**
• NASA ARC / FMI is working with the Planetary Science Division of the Science Mission Directorate to address PICA rayon sustainability concerns
• In FY16/17, Lyocell Based PICA (PICA-D) was manufactured and limited testing performed show it to be a good candidate replacement for heritage rayon
• Establishing PICA-D as a “drop in replacement” will allow missions to design with PICA-D without any competitive disadvantage over other competing proposals.
• Establishing the extended capability of PICA-D will allow Sample Return Missions with higher entry speeds not considered before.
Acknowledgement

- PICA sustainability activities are funded by NASA’s Planetary Science Division of the Science Mission Directorate.

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