Sustaining Phenolic Impregnated Carbon Ablator (PICA) for Future NASA Missions Including Discovery and New Frontiers

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**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**-
  - Under the Orion program PICA was shown to be capable for both ISS and lunar return missions but was not selected as the baseline TPS
  - PICA was transitioned to Mars Science Lab (MSL) post CDR in a tiled configuration when the mission environments went beyond the capabilities of SLA561V
  - OSIRIS-REx sample return capsule as a single piece
  - Mars 2020 – Utilizing last of the “heritage” Sniace rayon based PICA

- Stardust forebody TPS. (≈0.8m diameter)
- MSL Heatshield (4.5m diameter)
- OSIRIS-REx forebody TPS. (≈0.8m diameter)
- Bennu taken by the OSIRIS-REx spacecraft from a distance of around 50 miles (80 km).
Future Needs for PICA-D*

- Mars Sample Return (MSR) Campaign
  - Sample Retrieval Lander (SRL):
    - Heatshield
  - Earth Entry Vehicle (EEV):
    - Backshell
    - Option for heatshield
- Dragonfly: Heatshield
- Future Discovery and New Frontiers missions:
  - Backshell and Heatshield

*PICA-D = Domestically (US) manufactured PICA utilizing Lyocell
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
- Rayon precursor for PICA has become obsolete twice since the material was developed and used on Stardust
- Manufacturing of Rayon is not environmentally friendly (no longer produced in US)
- Lyocell has been identified as an alternative to the rayon based precursor
- Lyocell production is much more environmentally friendly
- Lenzing – sister factories in US, Austria and UK able to provide the same Lyocell precursor – multiple supply routes alleviate future sustainability concern

<table>
<thead>
<tr>
<th>Mission/Project</th>
<th>Precursor type</th>
<th>Rayon Sustainability</th>
<th>Changes/Updates to PICA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stardust - Near Net Shape (NNS)</td>
<td>Liberty rayon</td>
<td>US source – production ceased in the 90s</td>
<td>Developing process to fabricate single piece Near Net Shape (NNS) cast part within the density specification required</td>
</tr>
<tr>
<td>Orion - billets</td>
<td>Multiple sources – settled on Sniace</td>
<td>Multiple international sources evaluated</td>
<td>Optimized densification process for billets, tested the bounds of the density specification and the influence on performance/properties</td>
</tr>
<tr>
<td>MSL - billets</td>
<td>Sniace rayon</td>
<td>international source – production ceased in ~ 2017</td>
<td>Leveraged Orion data to allow adoption on MSL</td>
</tr>
<tr>
<td>OSIRIS Rex - NNS</td>
<td>Sniace rayon</td>
<td>international source – production ceased in ~ 2017</td>
<td>Cast FiberForm preform density spec modified compared to Stardust. Phenolic level adjusted based on lessons learned from Orion/MSL</td>
</tr>
<tr>
<td>M2020 - billets</td>
<td>Sniace rayon</td>
<td>international source – production ceased in ~ 2017</td>
<td>Leveraged MSL</td>
</tr>
<tr>
<td>PICA-D - billets</td>
<td>Lyocell</td>
<td>Domestic/international sister plants. Greener processing</td>
<td>Orion/MSL density specification range</td>
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Chopped, graphitized rayon/Lyocell-based carbon fiber slurry-cast into either block (billet) or single piece heatshield preforms.

Single piece cast heatshields have fiber oriented to optimize (minimize) 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 with limited testing indicated** PICA-D had good potential as a replacement for heritage PICA
  - Material properties and aerothermal performance in family with “heritage” PICA
- **FY18/FY19** – further efforts to characterize and extend the capability of PICA-D and establish Lyocell PICA as a replacement for heritage PICA
  - Establishing PICA-D as a replacement will allow missions to utilize PICA-D without having to address further sustainability risks.
  - Establishing extended capability of PICA-D will allow Sample Return Missions with higher entry speed and larger size that were not considered before.
    - Extended aerothermal operational capability
    - Larger single piece heatshield manufacturing
PICA-D Arc Jet Testing

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 0.3 atm)</th>
<th>Average centerline recession (220W/cm² and 0.08 atm)</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>

Run condition very relevant for proposers considering PICA as a forebody or backshell material

- Previous testing of PICA with RTV seams was only done in air under MSL and Orion programs
- In support of Dragonfly Phase A study, PICA-D built 2 wedge shear models with RTV seams for testing in a nitrogen environment

For a Given Test Condition (Same Run Time) Initial Results Indicate that Recession and In-depth Temperature Between a Lyocell-Derived PICA and a Heritage Rayon-Derived PICA are Comparable, in both Oxygen and Nitrogen.
Lyocell Fiberform/PICA Billet and Near Net Shape Cast Processing

- 9 Fiberform billets manufactured in FY17 to optimize process (Lyocell)
- Additional billets fabricated in FY18 (property and arc jet testing)
- Fabricated 3 net-shaped Fiberform heatshield blanks (OSIRIS REx scale) in FY17
- Fabricated 4 net-shaped ~1.5m single piece FiberForm castings (FY18/19)
  - Converted one into 1.4 m PICA heatshield: characterization underway
  - Limited Non Destructive Evaluation (NDE) on the near net shape Fiberform unit to evaluate fiber alignment
- Significant number of lessons learned captured/implemented and substantial risk reduction achieved
Test Campaign to Establish/Extend Capabilities

- **Arc jet campaign 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
  - Establishing the extended capability of PICA-D will allow Sample Return Missions with higher entry speed that were not considered before
Summary

• PICA has become a workhorse TPS for NASA and sustainment is essential
• NASA ARC / FMI are working together to address PICA rayon sustainability concerns
• Lyocell Based PICA (PICA-D) was manufactured and limited testing shows it to be a viable replacement for heritage rayon
• Scaled-up of single piece heatshield manufacturing also demonstrated
• Future NASA missions need PICA (SRL, MSR EEV and Dragonfly) and PICA sustainability effort will have a payoff for these missions
• Establishing the extended capability of PICA-D will allow Sample Return Missions with higher entry speeds and larger payload not considered before
Backup
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, Austria and UK able to provide the same Lyocell precursor – multiple 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
Test Campaign to Establish/Extend Capabilities

Entry Systems and Technology Division

1. Drop-in replacement testing on 4in and 2in diameter stagnation models
   - Objective: provide experimental evidence that PICA-D could be used with high confidence as a TPS material on variety of missions
   - Testing from ~ 200 W/cm² up to ~ 1500 W/cm² (cold wall) heat flux and 1.4 atm pressure
   - AHF and IHF 6in nozzle tests
   - Compare recession and in-depth temperature data with FIAT predictions
   - Some, but limited, comparison to heritage (MSL) PICA is also planned

2. Exploring PICA-D performance limits through testing at extreme environments
   - Objective: expanding PICA limits and thermal performance modeling capability
   - TBD condition, possibly ~ 1000 W/cm², 0.8 atm pressure, 1400 Pa shear, wedge test model
   - Testing at AEDC H2S facility

3. Exploring PICA-D performance limits through new test article design
   - Objective: expanding PICA limits and thermal performance modeling capability
   - Mini-SPRITE test model: ~2200 W/cm² (cold wall) stagnation heating, 500 Pa shear on the flank
   - IHF 8in nozzle test (limited number of coupons)

- **Arc jet campaign objectives**
  - Compare the thermal response and recession behavior of Lyocell derived PICA to rayon derived PICA
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