Sustaining PICA TPS for Future NASA Robotic Science Missions

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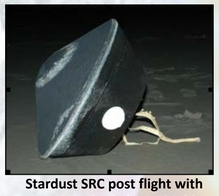
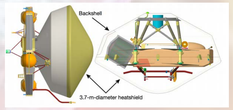
1. Background – PICA and PICA Sustainability

State of the Art Low Density Carbon Phenolic Ablators

- Phenolic Impregnated Carbon Ablator (PICA) is a low density (~ 0.27g/cm^3) ablator first used as the forebody heatshield for the Stardust sample return capsule (single piece heatshield)
- Since Stardust
  - PICA was used on the Mars Science Lab (MSL) in a tiled configuration
  - OSIRIS-REx sample return capsule (single piece)
  - Slated for Mars 2020 (tiled configuration)
- **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**



Stardust SRC post flight with PICA forebody heat shield (0.8m max. diameter)



Dragonfly forebody TPS (~3.7 m diameter) Currently NF – Phase A

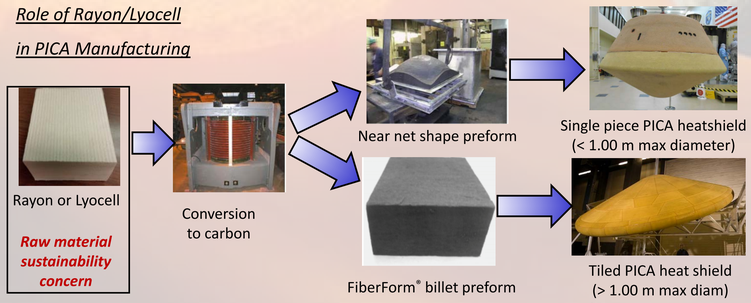
- In 2016 NASA ARC learned that the heritage rayon utilized in PICA was stopping production, leading to a flight-qualified PICA sustainability challenge
- In FY16/17, NASA ARC was funded by SMD/PSD to address PICA rayon sustainability
- Lyocell Based PICA (PICA-D) was manufactured and limited testing performed showing it to be a good candidate as a potential replacement for heritage rayon

2. Establishment of PICA-D as a Replacement for Heritage PICA

- In FY17, SMD-PSD funded ARC to manufacture and perform limited property and aerothermal characterization of Lyocell-based PICA
  - FY17 task successfully completed limited testing that indicated the viability of PICA-D as a potential replacement for heritage PICA

PICA Processing Steps

Role of Rayon/Lyocell in PICA Manufacturing



Lyocell is a sustainable domestic source of a "rayon alternative" fiber that can be used in the manufacture of carbon FiberForm®, the precursor to PICA.

Material Property Characterization

- In FY17, 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 100F and 350F 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

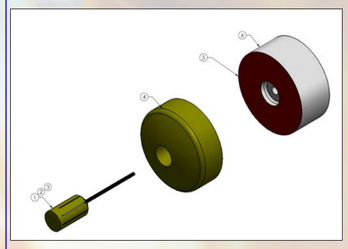
	Density (g/cc)	Average Failure Stress (psi)
Average Lyocell PICA IP properties	0.28	246 *160 - 255 for rayon PICA*
Average Lyocell PICA TTT properties	0.28	44 *43 to 54 for rayon PICA*

Thermal Property Comparison

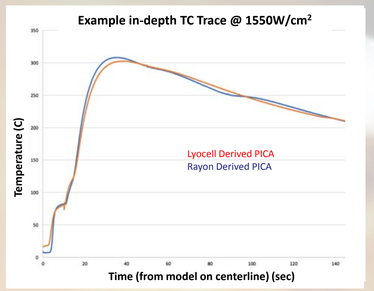
	Thermal Conductivity (BTU-in/hr-ft^2-^{o}F) at 100°F	at 350°F
Average Lyocell PICA TTT properties	0.94	1.32
Rayon PICA TTT properties	1.0 – 1.5	1.5 – 2.1

3. Arc Jet Characterization

- 3 arcjet conditions were tested in FY17
  - NF proposers provided guidance on test conditions
  - All conditions will be repeated in FY18/19 to demonstrate performance repeatability

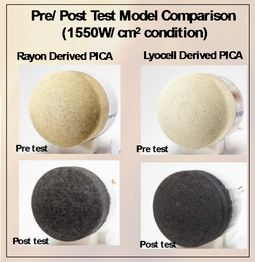


Coupon Geometry
- 4" iso-q coupons
- Each coupon instrumented with a plug containing 5 in-depth thermocouples consisting of 2 type-R and 3 type-K



Recession Comparison

Material	Average centerline recession (1550W/cm^2 and 1.3 atm)	Average centerline recession (400W/cm^2 and 0.3atm)	Average centerline recession (220W/cm^2 and 0.08atm)
Lyocell Derived PICA	4.0 mm	6.0 mm	3.8 mm
Rayon Derived PICA	4.2 mm	6.0 mm	3.9 mm

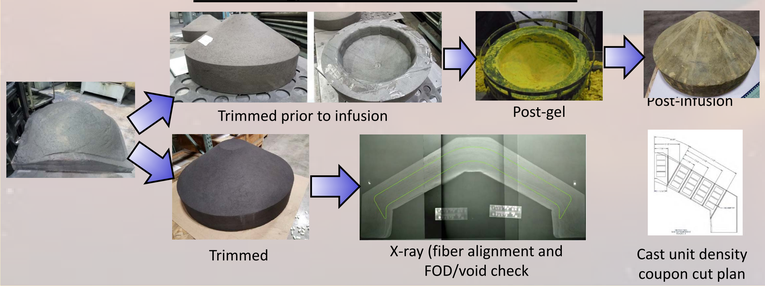


For a given test condition (same run time) initial results indicate that recession and in-depth temperature between a Lyocell derived PICA and a heritage rayon-derived PICA are comparable

3. Establishment of PICA-D Expanded Capability

- 9 billets of FiberForm were manufactured in FY17 to optimize the process using Lyocell fibers
  - Billets spanned the spec density range and billet FiberForm target densities were achieved
- Development and fabrication of three 0.8-m net-shaped FiberForm heatshield blank (OSIRIS REx scale) were also completed 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) completed on the Lyocell near net shape FiberForm unit to evaluate fiber alignment and check for off-nominal features
- FY18/19 work will expand on the work performed in FY17 and demonstrate repeatability as well as increase single piece net cast dimensions to >1.2-m

Net Casting, Billet Fabrication and Infusion



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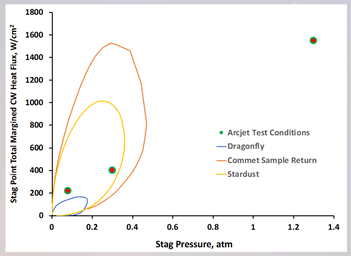
4. Exploration of Lyocell PICA (PICA-D) for Future Missions

In FY18/FY19, NASA Ames is leading an effort funded by SMD-PSD to characterize and extend the capability of PICA-D to 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 missions with PICA without the risks typical of a replacement.
- Establishing the extended capability of PICA-D will allow Sample Return Missions with higher entry speed that were not considered before.

Task 1: Establish PICA-D as a Drop-in replacement for Heritage PICA

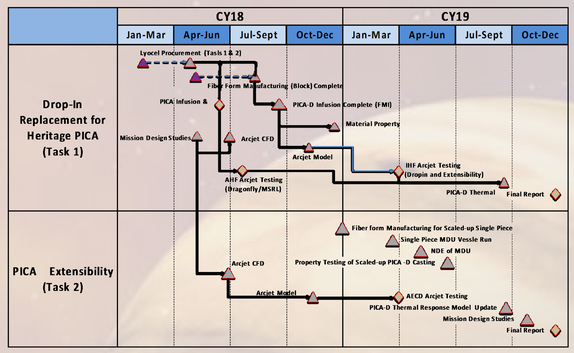
- Develop comprehensive material property database
  - Perform comprehensive material property testing (range of temperatures) for thermal and mechanical properties
- Perform comprehensive arcjet test campaign
  - Test at multiple conditions, including different material lots
  - Testing to include thermal response, instrumented stagnation and wedge shear coupons
- Develop PICA-D Thermal Response Model utilizing arcjet test data and new material property database



Task 2: Establish the Expanded Capability (Extensibility) of PICA-D

- Demonstrate Manufacturing and Scale-Up of a Single Piece Heatshield at a Scale of > 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 and heat flux / pressure conditions beyond which PICA has previously been tested and / or flown
- Publish all PICA-D Data for current and future missions

5. PICA-D Project Schedule



6. Summary

- 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.