Extensibility of PICA TPS for Future Sample Return Missions

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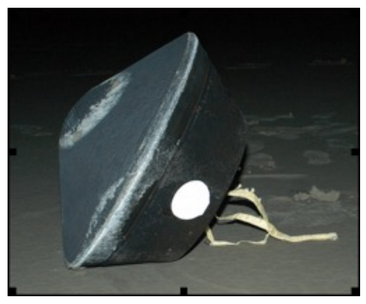
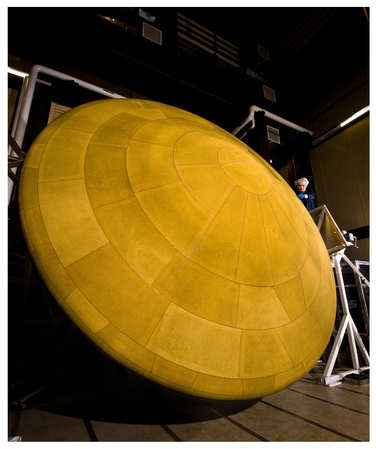
1. Background – PICA and PICA Sustainability/Extensibility

State of the Art Low Density Carbon Phenolic Ablators

- Phenolic Impregnated Carbon Ablator (PICA) was first used as the single piece forebody heatshield for the Stardust sample return capsule
  - Crew Exploration Vehicle (Orion) (2005 – 2008), evaluated the use of PICA in a tiled form for Earth return of Astronauts. At that time, a replacement for the rayon used in Stardust PICA was required and another foreign supplier product was qualified.
- Since Stardust PICA used on:
  - Mars Science Lab (MSL) and Mars 2020 in a tiled configuration
  - OSIRIS-REx sample return capsule as a single piece.
  - In 2016 the heritage rayon used in PICA was stopping production, leading to a flight-qualified PICA sustainability challenge
- In FY17, NASA Ames was funded by NASA's Space Mission Directorate / Planetary Science Division to address PICA rayon sustainability
- Lyocell Based PICA-D (PICA-Domestic) was manufactured, and limited testing performed showing it to be a good candidate as a potential replacement for heritage rayon
- Single piece near net shape PICA units have been manufactured to 1.4m diameter (compared to 0.8m stardust unit)



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



M2020 tiles PICA heatshield

2. 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

PICA Processing Steps

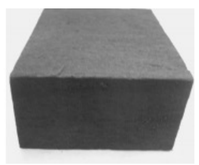
Role of Rayon/Lyocell in PICA Manufacturing

Rayon or Lyocell

Raw material sustainability concern

Conversion to carbon

Near net shape preform



FiberForm® billet preform

Single piece PICA heatshield (< 1.00 m max diameter)

Tiled PICA heat shield (> 1.00 m max diam)

Lyocell is a Sustainable, Eco-Friendly, Domestic Source of a "Rayon Alternative" Fiber that can be used to Manufacture Carbon FiberForm®, the Precursor to PICA

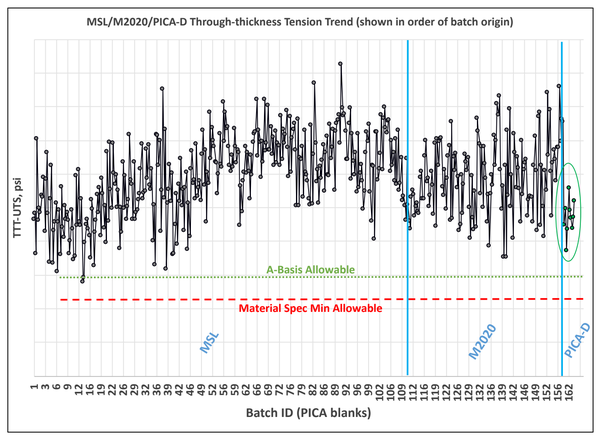
3. Characterize and extend the capability of PICA-D and establish Lyocell PICA as a replacement for heritage PICA

- NASA's Space Mission Directorate / Planetary Science Division funded NASA Ames to manufacture & perform limited property/aerothermal characterization of Lyocell-based PICA (PICA-D) in 2017/2018
  - Fiber Processing, billet fabrication, single piece heatshield preform fabrication, conversion to PICA (billets and single piece preform) PICA property testing and arc jet testing
- This early work with limited testing indicated PICA-D had the potential to be a replacement for heritage PICA

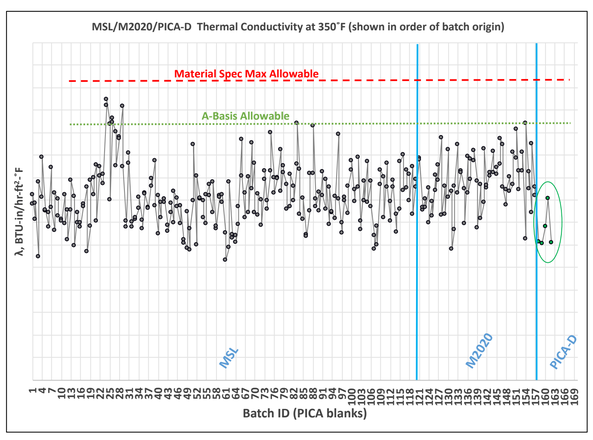
Establishing Fiberform billet Manufacturing and Material Property Characterization

- 3 billets of PICA-D were manufactured to support preliminary testing
- 7 additional billets were fabricated (property and aerothermal testing)
  - Initial sets of 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

Mechanical Property Comparison



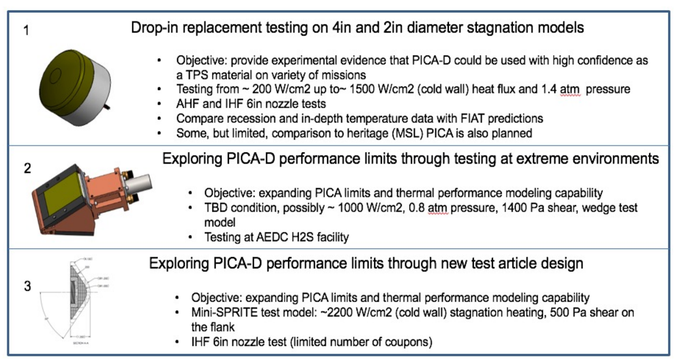
Thermal Property Comparison

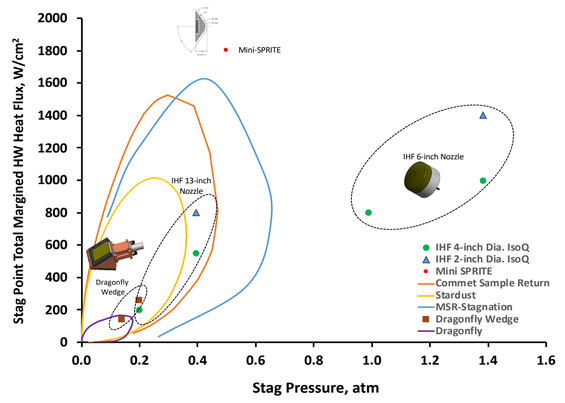


Thermal/Mechanical property data from PICA-D in family with previous production rayon PICA and data is well within Spec limits required for flight hardware

Approach to PICA-D Arc Jet Testing

Future mission proposers provided guidance on test conditions





3 Arcjet Conditions in Air

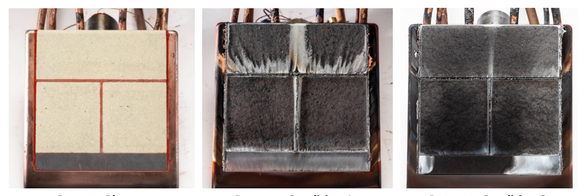
Rayon Derived PICA

Lyocell Derived PICA

Condition 1: Heat Flux ~ 220 W/cm², Pressure ~ 0.08 atm
Condition 2: Heat Flux ~ 400 W/cm², Pressure ~ 0.3 atm
Condition 2: Heat Flux ~ 1550 W/cm², Pressure ~ 1.3 atm

2 Arcjet Conditions in Nitrogen

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



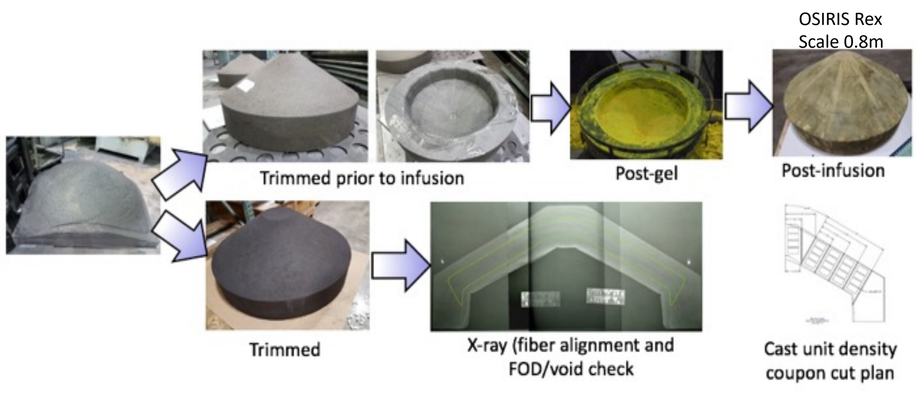
Pre-test Photo | **Post-test Condition 1** | **Post-test Condition 2**

Condition 1: Heat Flux = 140 W/cm², Pressure= 14 kPa
Condition 2: Heat Flux = 260 W/cm², Pressure= 19 kPa

For Given Test Condition (Same Run Time) Results Indicate that Recession and In-depth Temperature Between a Lyocell-Derived PICA and a Heritage Rayon-Derived PICA are Comparable, in both Air and Nitrogen.

4. Single Piece PICA-D Heatshield Scale Up

- Fabricated 3 near-net-shaped Fiberform™ heatshield blanks (OSIRIS REx scale of 0.8m diameter) to establish process and then fabricated 4 near-net-shaped ~ 1.5m single piece FiberForm™ castings to extend single piece manufacturability
- Non-Destructive Evaluation (NDE) of the near net shape Fiberform™ unit s completed to evaluate fiber alignment and check for any anomalies
- Converted one Fiberform™ unit into 1.4 m PICA heatshield



1.4m heatshield

Extended single piece heatshield manufacturing demonstrated

Significant number of lessons learned captured/implemented and substantial risk reduction achieved with 1.4m single piece heatshield manufacturing demonstration

5. Summary

- PICA has become a mainstay TPS for NASA
- NASA ARC / FMI have worked together and addressed PICA-D sustainability concerns by finding a domestic replacement.
  - Lyocell Based PICA (PICA-D) was manufactured and testing show it to be a viable replacement for heritage rayon
  - Lyocell will be available for decades and therefore missions that need PICA will be able to design with PICA-D without having to address sustainability risks in the near term.
- Quick mission timelines and the competitive proposal process highlight the need to maintain "off the shelf" TPS –thus why the long-term sustainability of a PICA TPS option is needed.
- Establishing an extended capability of PICA-D will allow future Sample Return Missions with higher entry speed that were not considered before.
  - Extended operational capability
  - Increased single piece heatshield manufacturing

Exciting future NASA missions are baselining PICA-D and the NASA TPS sustainability and extensibility effort has already demonstrated payoff for these missions

- Mars Sample Return Sample Retrieval Lander (MSR SRL)
- Mars Sample Return Earth Entry Vehicle (MSR EEV)
- Dragonfly

Establishing the extended capability of PICA-D, including scale-up to 1.4m, will allow Sample Return Missions with higher entry speeds and larger future payload capability

Acknowledgements

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