Development of Lyocell based Phenolic Impregnated Carbon Ablator (PICA-D) for Future NASA Missions

PICA-D and Three Exciting NASA missions

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Presented at NSMMS and CRASTE, Henderson NV June 24-27 2019

Outline

- **Background**
  - Heritage PICA
  - PICA Sustainability Challenge
- **PICA-D and Three Exciting NASA missions**
- **Sustainability**
  - 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 Arc Jet Campaign
  - Establish PICA-D as a drop-in replacement for Heritage PICA
  - Establish the Expanded Capability (Extensibility) of PICA-D
- **Summary**
- **Acknowledgements**

Background – PICA

State of the Art Low Density Carbon Phenolic Ablators

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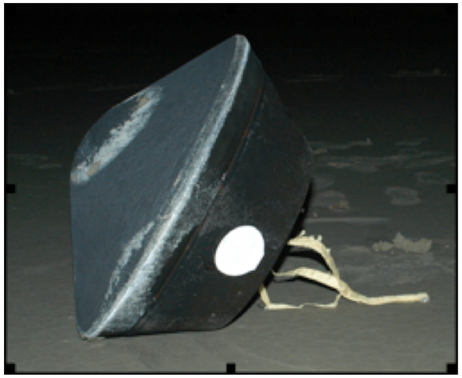
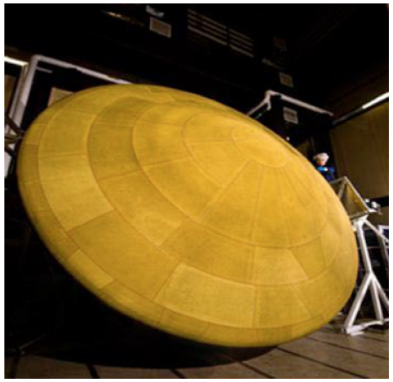
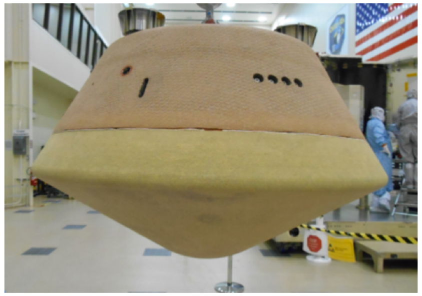
- **Phenolic Impregnated Carbon Ablator (PICA)**
  - first used as forebody single piece heatshield for Stardust
- **Low density coupled with efficient ablative capability at medium-high heat fluxes**
- **Since Stardust-**
  - Under the Orion program PICA was shown to be capable for both ISS and lunar 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
    - On Dec. 3, 2018, the OSIRIS-REx spacecraft arrived at its target, near-Earth asteroid Bennu



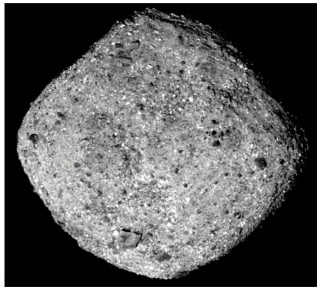
Stardust forebody TPS. (~0.8m diameter)



MSL Heat Shield (4.5m diameter)



OSIRIS-REx forebody TPS. (~0.8m diameter)



Bennu taken by the OSIRIS-REx spacecraft from a distance of ~ 50 miles

https://www.nasa.gov/osiris-rex

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

Mission/ Project	Precusror type	Rayon Sustainability	Changes /Updates to PICA
Stardust Near Net Shape (NNS)	Liberty rayon	US source – production ceased in the 90s	Developing process to fabricate NNS within the density specification required
Orion CEV ADP - billets	Multiple sources – settled on Sniace	Multiple international sources evaluated	Optimized densification process for billets, tested the bounds of the density specification and the influence on performance / properties
MSL- billets	Sniace rayon	international source – production ceased in ~ 2017	Leveraged ADP data to allow use on MSL
OSIRIS Rex NNS	Sniace rayon	international source – production ceased in ~ 2017	Spec tightened over Stardust for NNS casting range . Phenolic adjustments based on lessons learned from ADP/MSL
M2020 - billets	Sniace rayon – source depleted	international source – production ceased in ~ 2017	Leveraged MSL
PICA-D billets	Lyocell	Domestic/international sister plants. Greener processing	ADP/MSL specification range
PICA-D NNS	Lyocell	Domestic/international sister plants. Greener processing	Leveraged OSIRIS REx/MSL

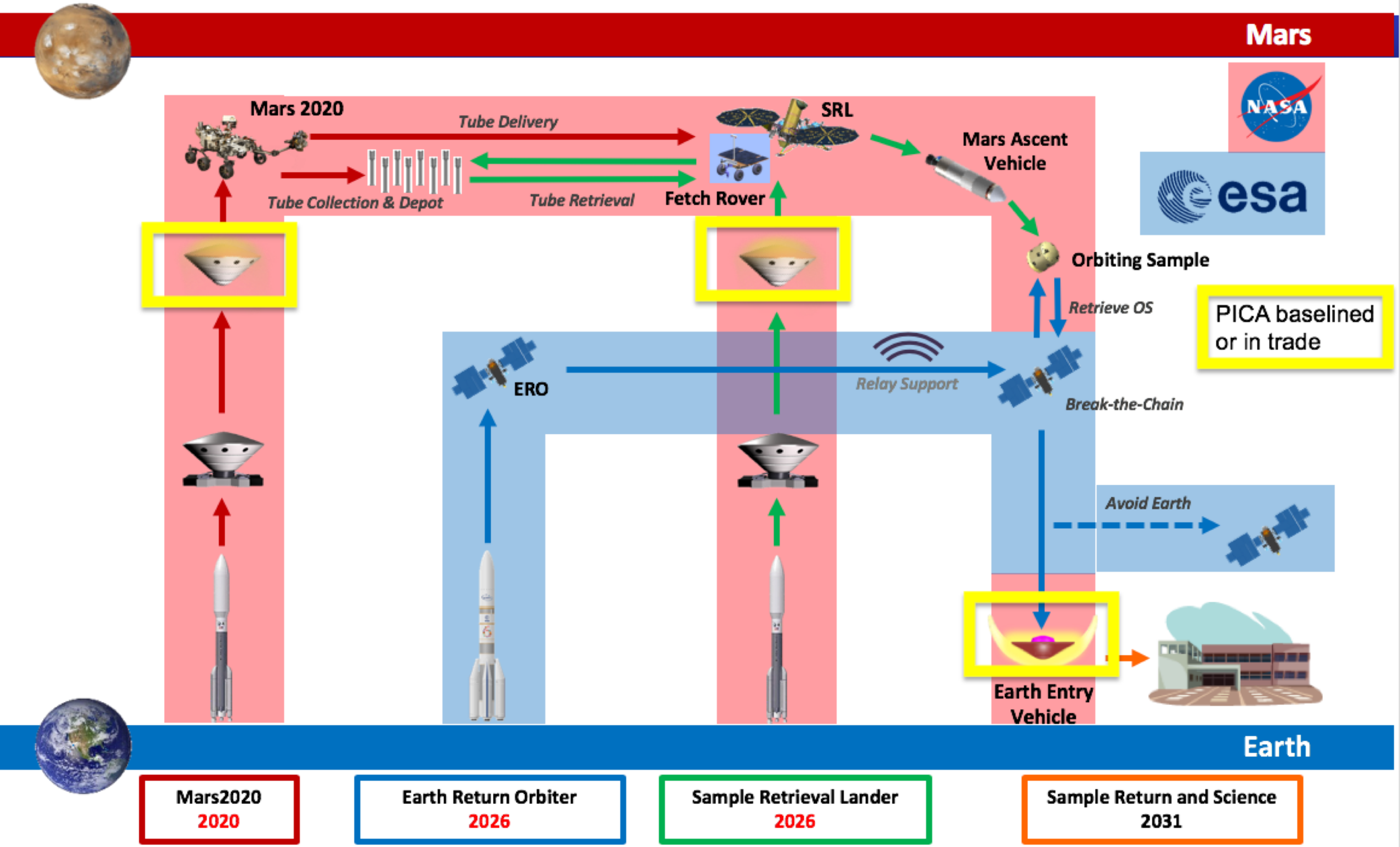
PICA-D = Domestically sourced lyocell derived PICA
PICA = Rayon derived PICA

PICA-D and Three Exciting NASA missions

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

Mission timelines highlight why a long-term sustainable PICA TPS option is needed

Mars Sample Return Campaign



Courtesy: Jet Propulsion Laboratory

Mars2020 and Sample Retrieval Lander (SRL)

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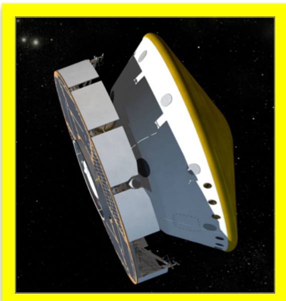
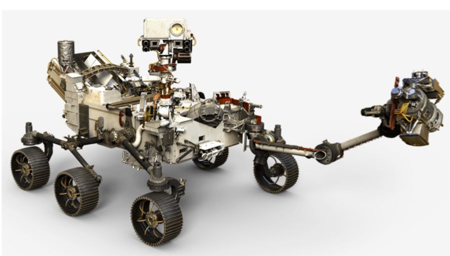
M2020 Mission

- 4.5m tiled configuration
- **Last sniace rayon mission**





Rover with science instruments will collect samples from the Martian surface and deposit tubes filled with samples at location for sample fetch rover to collect

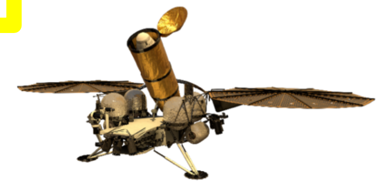
- **MSL "built to print" heatshield**

Courtesy: Jet Propulsion Laboratory

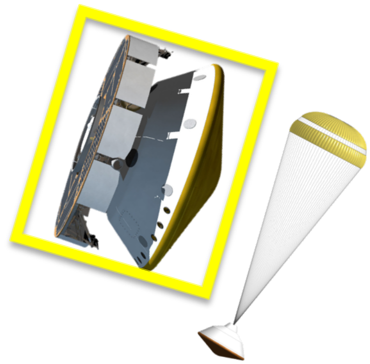
SRL Mission

- 5+m tiled configuration
- Lyocell derived PICA

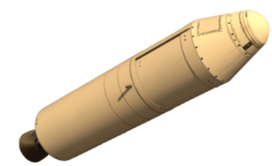
Platform



Cruise & EDL



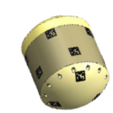
Mars Ascent Vehicle



Sample Fetch Rover

(JPL reference concept)

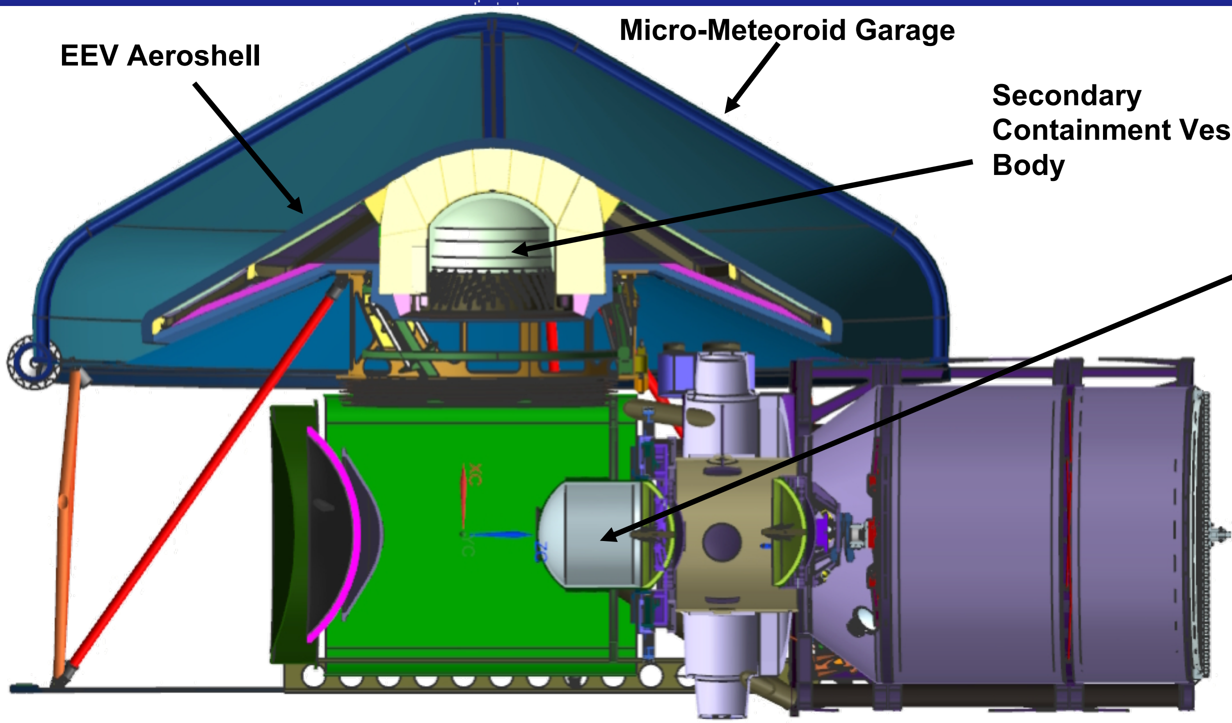
Orbiting Sample

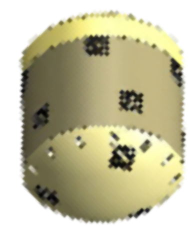


- **Vehicle has a different shape than Mars 2020**
- **Entry environment in family with Mars 2020/ MSL**

MSR Earth Entry Vehicle (EEV)

- ~ 1.4m single piece
- Lyocell derived PICA



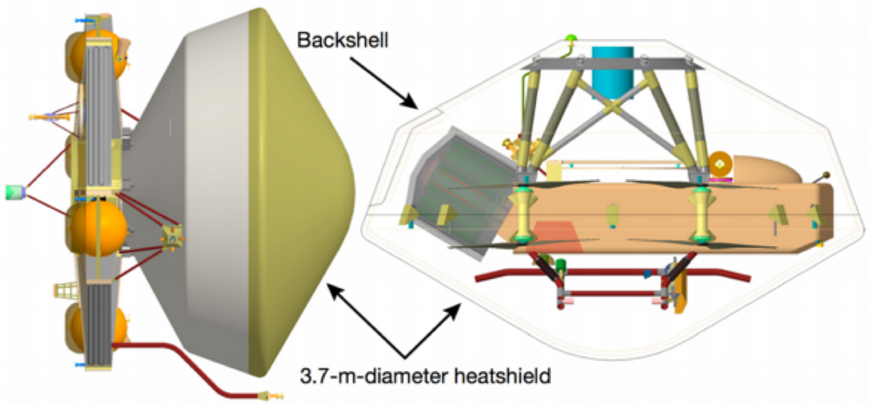


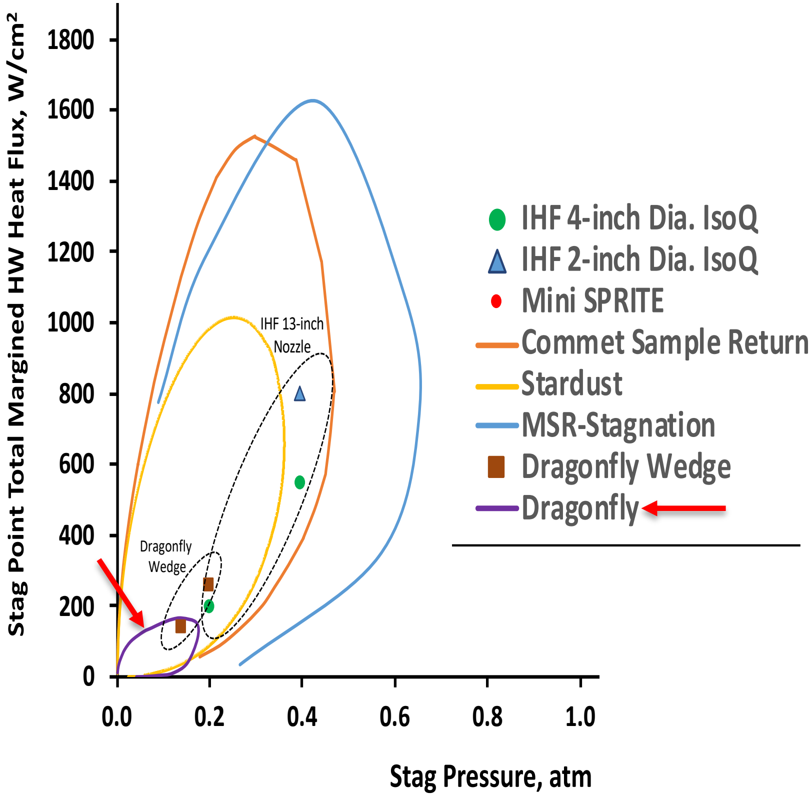
- Single piece PICA-D considered for MSR EEV foreboby
  - Requirements for MSR EEV – up to 1.4m which is greater than Stardust (0.8m)
  - Leveraging PICA-D for manufacturing scale-up demonstration
- Tiled backshell PICA baselined
- Expected conditions (~1600 W/cm^2, ~80kPa, ~1000 Pa shear)
- PICA performance beyond thermal needs to be assessed - potential MMOD impact and ground impact

Courtesy: Jet Propulsion Laboratory

Dragonfly

- Mobile robotic rotorcraft lander to Titan,
- Study prebiotic chemistry and extraterrestrial habitability at various locations
- Perform vertical-takeoff and landings





- Dragonfly forebody TPS (~4 m diameter)
- Currently NF – Phase A
- Benign environment for PICA
- Leverage MSL integration approach

- 4+m tiled configuration
- Lyocell derived PICA

Courtesy D. Adams, Applied Physical Laboratory

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

PICA Manufacturing Overview

Role of Rayon/Lyocell in PICA Manufacturing

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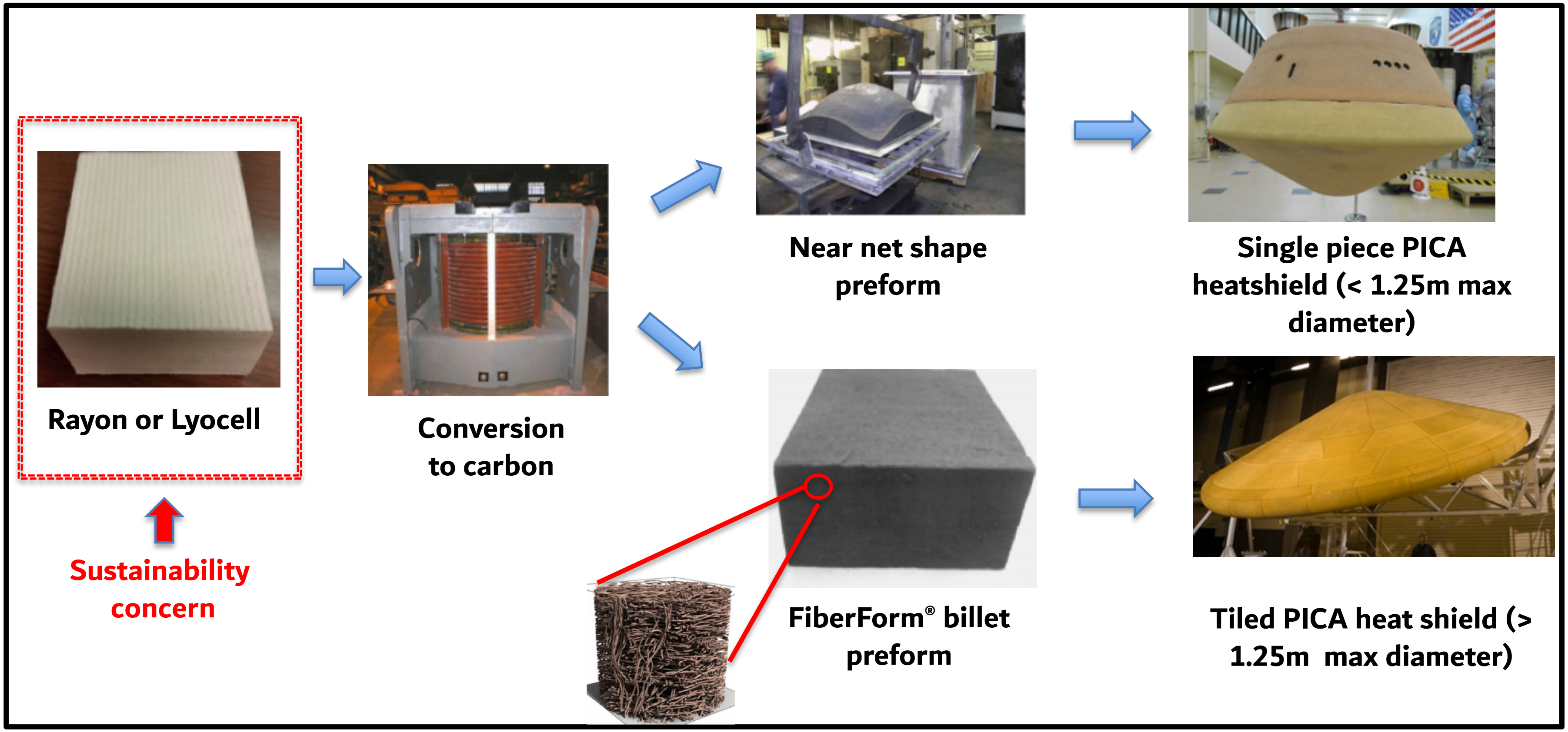

- Chopped, graphitized rayon or Lyocell - based carbon fiber slurry-cast into either block (billet) or single piece heatshield preforms
- Single piece cast heatshields have fiber oriented to optimize through-thickness thermal conductivity
- Lightweight phenolic sol-gel matrix is infiltrated into preform

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 with limited testing indicated PICA-D had the potential to be a replacement for 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 “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

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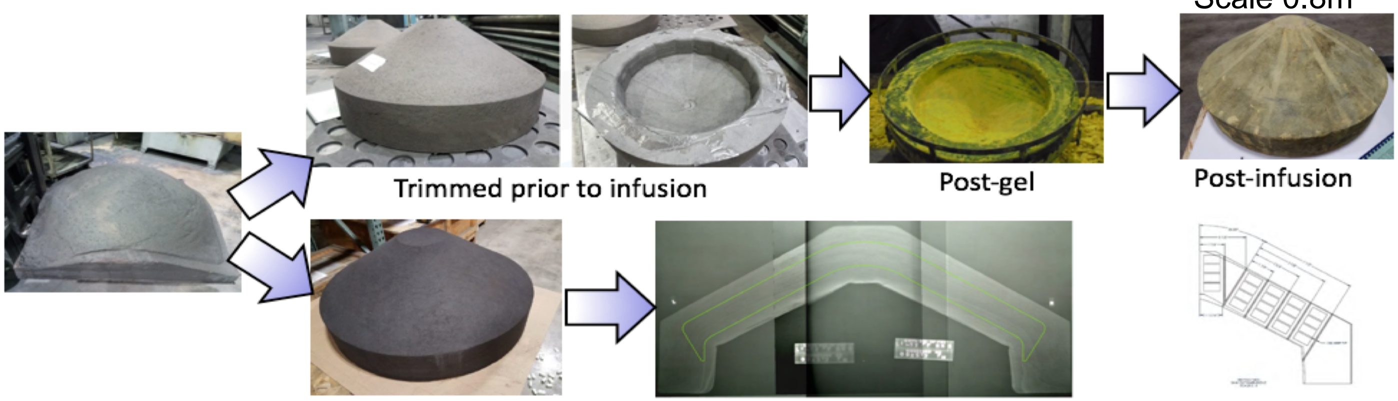
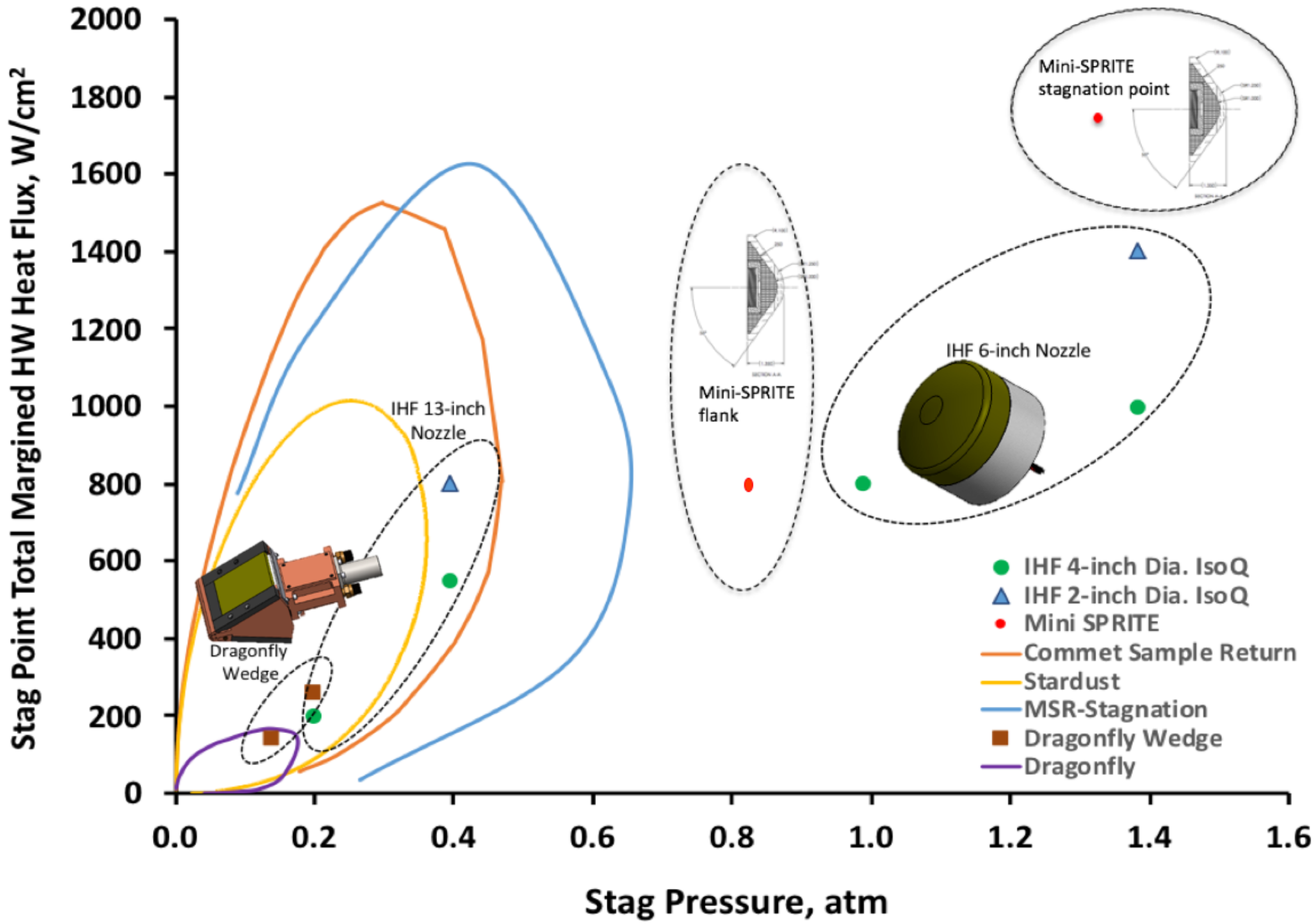
- 9 Fiberform billets manufactured in FY17 to optimize process (Lyocell)
- Additional billets fabricated in FY18 (property and arc jet testing)
- Fabricated 3 net-shaped Fiberform heatshield blanks (OSIRIS REx scale) in FY17
- Fabricated 4 net-shaped ~ 1.5m single piece FiberForm castings (FY18/19)
  - 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



1.4m heatshield

Extended single piece heatshield manufacturing demonstrated

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 speeds not considered before

PICA-D Arc Jet Testing Quick Look

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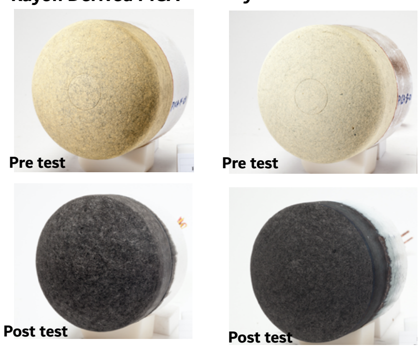
Runs in Air 2017

Pre/Post Test Model Comparison ($1550 W/cm^2$ condition)

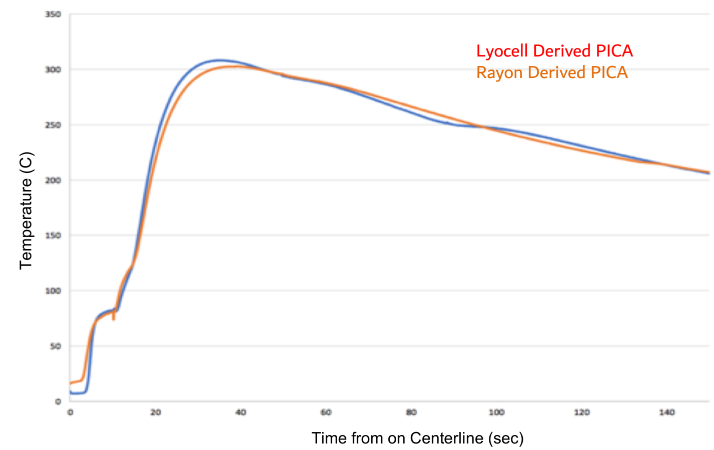
Rayon Derived PICA | **Lycocell Derived PICA**



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 PICA	4.0mm	6.02mm	3.79mm
Rayon PICA	4.2mm	5.97mm	3.89mm

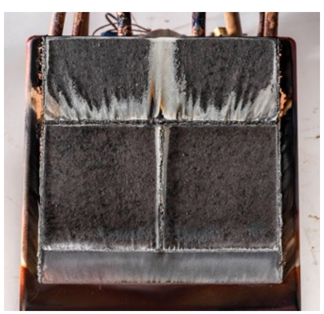
Example in-depth TC Trace @ $1550W/cm^2$



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

Runs in N_2 2018/19

Heat Flux = $140 W/cm^2$,
Pressure= 14 kPa



Heat Flux = $260 W/cm^2$,
Pressure= 19 kPa

- 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.

Summary

- PICA has become a workhorse TPS for NASA and sustainment is essential
  - Looking for a viable precursor that will be available for decades
- NASA ARC / FMI have been and will continue to work together and address any PICA rayon sustainability concerns
- Lyocell Based PICA (PICA-D) was manufactured and limited testing performed show it to be a viable replacement for heritage rayon, scaled-up single piece heatshield manufacturing also demonstrated
- Exciting future NASA missions need PICA (SRL, MSR EEV and Dragonfly) and NASA TPS 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.

Acknowledgement

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

- The authors would also like to acknowledge Y-K Chen, D. Ellerby, F. Milos, G. Gonzales, D. Prabhu, and K. Skokova and Franklin Taylor.