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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Outline

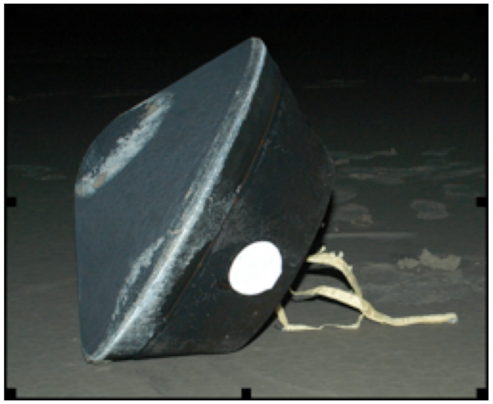
- **Background**
  - Heritage PICA
  - PICA Sustainability Challenge
- **Sustainability**
  - Lyocell: An alternative precursor to rayon
  - PICA Manufacturing
- **Development of PICA-D**
  - Establish PICA-D as a drop-in replacement for Heritage PICA
  - PICA-D Arc Jet Campaign
  - Lyocell Fiberform/PICA-D Billet and Near-Net-Shape Single-Piece Aeroshell Processing
- **PICA-D and Three Exciting NASA missions**
- **Summary**
- **Acknowledgements**

Background – PICA

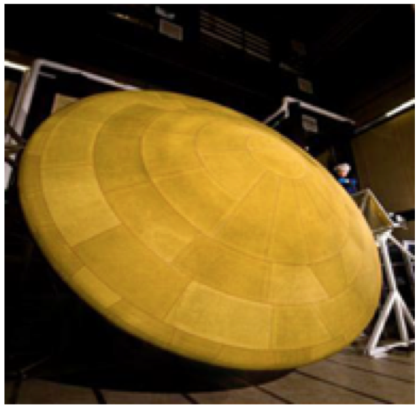
State of the Art Low Density Carbon Phenolic Ablators

Entry Systems and Technology Division

- **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

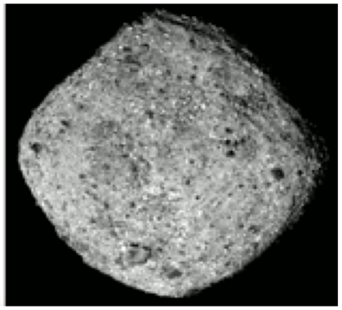


Stardust forebody TPS. (~0.8m diameter)



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	Precursor Type	Rayon Sustainability	Changes /Updates to PICA
Stardust Near Net Shape 0.8m	Liberty rayon	US source – production ceased in the 90s	Developing process to fabricate NNS within the project density specification required
Orion CEV ADP Billets	Multiple sources – settled on SINACE	Multiple international sources evaluated	Optimized densification process for billets, tested the bounds of the density specification and the influence on performance / properties
MSL Billets	SINACE rayon	International source – production ceased in ~ 2017	Leveraged ADP data to allow use on MSL
OSIRIS Rex Near Net Shape 0.8m	SINACE 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	SINACE rayon – source depleted	International source – production ceased in ~ 2017	Leveraged MSL
PICA-D Development Billets	Lyocell w/ Ti Dulling Agent	Domestic/international sister plants. Greener processing	MSL specification range – Eliminated use of "re-grind"
PICA-D Development Near Net Shape 0.8m	Lyocell w/ Ti Dulling Agent	Domestic/international sister plants. Greener processing	Leveraged OSIRIS REx/MSL – No re-grind
PICA-D Development Billets	Lyocell	Domestic/international sister plants. Greener processing	MSL/M2020 specification range – No re-grind
PICA-D Development Near Net Shape 1.5m	Lyocell	Domestic/international sister plants. Greener processing	Leveraged OSIRIS REx/MSL – No re-grind

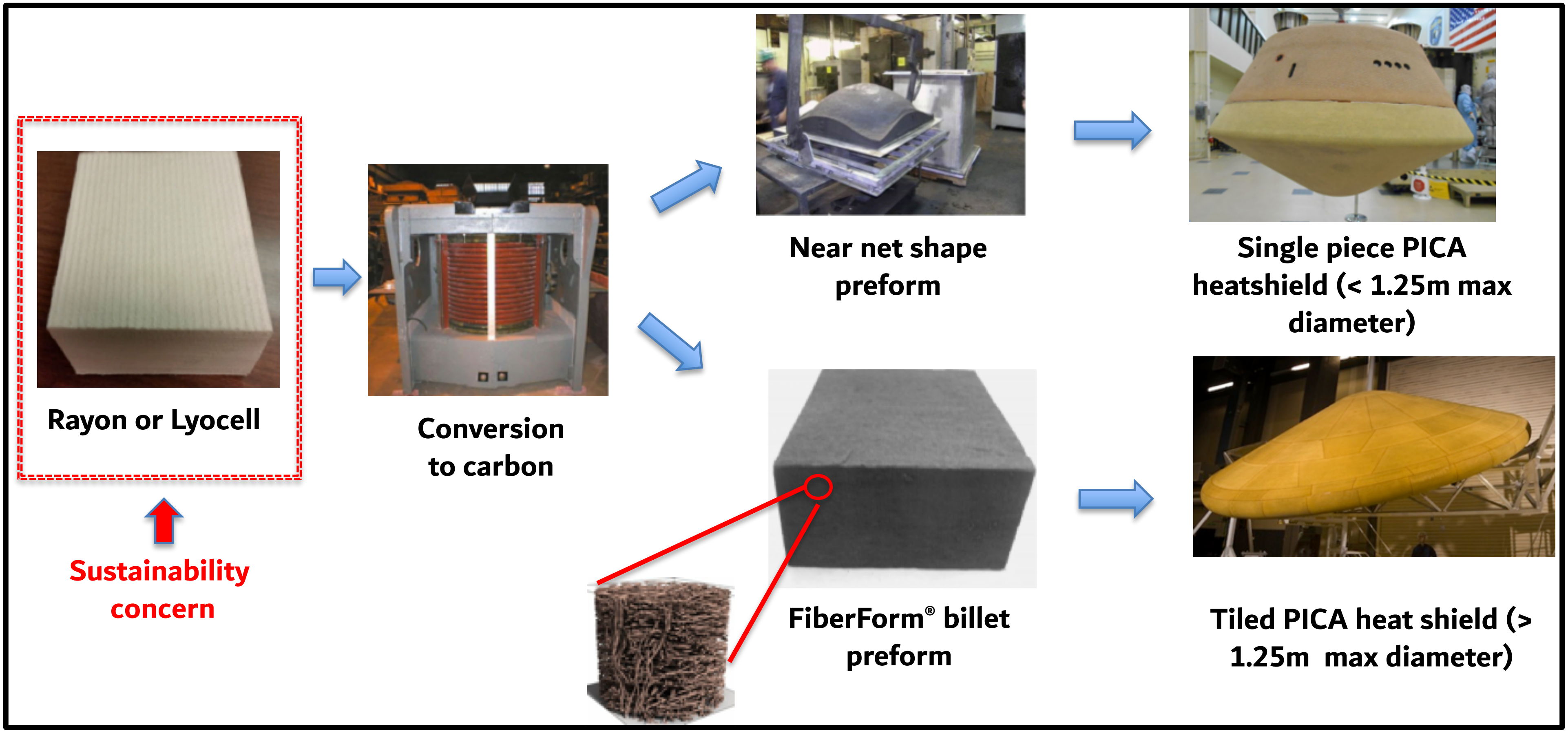
Lyocell – A Sustainable Precursor

- 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



- 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

PICA-D Property Testing

- Coupon level testing of PICA-D provides an initial material screening that will:
  - Allow for identifying differences with heritage PICA
- Structural testing objectives:
  - Determine moduli, strength, and thermal expansion over a range of temperatures.
  - Develop and deliver a preliminary material property database that can be used in future mission analyses
  - Identify any differences in material properties and allowables between PICA-D and heritage PICA
- Thermal properties test objectives:
  - Determine in-plane and through-the-thickness thermal conductivity over a range of temperatures
  - Identify any differences in thermal conductivity between PICA-D and heritage PICA

Test Type	Virgin Property Testing			Fiberform Property Testing
	-250°F	RT	350°F	RT
IP tension	3	10	3	4
TTT Tension	3	10	3	4
IP Compression	3	3	3	
TTT Compression	3	3	3	
IP Shear	3	3	3	4
Transverse Shear	3	10	3	4
IP CTE	2			2
TTT CTE	2			2

Structural Test: Matrix 1

Test Type	PICA-D Char		FiberForm	
	3300°F	4500°F	3300°F	4500°F
TTT Compression	3	3	3	3

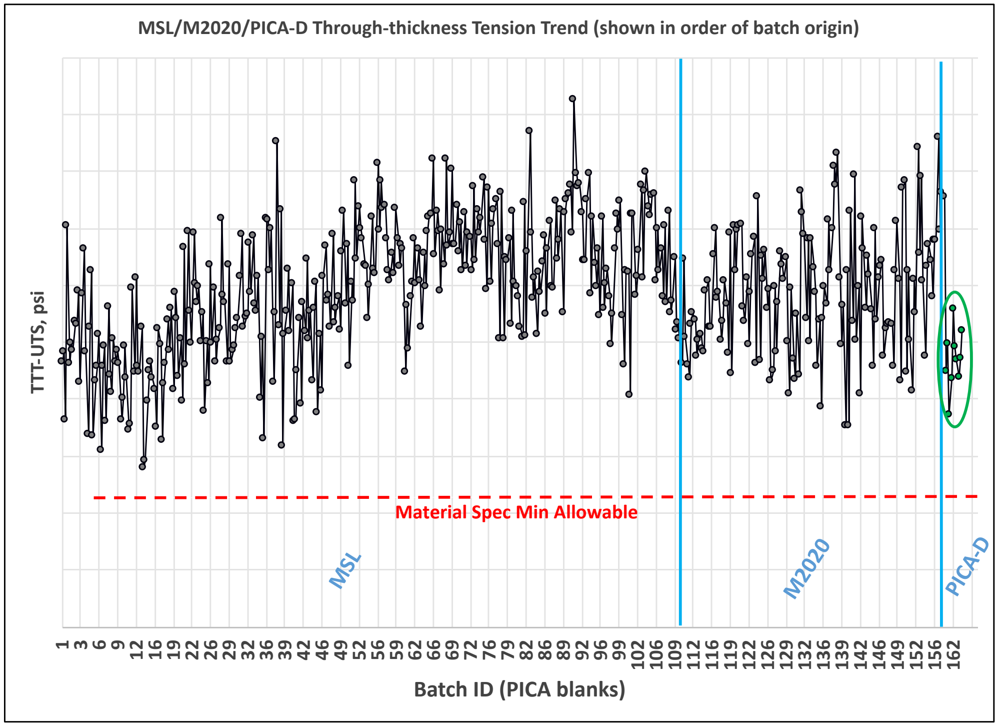
High-Temp Structural Test: Matrix 2

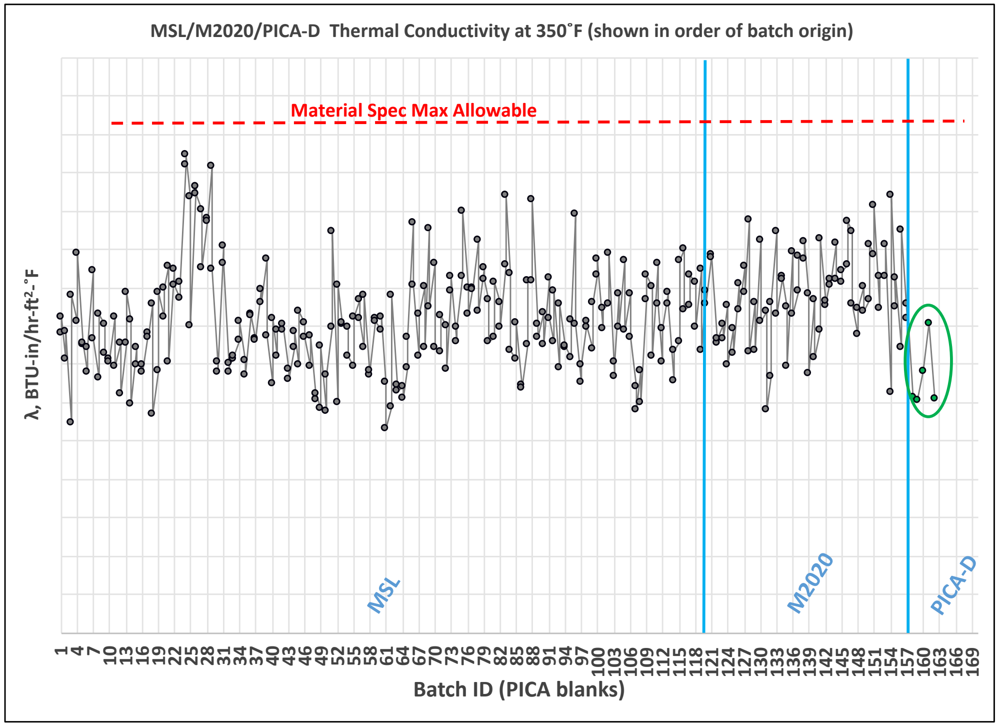
Test Type	Virgin Property Testing	
	100°F	350°F
TTT Conductivity	2	2
IP Conductivity	2	2

Thermal Test Matrix

PICA-D Property Testing

- PICA lot acceptance test (LAT) results: in-plane (IP) tension, through-thickness (TT) tension, and through thickness thermal conductivity at 100F and 350F
- The data was compared to Mars Science Laboratory (MSL) and Mars 2020 production LAT results





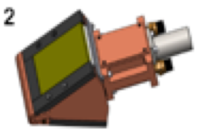
PICA-D LAT results are comparable to Heritage PICA and within the expected scatter indicating potential updates to Thermal and/or Structural performance models are not required

Test Campaign to Establish/Extend Capabilities

1 Drop-in replacement testing on 4in and 2in diameter stagnation models

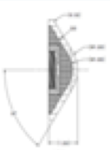
- Objective: provide experimental evidence that PICA-D could be used with high confidence as a TPS material on variety of missions
- Testing from ~ 200 W/cm2 up to~ 1500 W/cm2 (cold wall) heat flux and 1.4 atm pressure
- AHF and IHF 6in nozzle tests
- Compare recession and in-depth temperature data with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

2 Exploring PICA-D performance limits through testing at extreme environments

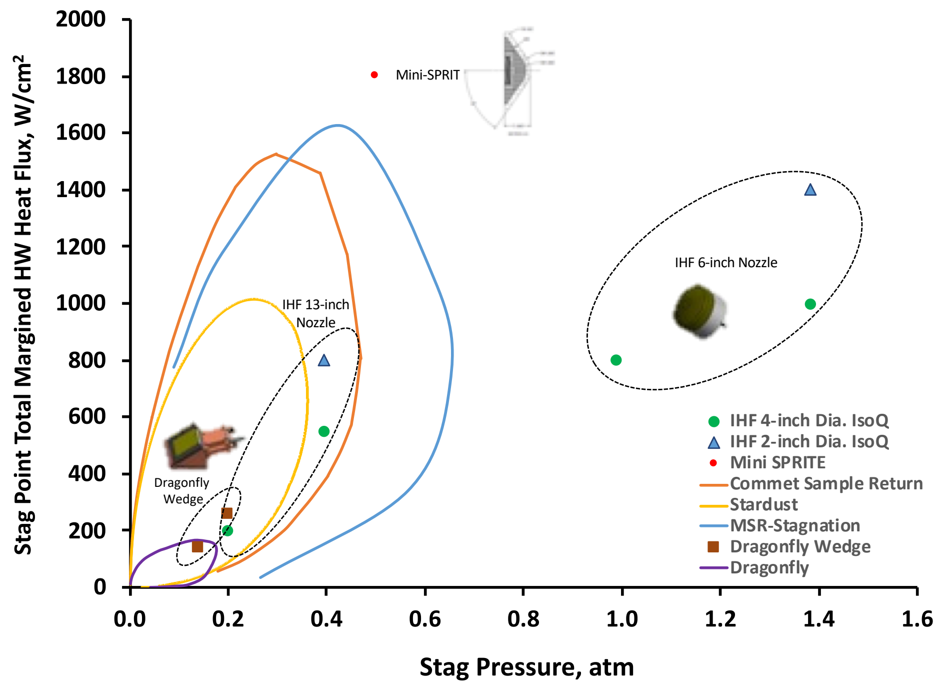


- Objective: expanding PICA limits and thermal performance modeling capability
- TBD condition, possibly ~ 1000 W/cm2, 0.8 atm pressure, 1400 Pa shear, wedge test model
- Testing at AEDC H2S facility

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 6in 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
  - 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

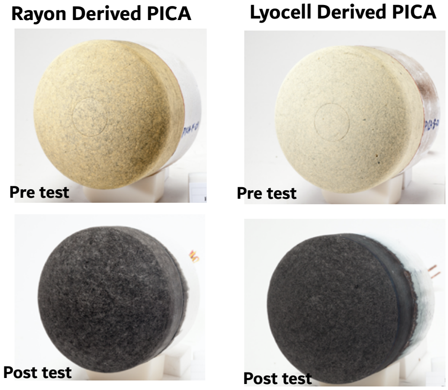
PICA-D Arc Jet Testing

Entry Systems and Technology Division

Runs in Air 2017

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

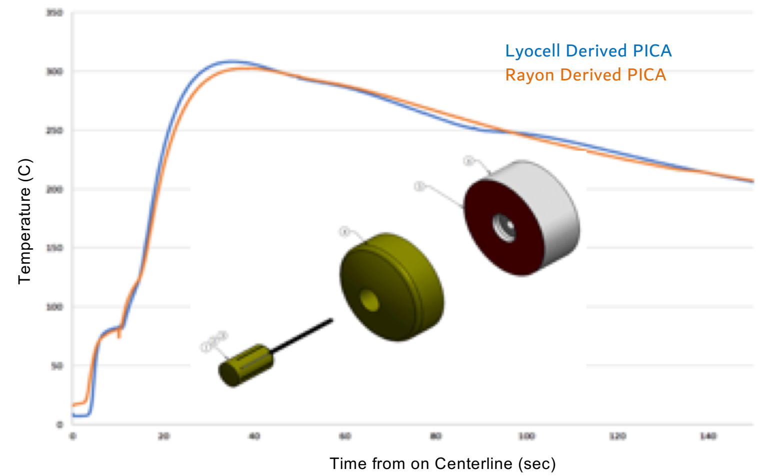
Rayon Derived PICA | **Lyocell Derived PICA**



Recession Comparison

Material	Average centerline recession (1550W/cm² and 1.3 atm)	Average centerline recession (400W/cm² and 0.3atm)	Average centerline recession (220W/cm² 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/cm²



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

Runs in N_2 2018/19

Heat Flux = 140 W/cm², Pressure= 14 kPa

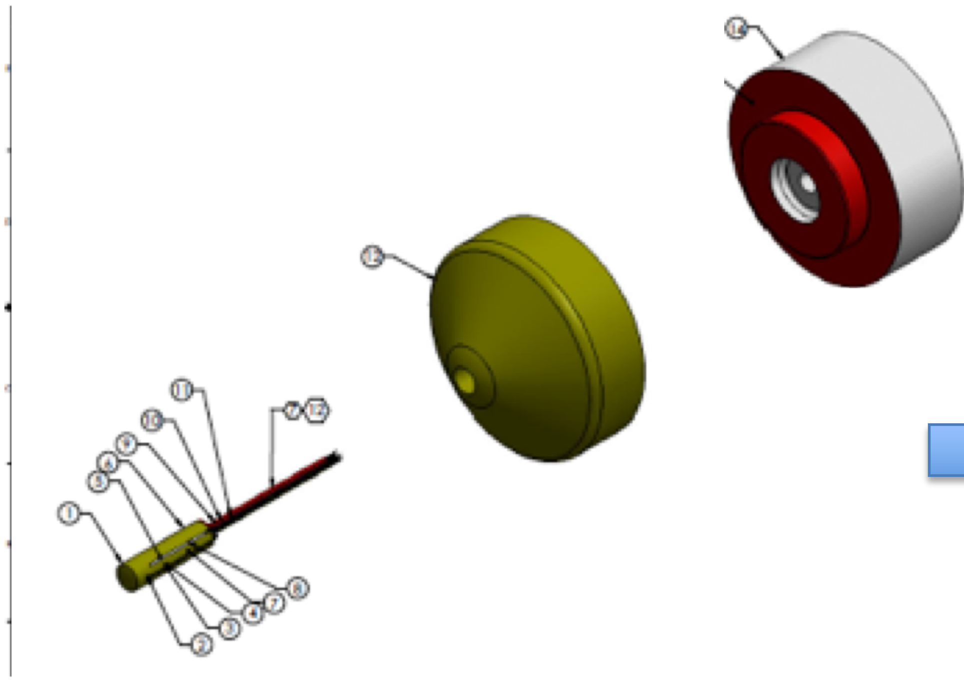
Heat Flux = 260 W/cm², Pressure= 19 kPa

- 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

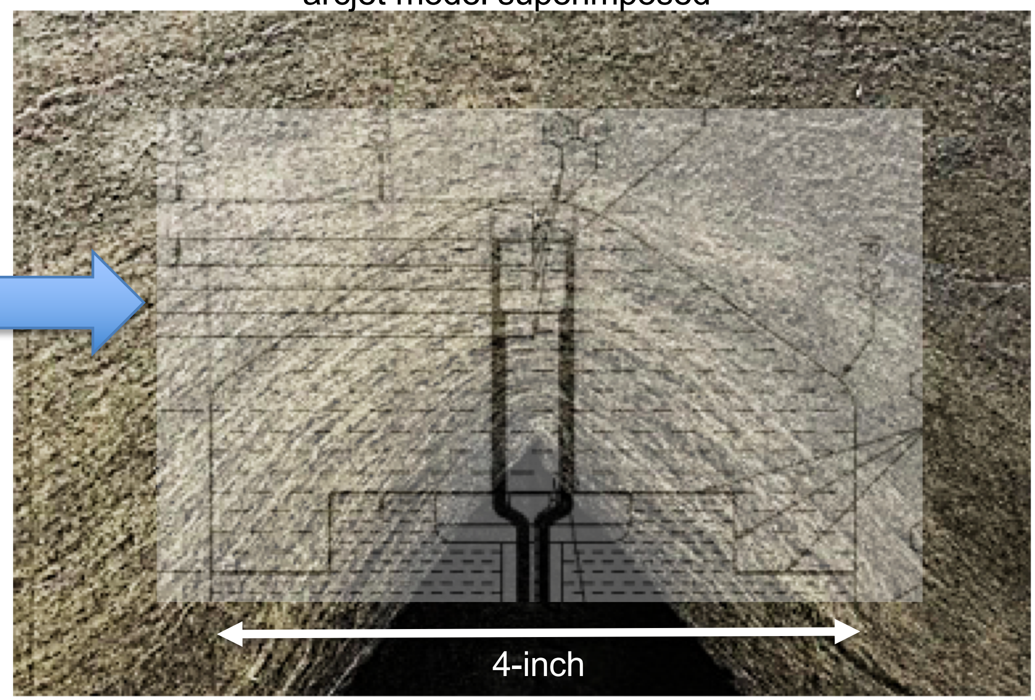
For a Given Test Condition (Same Run Time) Initial Results Indicate that Recession and In-depth Temperature Between a Lyocell-Derived PICA and a Heritage Rayon-Derived PICA are Comparable, in Both Oxygen and Nitrogen.

PICA-D Mini-SPRITE Arc Jet Testing

– 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
  - 4-inch diameter coupons

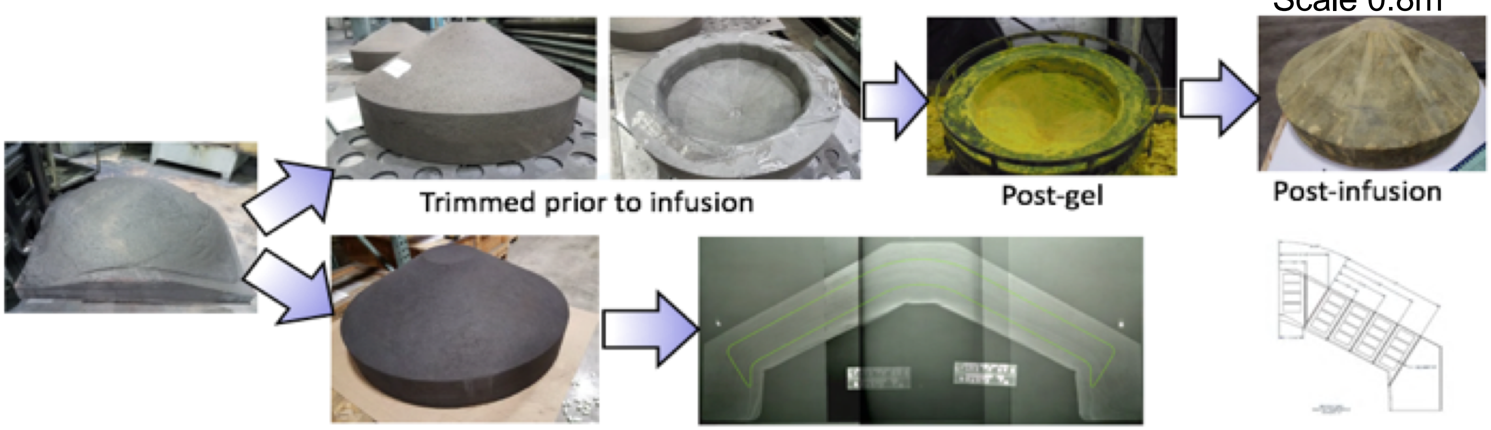


Mini-SPRITE Test Casting with arcjet model superimposed



Lyocell Fiberform/PICA Billet and Near Net Shape Cast Processing

- Fabricated 3 near-net-shaped Fiberform heatshield blanks (OSIRIS REx scale) in FY17
- Fabricated 4 near-net-shaped ~ 1.5m single piece FiberForm castings (FY18/19)
  - Non Destructive Evaluation (NDE) on the near net shape Fiberform unit to evaluate fiber alignment indicated good alignment from nose to shoulder
  - Density
  - Converted one into 1.4 m PICA heatshield
- Significant number of lessons learned captured/implemented and substantial risk reduction achieved



1.4m heatshield

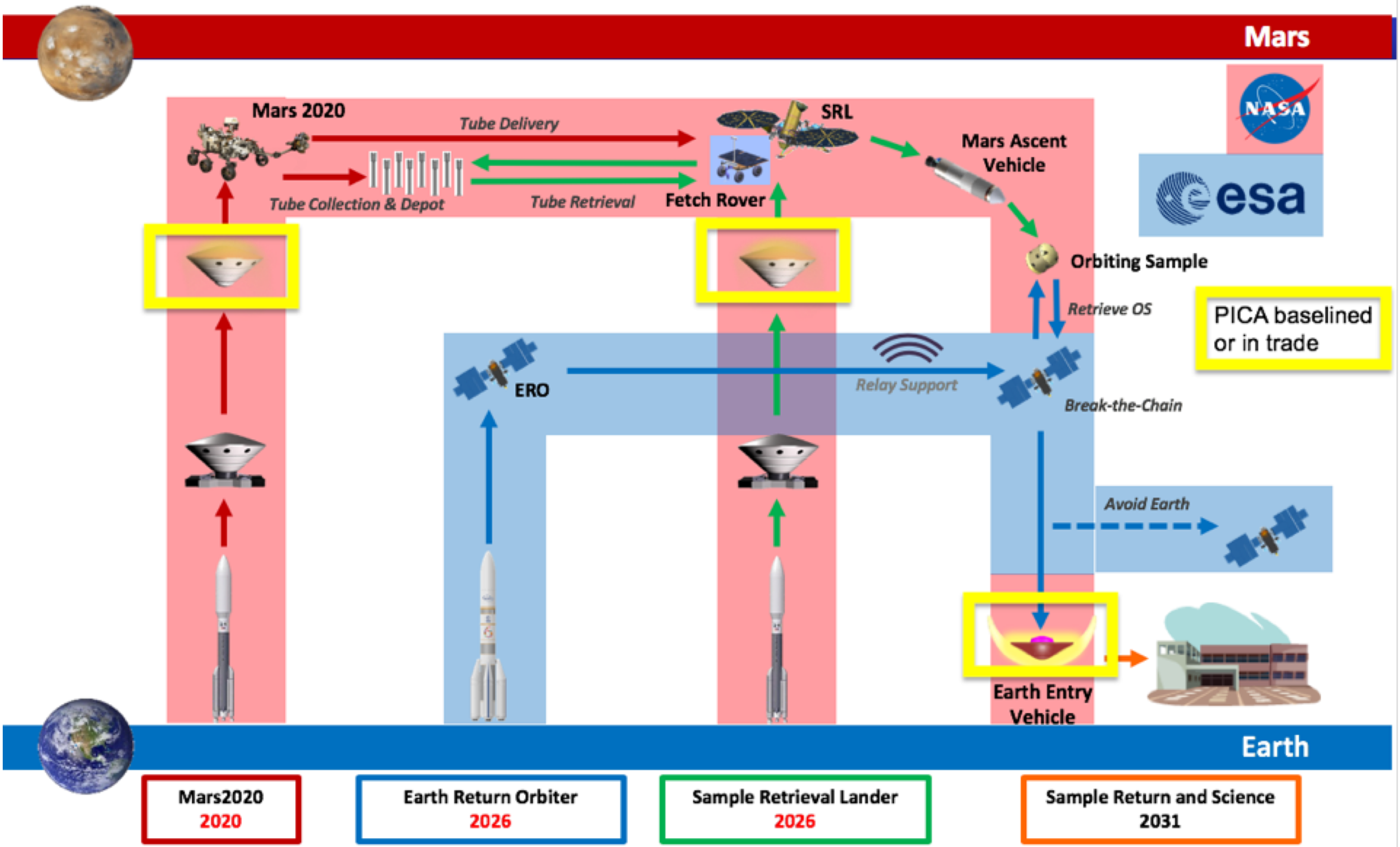
Extended single piece heatshield manufacturing demonstrated

PICA-D and Three Exciting Future NASA missions

- Mars Sample Return **Sample Return 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



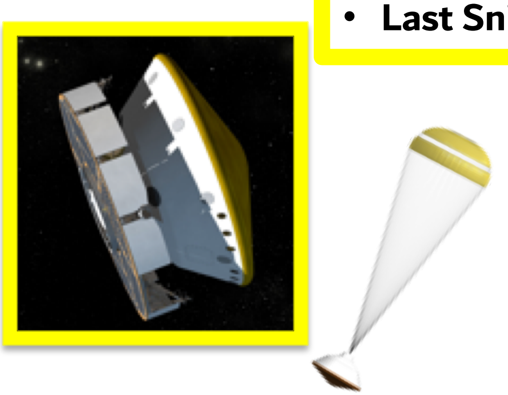
Courtesy: Jet Propulsion Laboratory

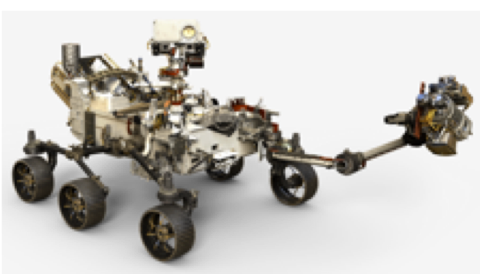
Mars2020 and Sample Retrieval Lander (SRL)

Entry Systems and Technology Division

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

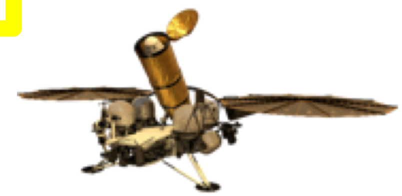
- **MSL "built to print" heatshield**

Courtesy: Jet Propulsion Laboratory

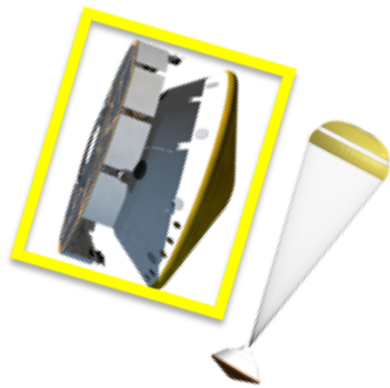
SRL Mission

- 5+m tiled configuration
- Lyocell derived PICA

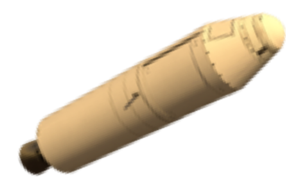
Platform



Cruise & EDL



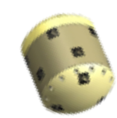
Mars Ascent Vehicle



Sample Fetch Rover

(JPL reference concept)

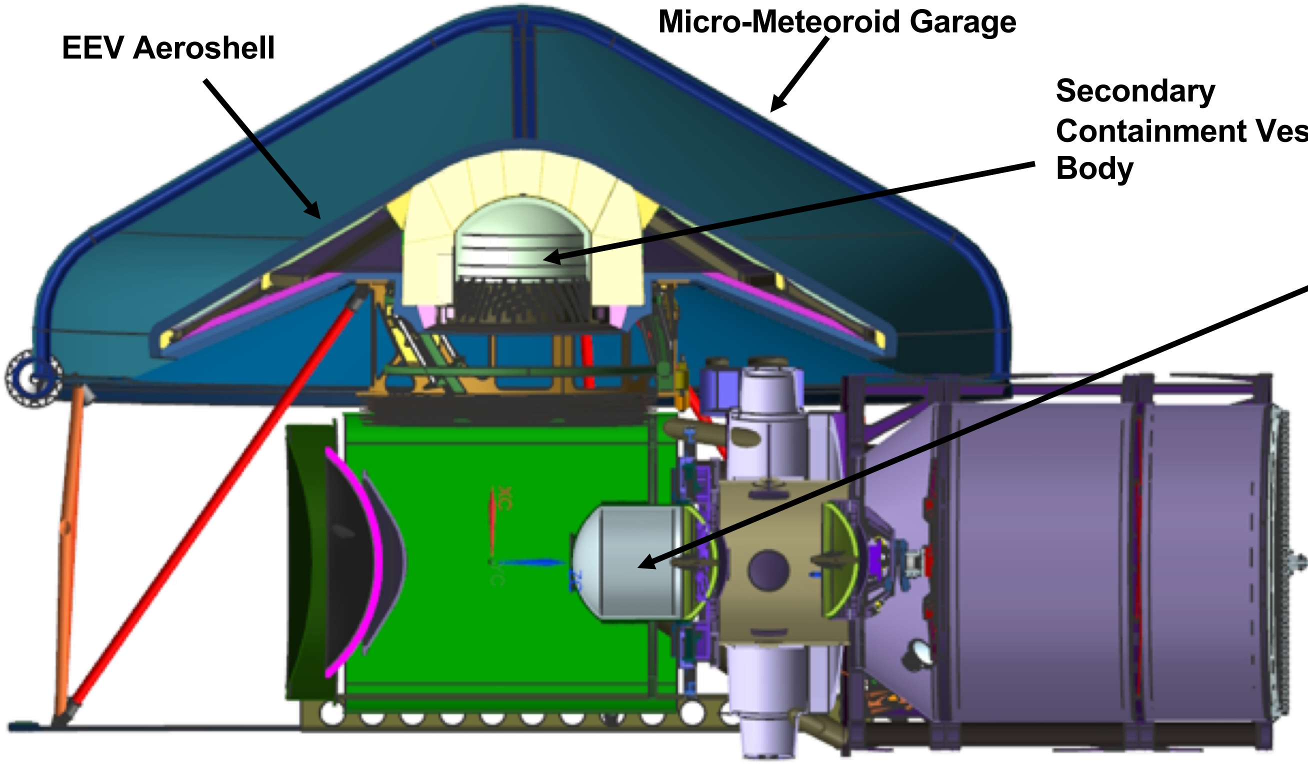
Orbiting Sample



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

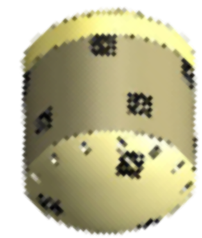
MSR Earth Entry Vehicle (EEV)

Entry Systems and Technology Division



- ~ 1.4m single piece
- Lyocell derived PICA

Orbiting Sample Capture

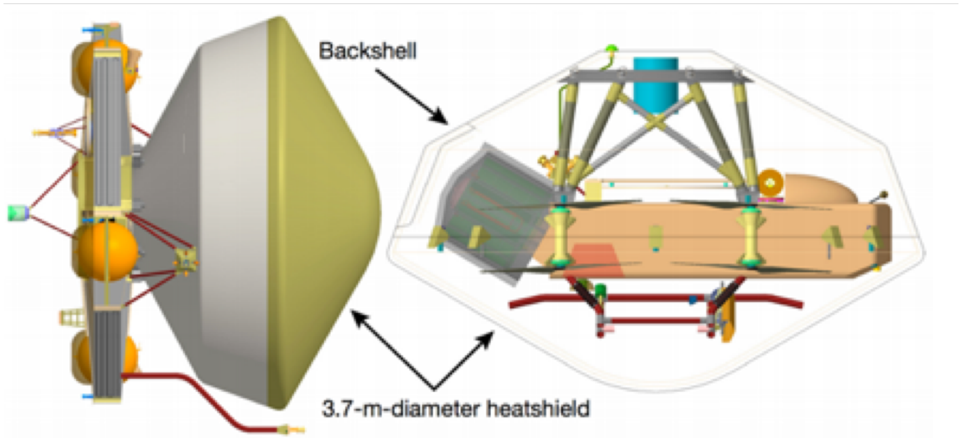


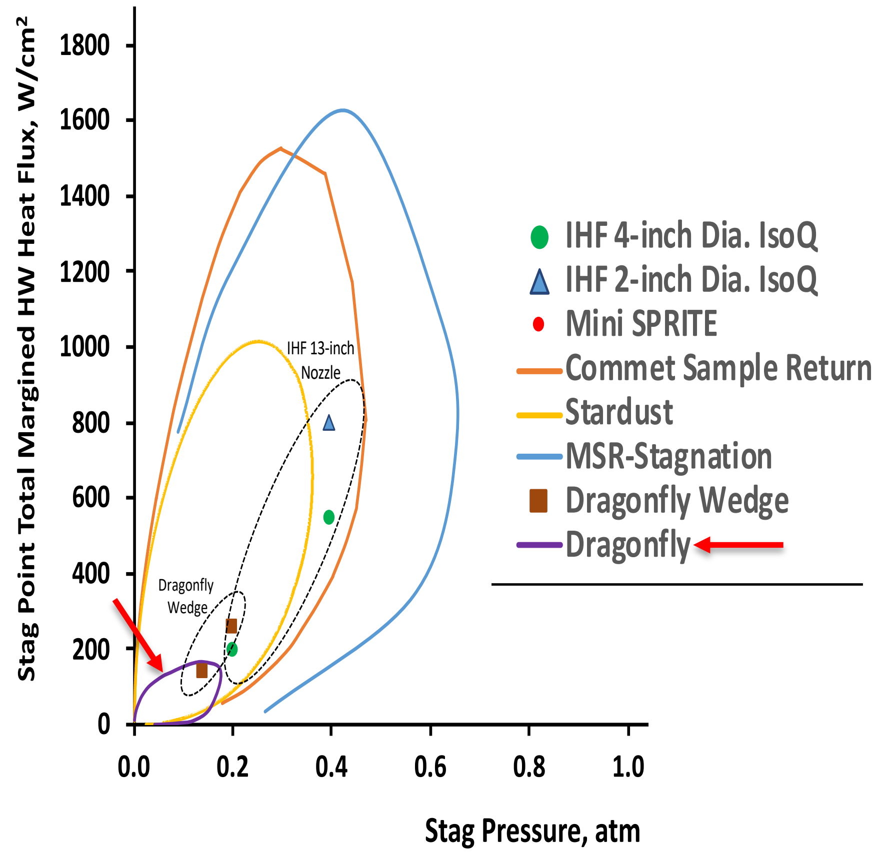
- Single piece PICA-D considered for MSR EEV foreboby
  - Requirements for MSR EEV – up to 1.4m which is greater than Stardust (0.8m)
  - Leveraging PICA-D for manufacturing scale-up demonstration
- Tiled backshell PICA baselined
- Expected conditions (~1600 W/cm^2, ~80kPa, ~1000 Pa shear)
- PICA performance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

Summary

- PICA has become a workhorse TPS for NASA and sustainment is essential
- NASA ARC / FMI have been and will continue to work together and address any PICA sustainability concerns
  - Lyocell, a viable precursor, will be available for decades
- Lyocell Based PICA (PICA-D) was manufactured and testing performed to-date show it to be a viable replacement for heritage rayon
- Establishing the extended capability of PICA-D, scale-up to 1.4m, will allow Sample Return Missions with higher entry speeds and larger payload in the future including Mars Sample Return Mission
- Exciting future NASA missions need PICA (SRL, MSR EEV and Dragonfly) and NASA TPS sustainability effort will have a payoff for these missions

Acknowledgement

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