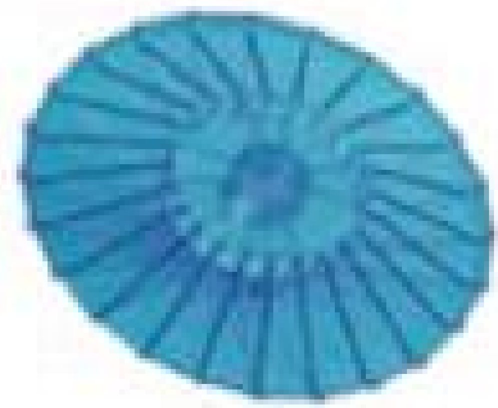
Development of Low Density, Flexible Carbon Phenolic Ablators



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Outline

Background

Motivation

Applications

Testing

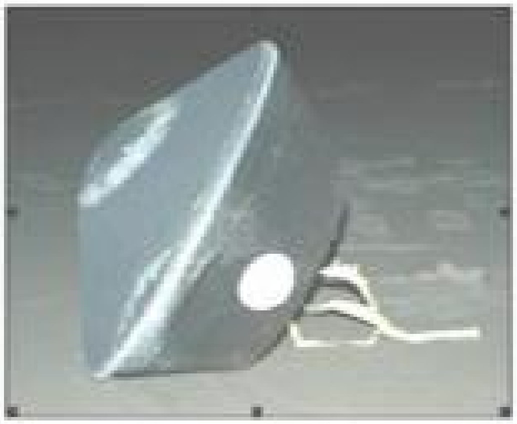
Summary

State-of-the-Art (SoA) Low Density Carbon Phenolic Ablators

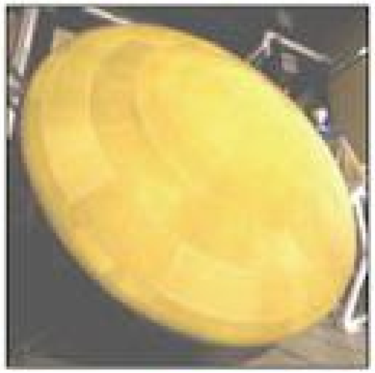
- **Phenolic Impregnated Carbon Ablator (PICA)**, an enabling TPS material for the Stardust mission used as **a single piece heatshield**

- **PICA is low- density** (~0.27g/cm^3) **and efficient at high heat fluxes**

- **PICA** is the **primary heat shield material** for **Mars Science Lab (MSL)** and the **Space-X Dragon as a tiled configuration**



Stardust capsule (0.8m diameter)



MSL heat shield (4.5m diameter)

Challenges with PICA

- Low strain to failure
- May require use of strain isolation pad
- Relatively large part count in tiled configuration
- Brittle char
- Needs a compatible gap filler

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Advantages of Flexible Ablators

Flexible Ablator Advantages Compared to Rigid TPS

- Less complex design
- More straightforward system integration
- Easier to manufacture
- Requires fewer segments (larger tiles can be made)
- Easier to assemble
- Enables larger diameter aeroshells
- Reduces gap and seam issues

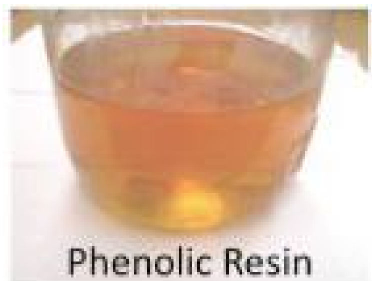
Orion Heat Shield
(5 m diameter)

MSL Heat Shield
(4.5 m diameter)

Making PICA Flexible

- **PICA is a low density carbon phenolic thermal protection material**
- **Composition works well up to 1000 W/cm^2**
- **Goal = retain the composition but change the architecture**

+



heat

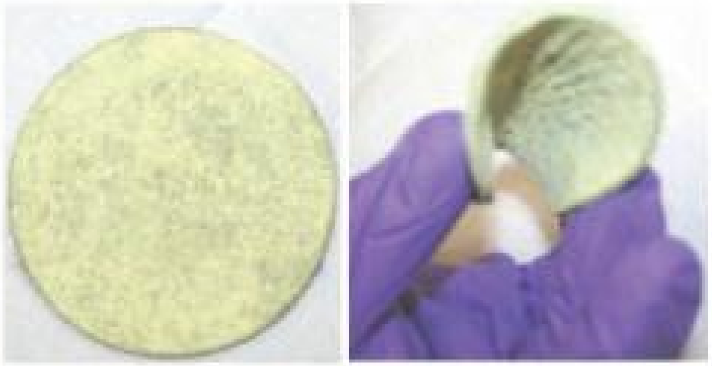
cure

Substrate	***Matrix***	
Carbon Fiiberform	*Phenolic Resin*	***PICA***
Carbon Felt	*Modified Resins*	***PICA FLEX***

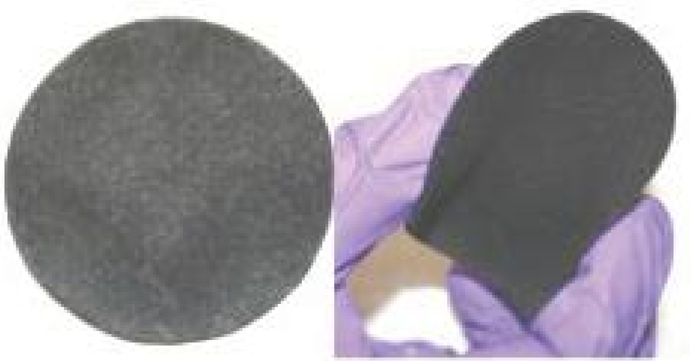
Making PICA Flexible

Flexible PICA from a Felt Substrate

- Comparable in composition to PICA
- Remains flexible after charring
- Can be processed as large pieces
- Parameters such as thickness, density, etc can be tailored



virgin state



charred state

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Potential Conformable Applications

Entry Systems and Technology Division

Lunar Return Missions

Vehicle					
Orion, LEO	Shoulder max. heating	65	no	101	88
Orion, Lunar	Shoulder max. heating	433	no	101	146

Flexible ablators can mitigate PICA integration issues

Orion Heat Shield
(5 m diameter)

Mars Missions

Vehicle	Location	q (W/cm^2)	Margin q?	Pressure (kPa)	Shear (Pa)
MSL	Lee shoulder, max	203	YES	19.7	490
Mars 2018	Shoulder	98	no	19	137
Mars 2018	Dish	69	no	24	43

Flexible ablators are an attractive alternative to rigid PICA for future MSL class rigid aeroshells

MSL Heat Shield
(4.5 m diameter)

Potential Flexible Applications

Mars Vehicle Concepts

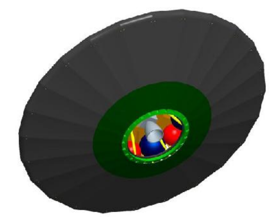
Entry Vehicle Concept	Location	q (W/cm^2) A/E	Margin q?	Pressure (kPa) A/E	Shear (Pa) A/E
EDL SA (23 m)	Peak Forebody	106 / 32	YES	11 / 8	42 / 25
EDL SA (23 m)	Peak Forebody	67 / 21	no	9 / 6	27 / 16

A/E = Aerocapture/Entry

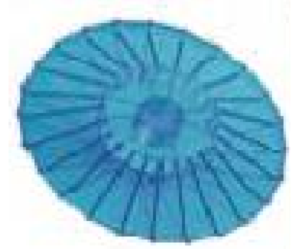
HIAD[1] Concept
(23 m diameter)

Venus / Saturn Vehicle Concepts

Entry Vehicle Concept	Location	q (W/cm^2)	Margin q?	Pressure (kPa)	Shear (Pa)
ADEPT, Venus	Peak Forebody	230	no	7	210
ADEPT, Saturn	Peak Forebody	295	no	11	245



ADEPT[2] Concept
(23 m diameter)



ADEPT Concept
(2.13 m diameter)

[1] Hypersonic Inflatable Aerodynamic Decelerator
[2] Adaptive Deployable Entry-system Project

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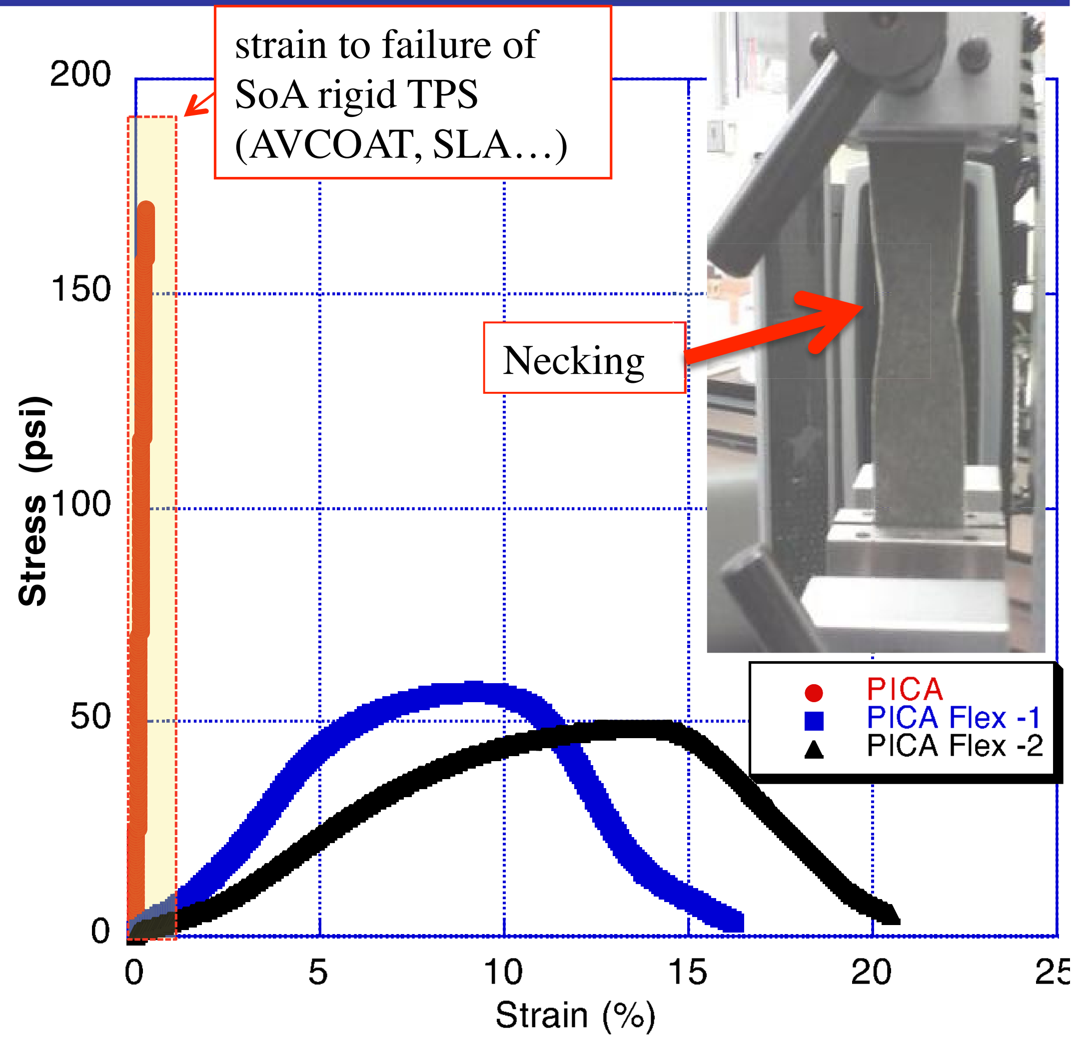
Preliminary Screening Test Results

- 4 candidate PICA FLEX systems evaluated

- Preliminary Results:
  - Tensile tests
  - Thermal Conductivity
  - Microstructure
  - LHMEL Testing
  - Arc Jet testing

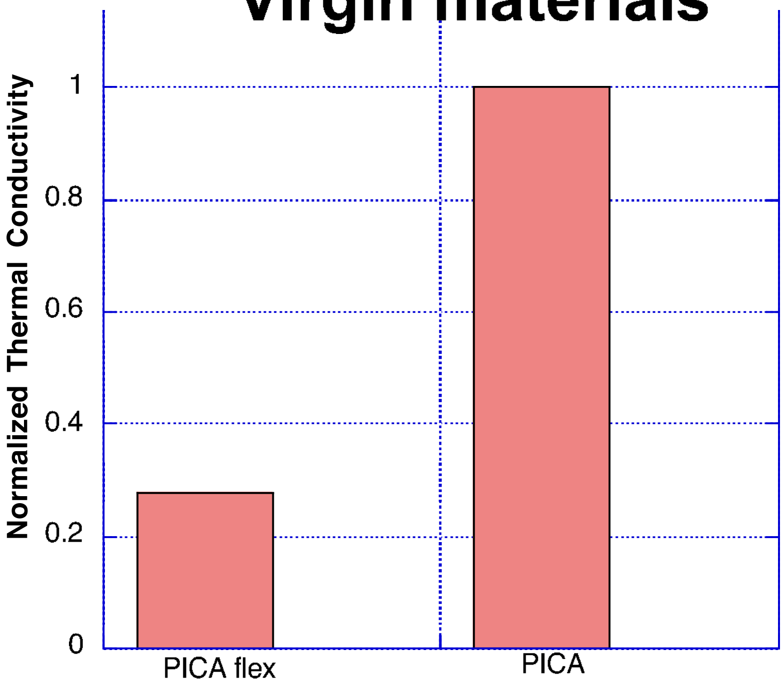
Mechanical Properties (Tensile)

- **Samples were tested to evaluate strength and strain to failure. (8” x 1”)**
- **PICA flex failed gracefully and showed necking behavior**
- **PICA flex could withstand approx. 8%-12% strain before onset of necking**

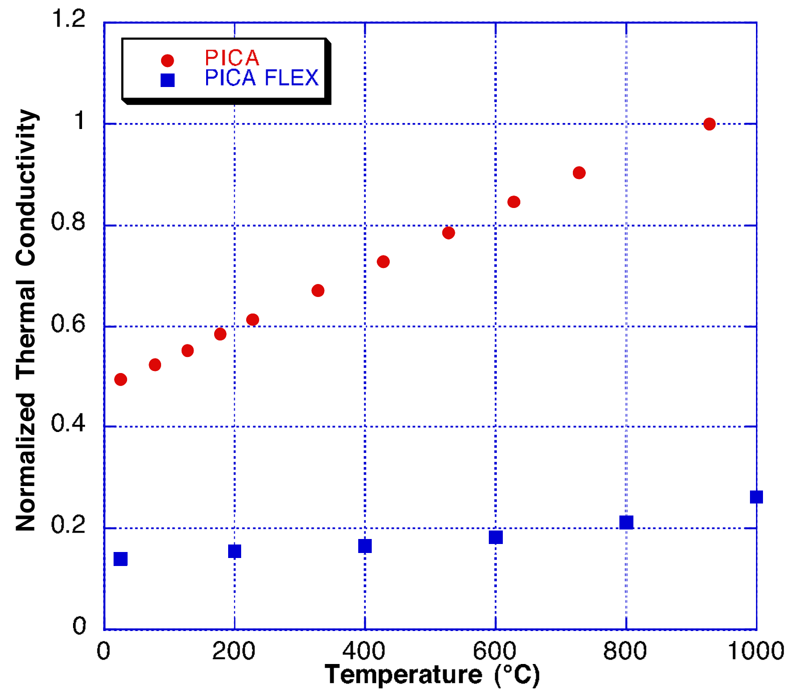


Thermal Conductivity Comparisons

Virgin materials



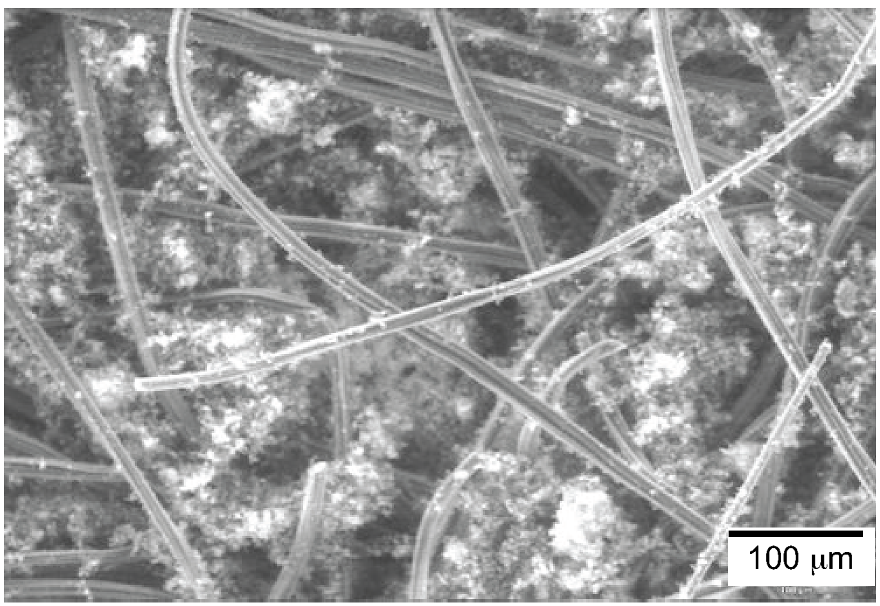
Charred materials



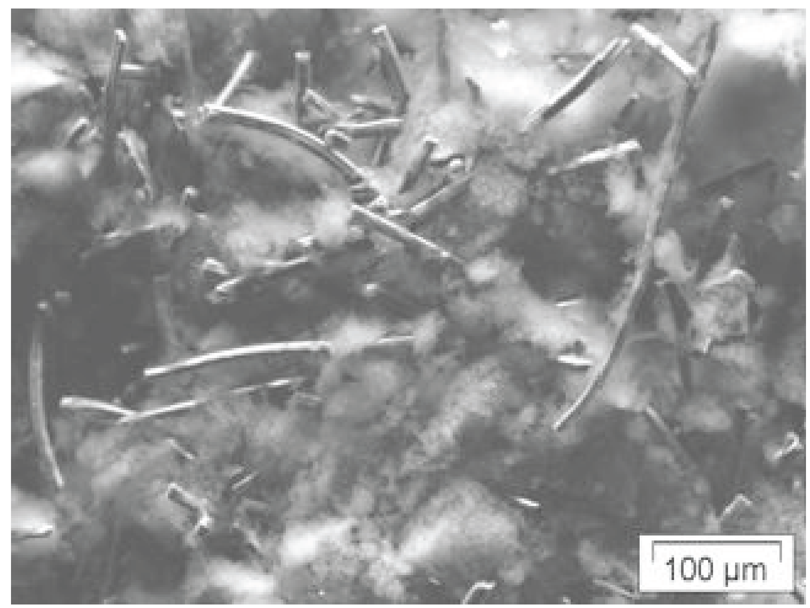
- **PICA thermal conductivity values taken from Orion Database**
- **Laser flash method used for PICA FLEX**
- **Data is an average of 3 samples**
- **PICA and PICA flex samples have comparable densities, however, the thermal conductivity of PICA flex is approximately one-third of rigid PICA**

Microstructure

- **Microstructure influences properties**
- **PICA flex microstructure resembles PICA in many aspects; distributed phenolic phase in a carbon matrix**



PICA flex microstructure



PICA microstructure

LHMEL* Screening Tests

- **Exposure 450 W/cm² for 25 seconds**
- **Comparable areal mass for all materials**

Material	Max. Backface Temperature (°C)	Time to Reach Max. Backface Temperature (sec)
PICA	240	93
PICA Flex Variant 1	118	213
PICA Flex Variant 2	75.5	246
PICA Flex Variant 3	133	143

Pre test

Post test

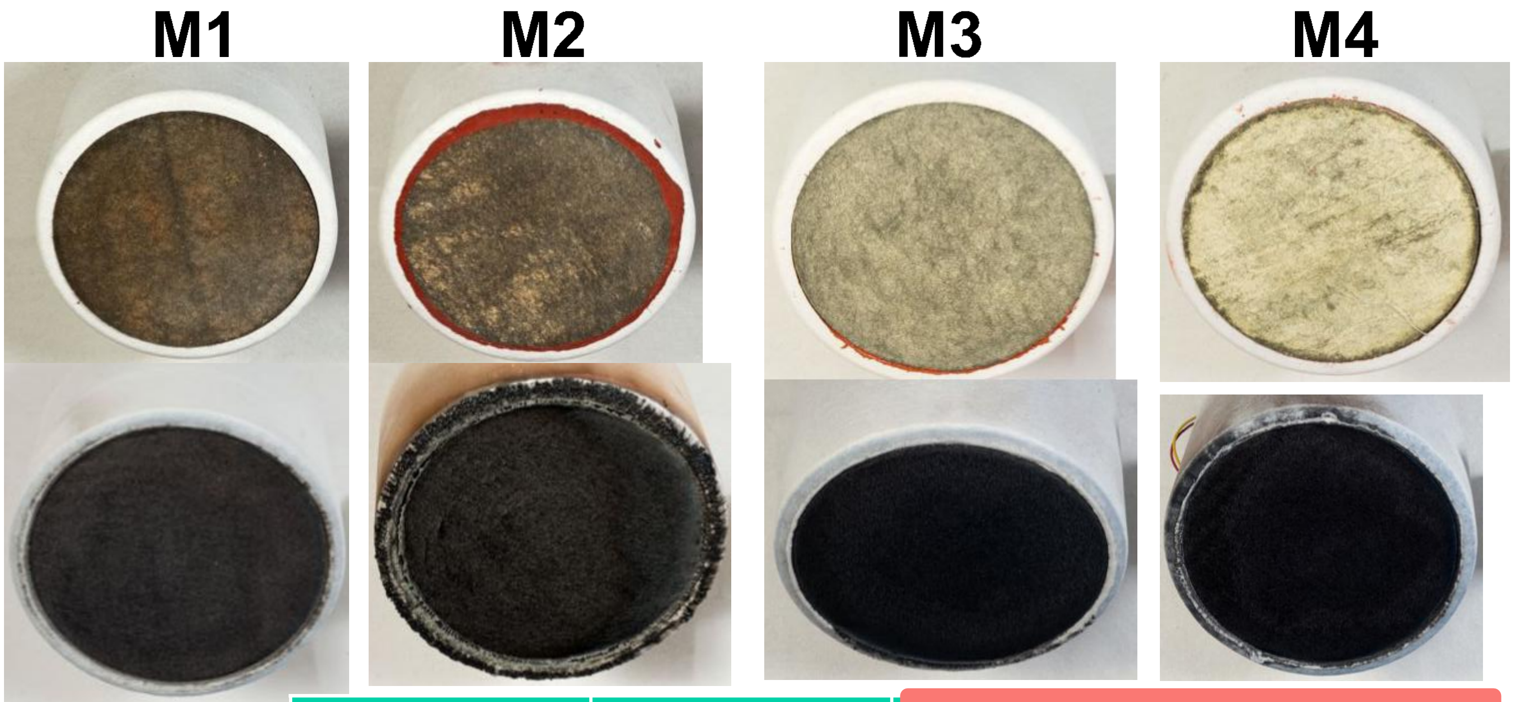
*LHMEL - Laser Hardened Materials Evaluation Laboratory, Air Force Research Laboratory Wright-Patterson AFB, OH

Courtesy S. White NASA ARC

Arc-Jet Screening Tests

- **Initial testing completed at Johnson Space Center**
- **Samples were:**
  - **3.5" diameter by ~ 1" thick**
  - **bonded to an LI 2200 tile holder with collar**
  - **instrumented with a backface thermocouple**
- **2 conditions evaluated**
  - **Heat Flux: 250 W/cm^{2}, Pressure: 0.2 atm and Duration: 30 seconds**
  - **Heat Flux: 540 W/cm^{2}, Pressure: 0.3 atm and Duration: 20 seconds**
- **PICA flex performed well up 540 W/cm^{2}**
- **Performance limits for flexible ablators TBD**

Pre- and Post-Test Comparisons



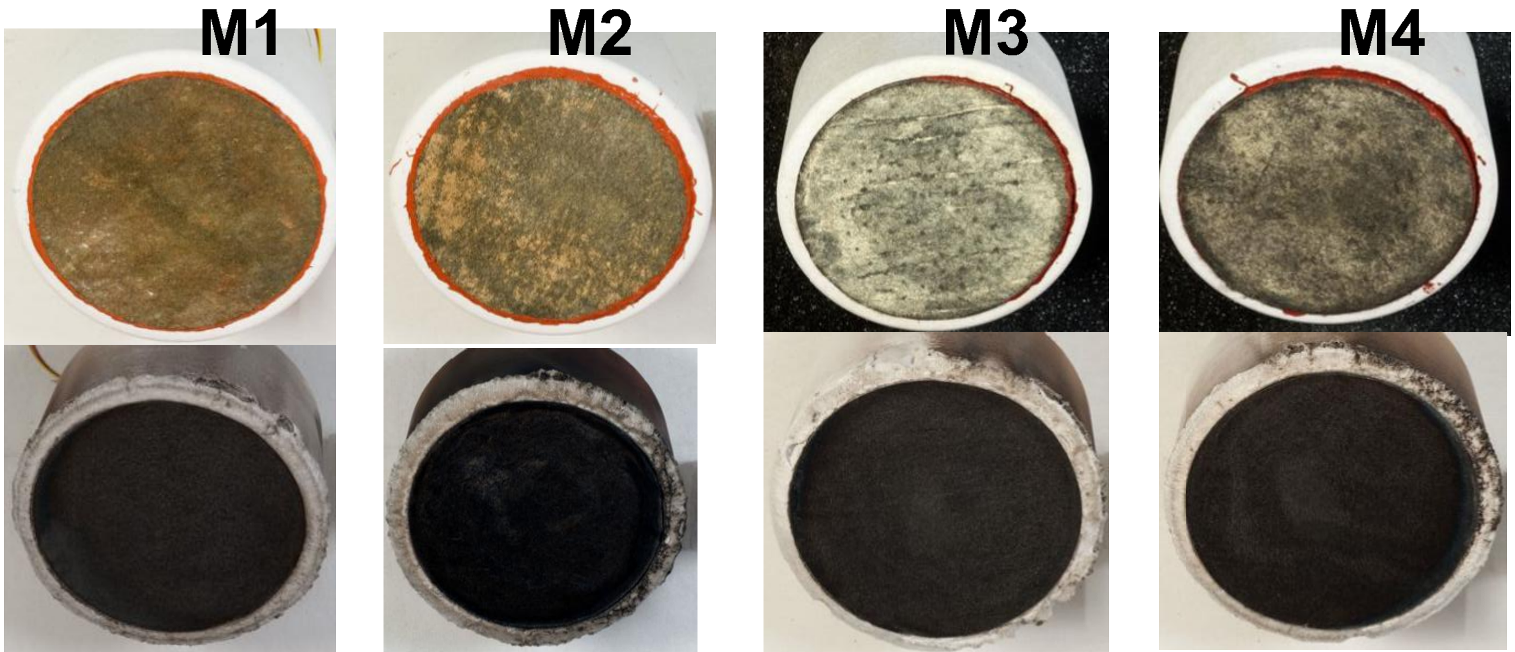
Heat Flux: 250 W/cm^2

Pressure: 0.2 atm

Duration: 30 sec

Description	Peak Surface Temperature °C	Backface Temperature Delta °C	Recession cm
PICA	2041	195	0.6
PICA FLEX **M1**	2027	52	0.6
PICA FLEX **M2**	1967	74	1.0
PICA FLEX **M3**	1996	53	0.8
PICA FLEX **M4**	2023	74	1.0

Pre- and Post-Test Comparisons



Heat Flux: 540 W/cm^2

Pressure: 0.3 atm

Duration: 20 sec

Model	Description	Peak Surface Temperature °C	Backface Temperature Delta °C	Recession cm
3261	PICA	2421	141	0.5
3240	PICA FLEX **M1**	2376	56	0.7
3241	PICA FLEX **M1**	2331	49	0.8
3243	PICA FLEX **M2**	2331	41	1.3
3244	PICA FLEX **M2**	2283	41	1.5
3245	PICA FLEX **M3**	2529	83	0.8
3247	PICA FLEX **M4**	2474	102	1.0

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- Currently evaluating alternative architectures for flexible and more conformal carbon phenolic materials with comparable performance to PICA

- Flexible TPS concepts address some of the design issues faced in the use of a tiled PICA heat shield

- Initial testing of flexible PICA concepts has shown:
  - Substantially higher strain to failure than PICA
  - Lower thermal conductivity than PICA
  - Survived a 540 W/cm^2, arc jet exposure

- Flexible ablator technology is applicable for upcoming NASA missions needing either rigid or flexible TPS, e.g., HIAD and ADEPT deployable decelerators

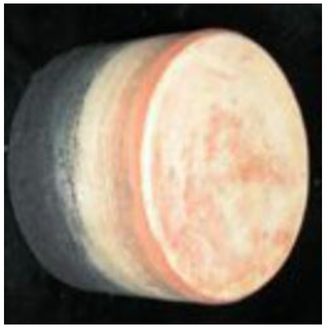
- PICA FLEX evaluation ongoing under OCT funded CFA TPS program

Families of Ablators Under Development at NASA ARC

Entry Systems and Technology Division

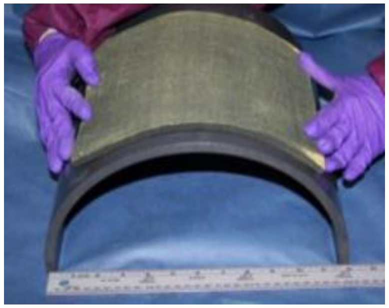
Rigid Ablators

Advanced PICA -like ablators



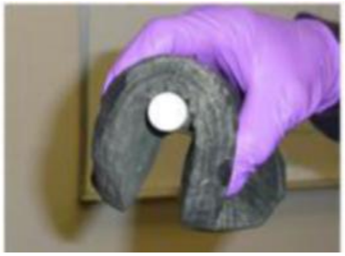
Graded Ablators

Conformable Ablators

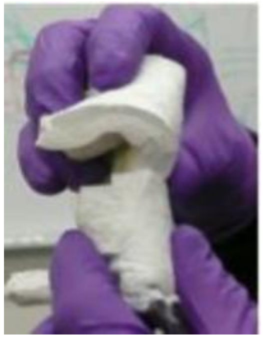


Conformable PICA

Flexible Ablators

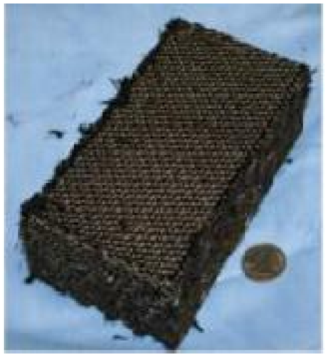


Flexible PICA

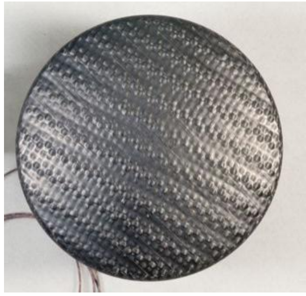


Flexible SIRCA

Woven TPS



Mid density TPS



Carbon phenolic replacement

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