Woven Thermal Protection System (WTPS) - a Novel Approach to Meet NASA's Most Demanding Missions

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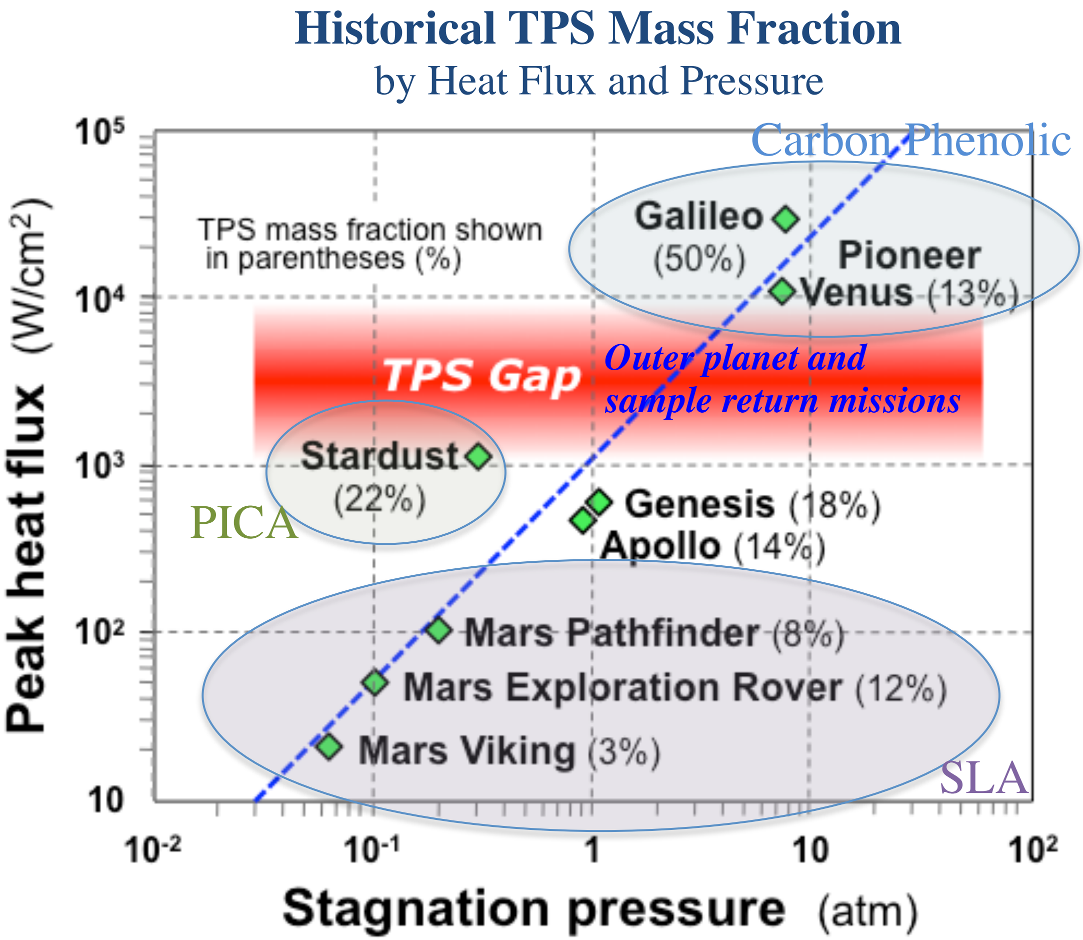
Outline

- **Heritage TPS Challenges**
- **WTPS Evolution**
- **Intro. to HEEET (Heatshield for Extreme Entry Environment Technology) Project**
- **Downselected HEEET Architecture**
- **Benefits of HEEET Architecture**
- **Aerothermal Testing Summary**
- **Heatshield Components and Technology Maturation Challenges**
- **Summary**

TPS Challenges for Venus, Saturn, Neptune, Uranus, Jupiter and High Speed Sample Return Missions

- **Science and Mission Design goals**
  - Maximize science payload,
  - Minimize mission risk, cost
- **Missions currently baseline "heritage like" Carbon Phenolic**
  - CP is very capable, robust, flight proven
  - CP enabled Pioneer-Venus & Galileo
- **Carbon Phenolic is mission enabling, but trajectory constraining**

  Missions with CP + normal payloads result in:
  - Steeper trajectories, extreme g loads
  - Heat-flux, pressures exceed test capability

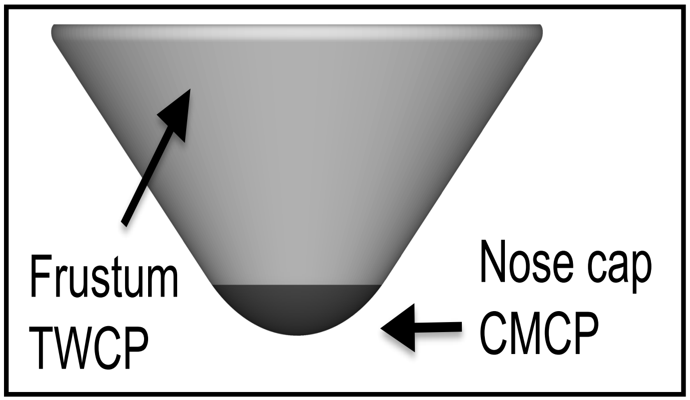


For typical Entry Systems Missions

- *at high heat fluxes, CP is an efficient TPS.*
- *below ~ 2,000 W/cm², PICA and other ablators perform well.*
- ***There is no efficient TPS option in the gap!***

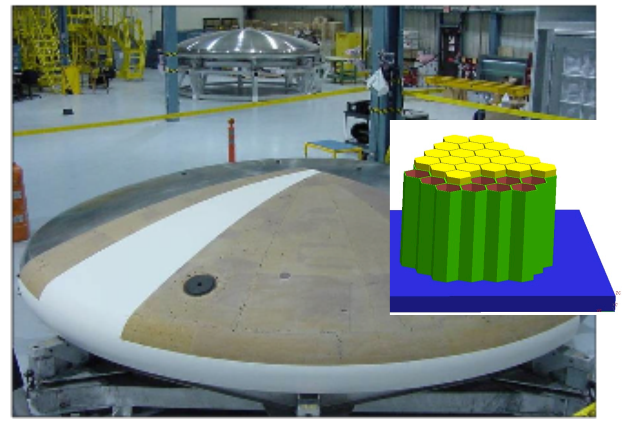
Sustainability Challenges with State of the Art TPS

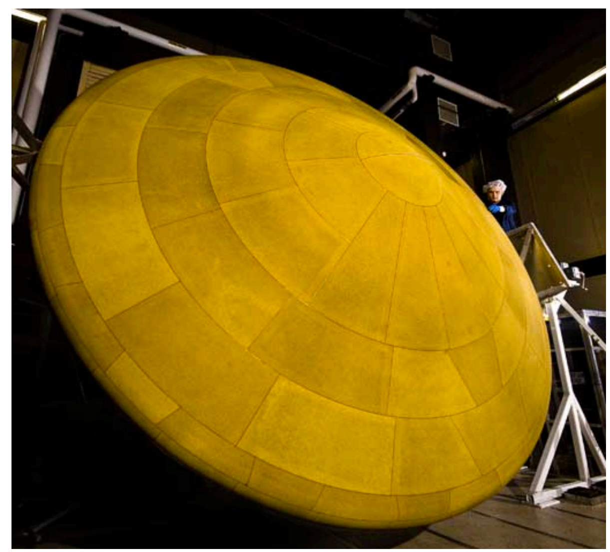
Tape-wrapped & chop-molded carbon phenolic



- Challenges for using traditional CP
  - Heritage CP used for entry no longer available (Avtex)
  - New CP material would need to be certified
  - Chop-molded CP has not be used for NASA application since 1980s

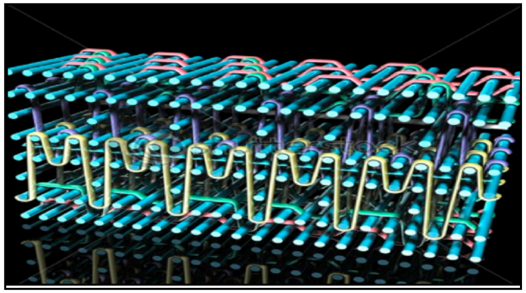
Sustainability and Life Cycle Costs

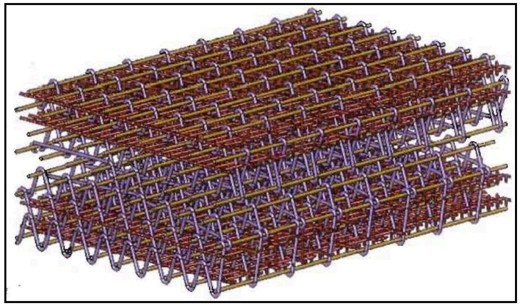

AVCOAT

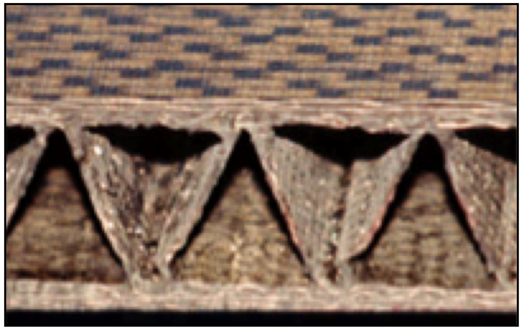

PICA MSL

What is the 3D Woven TPS concept?

An approach to the design and manufacturing of **ablative** *TPS by the combination of weaving precise placement of fibers in an optimized 3D woven manner and then adding a polymeric matrix if needed*

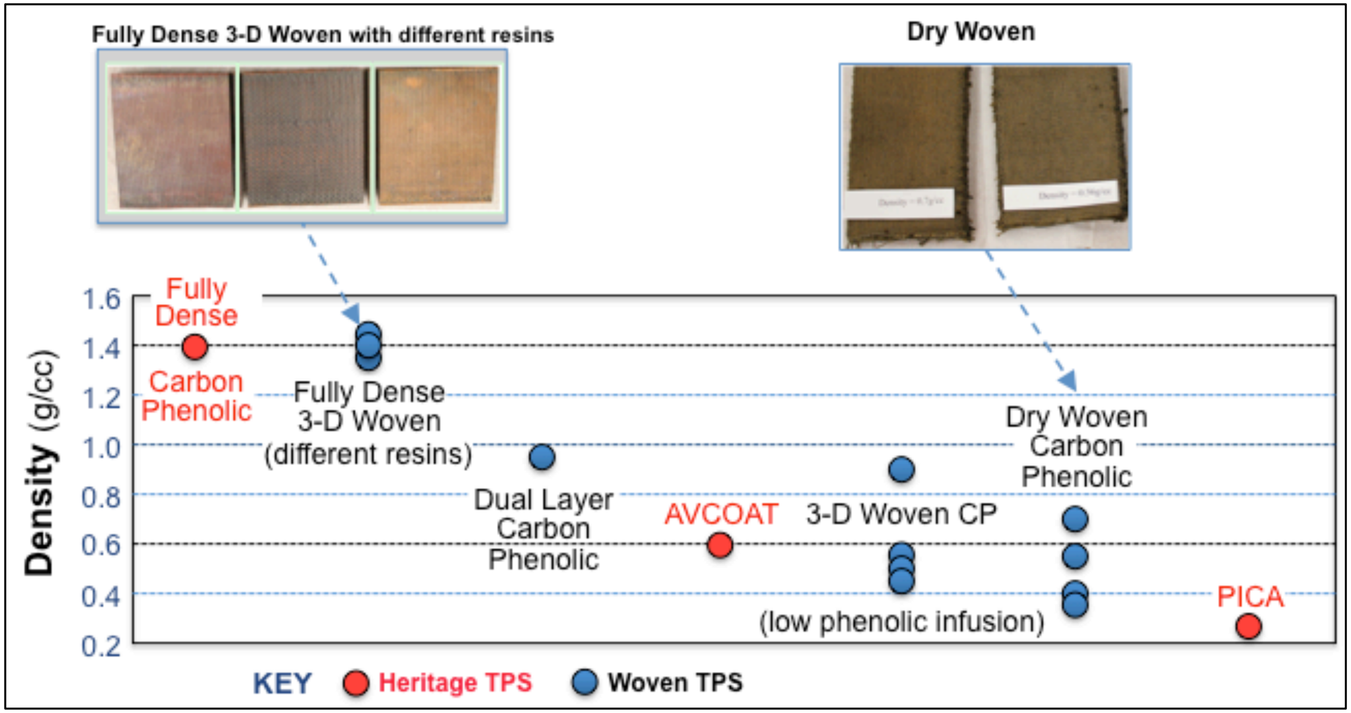






- Ability to design TPS for a specific mission
- Tailor material composition by weaving together different types of fibers (e.g. carbon, ceramic, glass, polymeric)
- One-step process for making a mid-density dry woven TPS
- Ability to infiltrate woven structure with a polymeric resin to meet more demanding thermal requirements
- WTPS leverages a ***sustainable*** weaving technology (not NASA-unique)

Large Application Space Possible

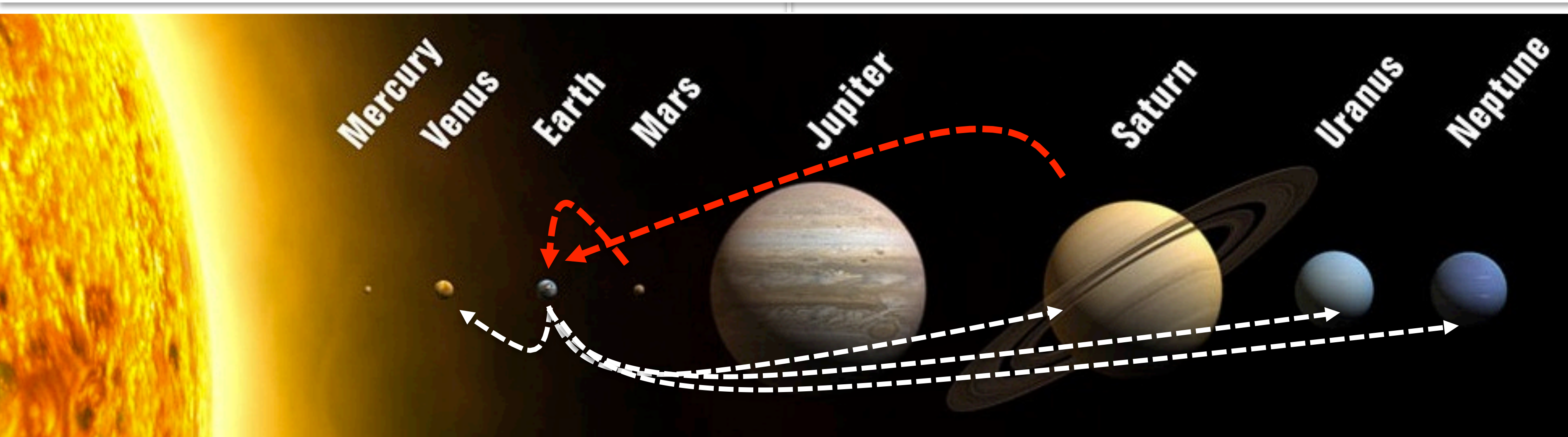


- Many ablative TPS options possible and have been manufactured
  - Dry-woven to fully resin infused systems
  - Density ranging from 0.3 g/cc – 1.4 g/cc
- Current HEEET activity has downselected to a dual layer system to meet specific mission needs for extreme entry (Venus, Saturn, outer planets, sample return)
  - Depending on mission needs many other options are possible

HEEET Background
(Heatshield for Extreme Entry Environment Technology)

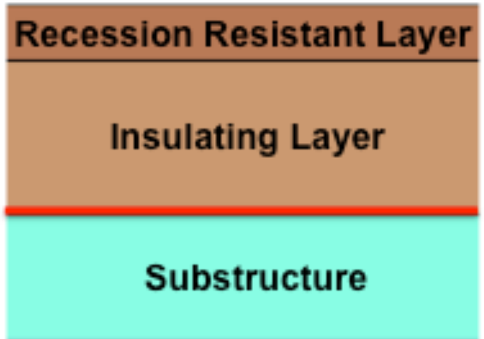
- HEEET is an technology development project to advance 3-D woven resin infused TPS materials (ablators) that can be tailored to SMD robotic missions ***without constraining the mission or limiting the science***.
- Recommended science missions include:
  - Venus probes and landers
  - Saturn and Uranus probes
  - High speed sample return missions

	OML Shape	Diameter	Nose Radius	TPS Thickness
Saturn	45º spherecone	~1m (40”)	~7.0”	~2.5”
Venus	45º spherecone	~3.5 m (140”)	~25”	~1.5”
Earth Sample Return	45º spherecone	~1m (40”)	~7.0”	~1.5”

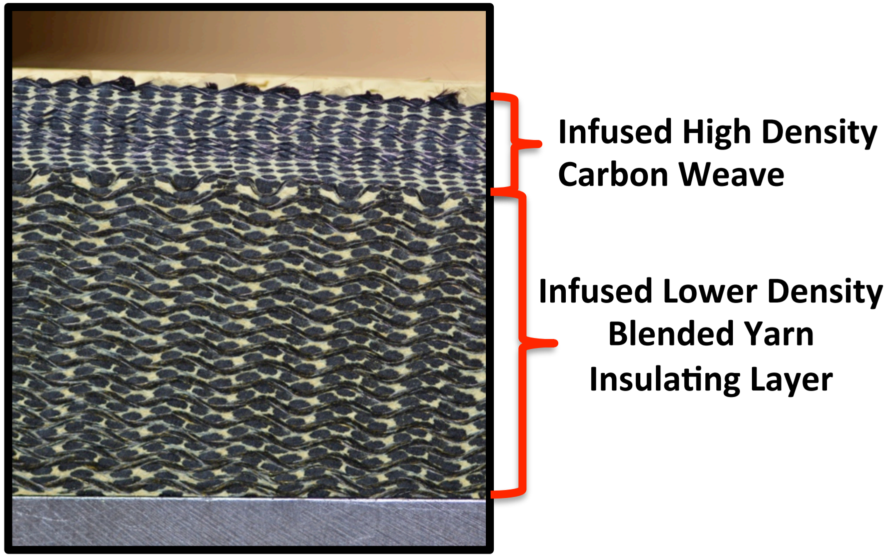


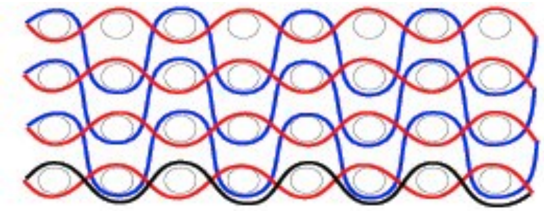
HEEET Material

- Recession and insulating layers are woven together in 3D
  - Mechanically interlocked (Z fibers)
- Weaving results in orthotropic material
  - Properties vary in Warp, Fill and Through-The-Thickness (TTT) (X,Y and Z)
- Single uniform resin infusion (vacuum assisted infusion)
- Weave architecture and resin infusion level downselected during HEEET Formulation (FY13)



3-D Woven Dual Layer





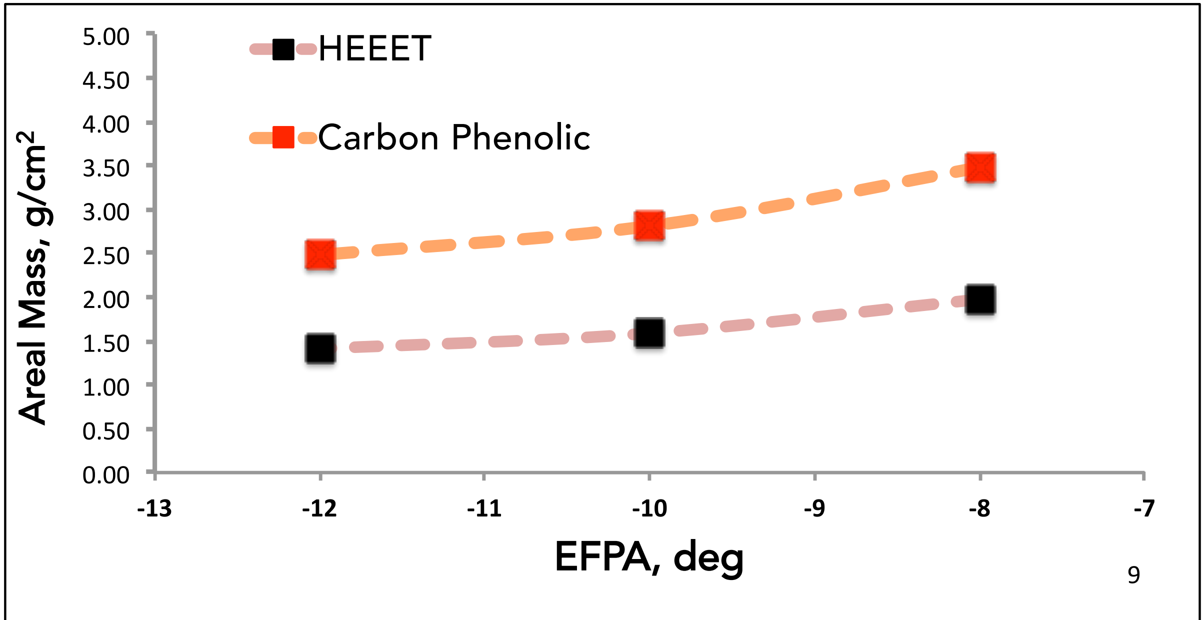
Example Layer to Layer Weave

Benefits of HEEET Dual Layer Architecture

- Areal Mass Trade Studies Completed for:
  - Saturn Probes
  - Venus
  - Uranus small probes
  - Sample Return Missions
- All trades indicate substantial TPS mass savings over heritage carbon phenolic with zero margin sizing and using a preliminary HEEET response model

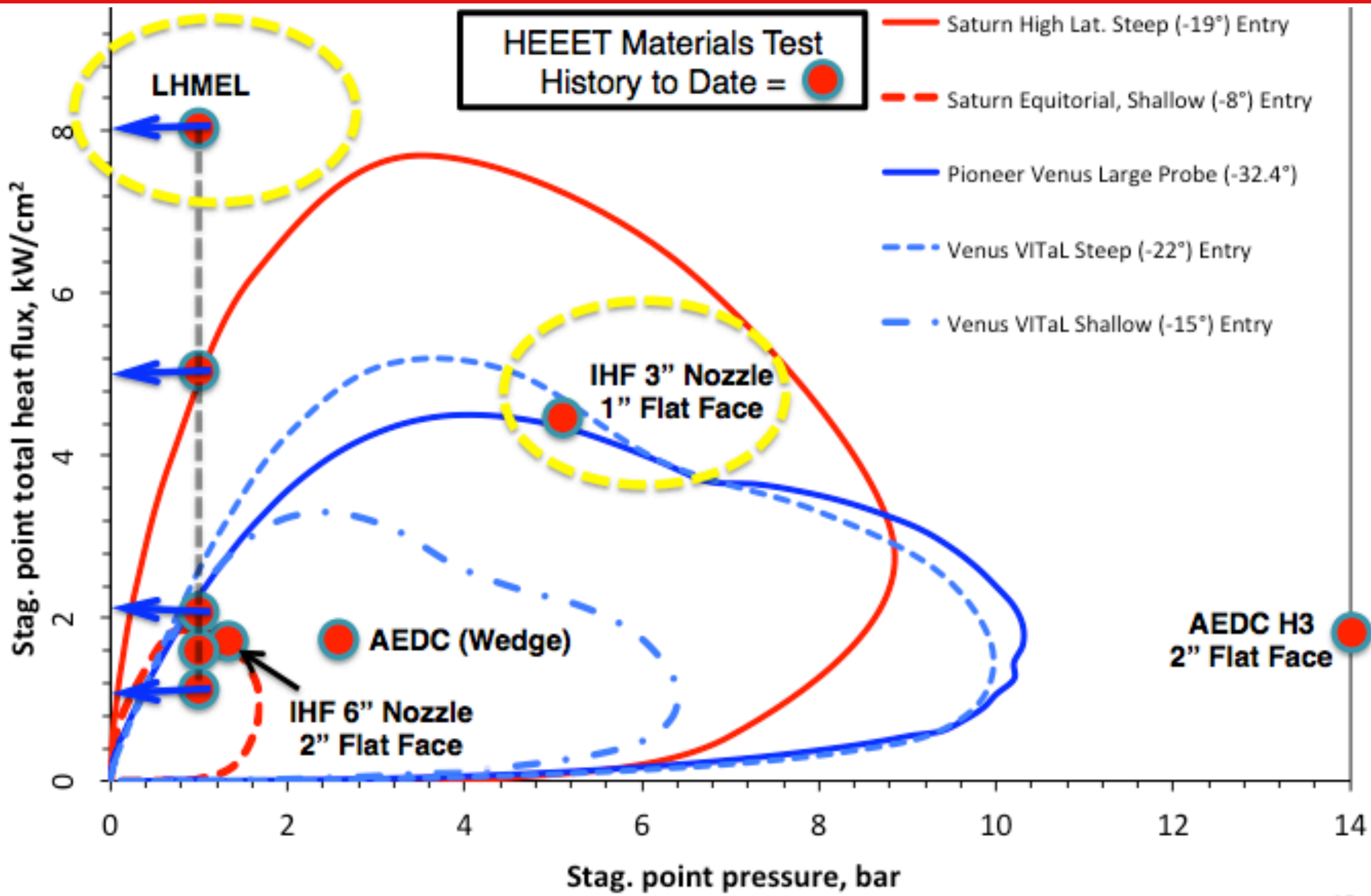
- 3-D WTPS allows for robustness and mass efficiency
- Mass savings of ~40% over CP

Sample Return Mission Trade Studies
(V = 15 km/s, M = 50 kg, Dia. = 0.8 m) :
TPS Areal Mass and Thickness



Aerothermal Testing

Arcjet Design Space & HEEET Test History



Piecewise testing approach used across available ground test facilities to qualify/ verify TPS performance

Testing Approach

Test Coupon Design

- Drew upon heritage Pioneer Venus / Galileo test configurations to design test article geometries where applicable
- Utilized modern CFD capabilities to refine test article configurations, position within test facilities and estimate arc heater settings
- LHMEL testing utilized heritage Carbon Phenolic test techniques used to qualify material for Shuttle solid rocket motors to test for failure modes

Facility Capability Enhancement

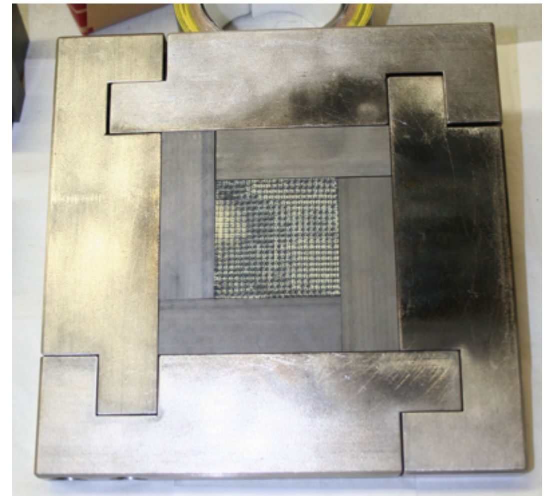
- IHF 3-inch nozzle design and fabrication was supported by NASA's SMD

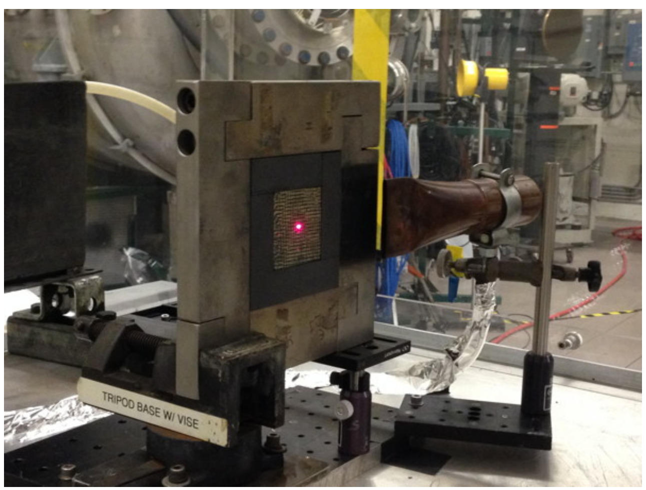
Baseline Material Tested for Comparison to HEEET

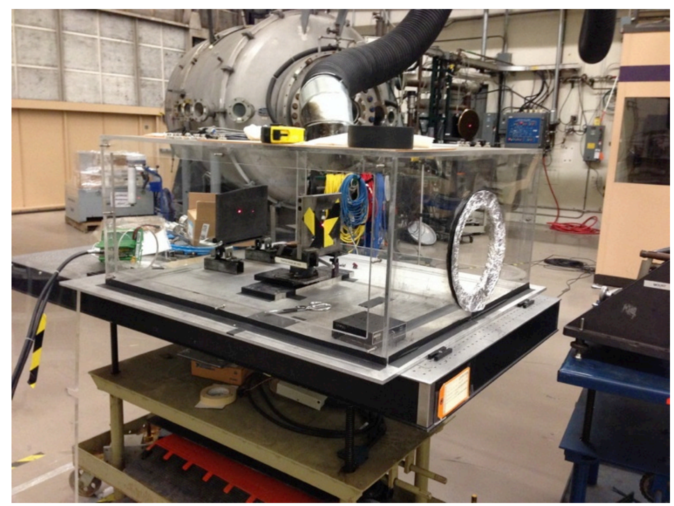
- Test articles included fully dense tape wrap and chop molded carbon phenolic

LHMEL: Failure Mode Testing

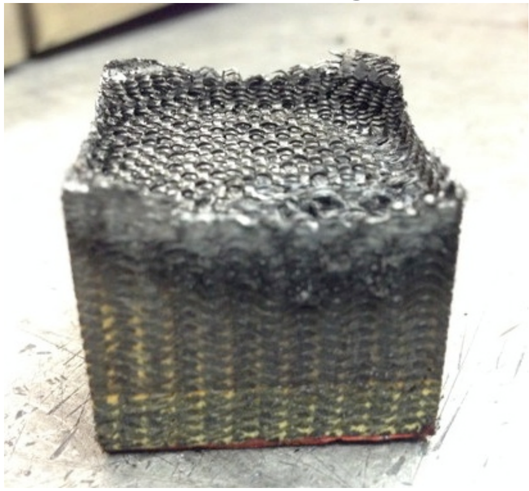
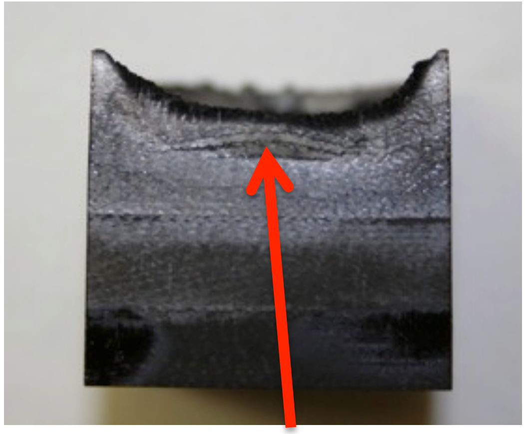
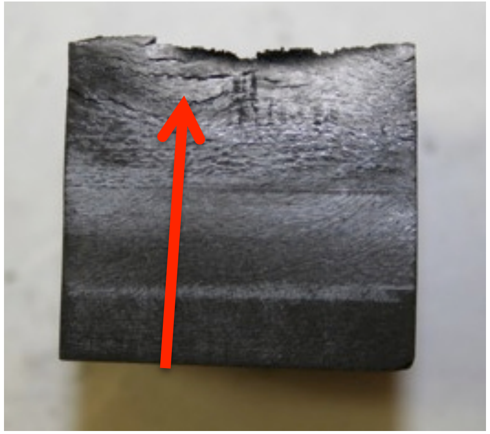
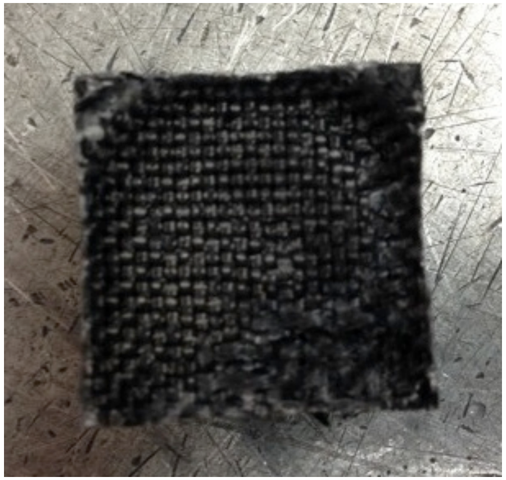
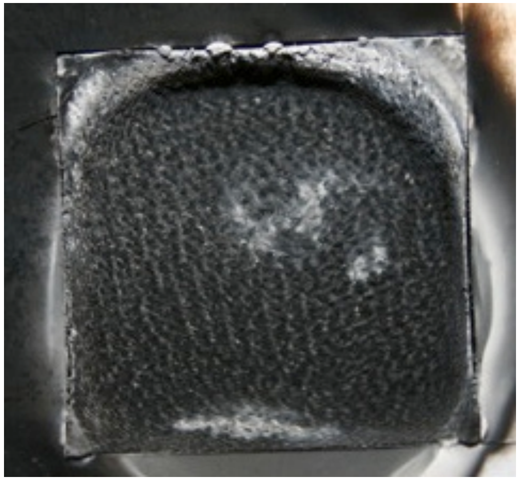
Model ID	Description	Density (g/cm^3)	Duration (sec)
HEEET 2	1000 W/cm^2	0.88	30
CMCP 3		1.45	30
TWCP 3		1.45	30
HEEET 6	2000 W/cm^2	0.88	15
CMCP 1		1.45	15
TWCP 1		1.45	15
HEEET 40	5000 W/cm^2	0.89	6-7
HEEET 20	8000 W/cm^2	0.89	5
CMCP 4		1.45	5
TWCP 4		1.45	5





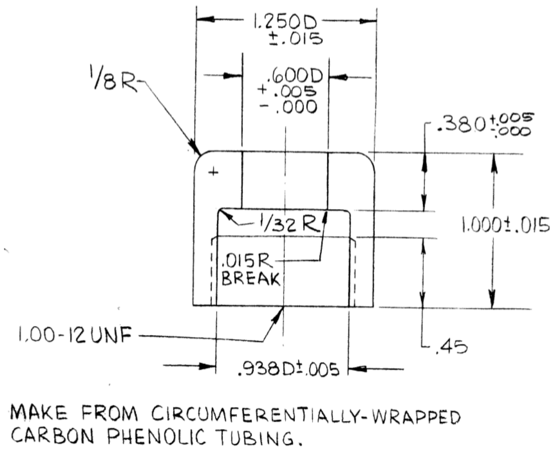


LHMEL: Failure Mode Testing Post-Test: 8000 W/cm^2, 5 sec.

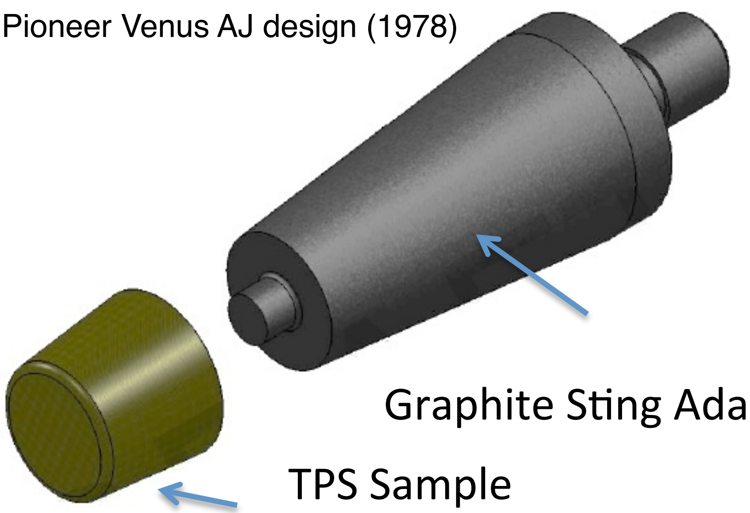
HEEET Acreage	Tape Wrap CP	Chop Molded CP
		
		
No surface spallation, delamination or cracks	Ply lift and sub-surface cracking	Ply lift and sub-surface cracking

IHF 3” Nozzle 1” Flat Face Stagnation
Acreage HEEET Stag. Heat-Flux ~5000 W/cm^2 @ 5 atm

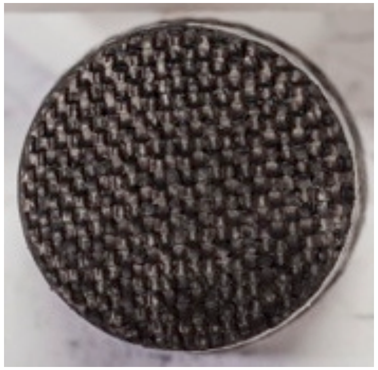
- 4 HEEET models tested
  - Exploratory test to confirm facility operability with new nozzle configuration



Pioneer Venus AJ design (1978)



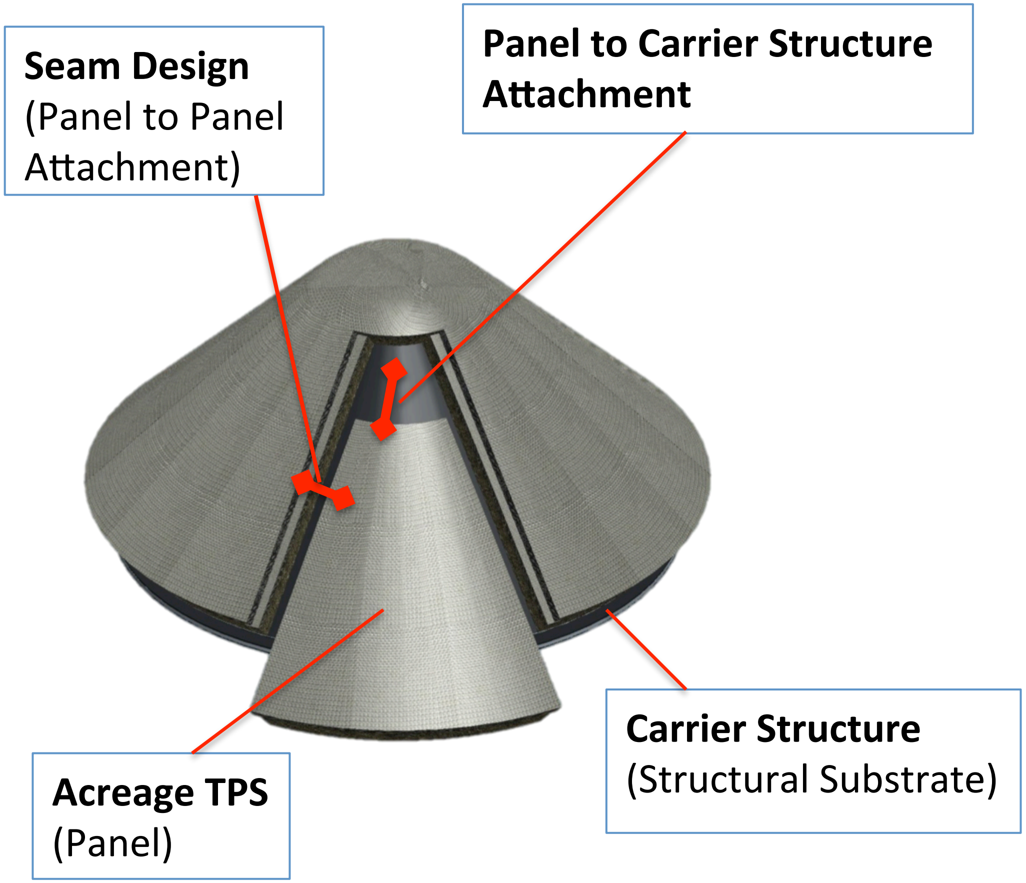
Pre-Test



Post-Test

- Failure mode test
- Uniform Recession observed for HEEET material

HEEET Heatshield Components



- 45° Sphere cone assumed for Venus and Saturn
- Nose is separate molded part

- 4 Basic Heatshield Components
  - **Acreage Material**
  - Seam Design/Material
  - Panel to Carrier Structure Attachment
  - Carrier Structure
- Building and Testing of 1m Prototype (engineering test unit) is culmination of Manufacturing, AI&P (assemble, integration and production) and Design/Analysis activities

Technology Maturation Challenges

- System/Manufacturing
  - Seam Design
  - Scalable architecture
    - Forming gores and nose
- Integration
  - Aeroshell sub-structure
  - back shell
- Flight System design tools development and verification
  - Thermal response an example of design tool needed
  - Arc jet testing at relevant scales
  - Prototype Test Unit

Summary

- HEEET woven material options are viable alternatives to heritage carbon phenolic
- Facility upgrades have widened the envelope for ground-based testing capabilities allowing more extreme conditions to be tested
- HEEET team is committed to delivering a mature technology by 2017
  - Successful formulation activities (testing, system studies and planning) and community advocacy has resulted in mission infusion opportunities for upcoming Discovery and New Frontier Missions
  - Team is working challenges in maturing the technology and on-going studies and progress will be reported to the community

Acknowledgements

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- The HEEET team is very grateful to the staff at AEDC , NASA Ames and LHMEL for excellent test support
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