Heatshield for Extreme Entry Environment Technology (HEEET) – Enabling Missions Beyond Heritage Carbon Phenolic

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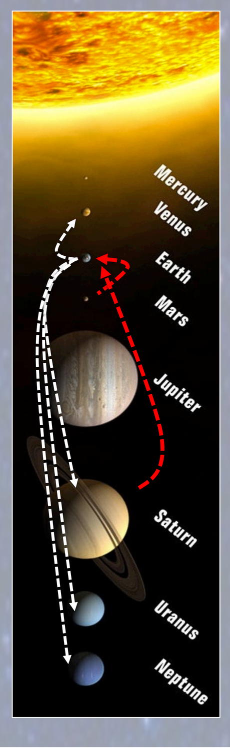
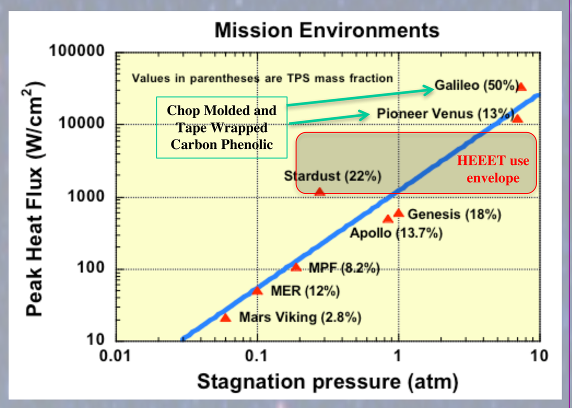
1: Heritage Carbon Phenolic – Sustainability Challenges

- NASA's future robotic missions utilizing an entry system into Venus and the outer planets, results in extremely high entry conditions that exceed the capabilities of state of the art low to mid density ablators such as PICA and AVCOAT
- In the past mission planners had to use a fully dense carbon phenolic heat shield similar to what was flown on Pioneer Venus and Galileo.
- Carbon phenolic is a robust TPS material however its high density & relatively high thermal conductivity constrain mission planners to steep entries, high heat fluxes & pressures and short entry durations.
  - The high entry conditions pose challenges for certification in existing ground based test facilities
- Longer-term sustainability of CP continues to pose challenges especially with the chopped molded nose cap.



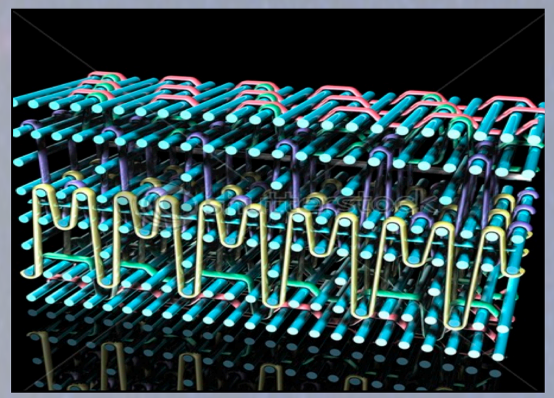
NASA has decided to invest in new technology development rather than invest in reviving carbon phenolic.

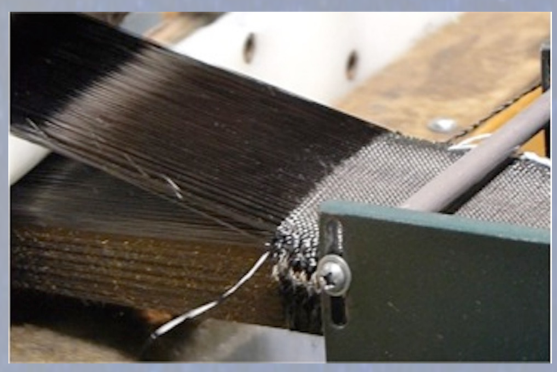


2: HEEET - 3D Woven TPS for Extreme Entry Environments

HEEET – co-funded by NASA's Space Technology Mission Directorate and Science Mission Directorate to mature and scale-up a game changing Woven TPS technology for insertion into future NASA robotic missions.

- HEEET leverages a mature weaving technology that has evolved from a well-established textile industry
- HEEET has down selected a single Woven TPS architecture for maturation.
  - Architecture consists of a high density all carbon surface layer designed to manage recession and a lower density insulating layer composed of a blended yarn to manage heat load.
  - This HEEET architecture is infused with phenolic
  - A layer to layer weave is utilized in HEEET which mechanically interlocks the different layers together and minimizes TTT thermal conductivity
  - Dual layer design allows some tailor-ability of TPS for mass efficiency across a wide range of entry environments


Schematic of complex 3D weave


Weaving dual layer HEEET construct

HEEET project goal is to mature the heat-shield system that is efficient for NASA missions based on woven TPS technology to TRL 6 by the end of FY 2018

3: HEEET Mission Infusion

NASA's Science Mission Directorate encouraged the adoption of HEEET technology by the community for mission infusion into the the New Frontiers - 4 proposals

- HEEET is an incentivized new technology for New Frontiers - 4
- Multiple mission proposals (NASA's NF-4) have availed themselves of this opportunity
- HEEET development is targeted to meet the NASA NF-4 mission requirements

From NNH16ZDA008J Announcement of Opportunity NF 4 Table 4. Infusion strategies of NASA-developed technologies

Technology	What is GFE?	Incentive for use?	Evaluation of Risk?
Heatshield for Extreme Entry Environment Technology (HEEET)	**NASA pays for HEEET team consulting & technology transfer**	**$20M**	**Risk of developing 3Dwoven TPS on time will not impact proposal evaluation.**

Interaction with Proposal Teams:

- Provided in-depth briefing on HEEET technology development
- HEEET Team participation in critical reviews to assess HEEET infusion and gaps
- HEEET Team reviewed proposal implementation approach for HEEET
- HEEET Team provided TPS sizing
- HEEET Team participation is limited to HEEET technology, and not to EDL in general

4: Integration Approach Development

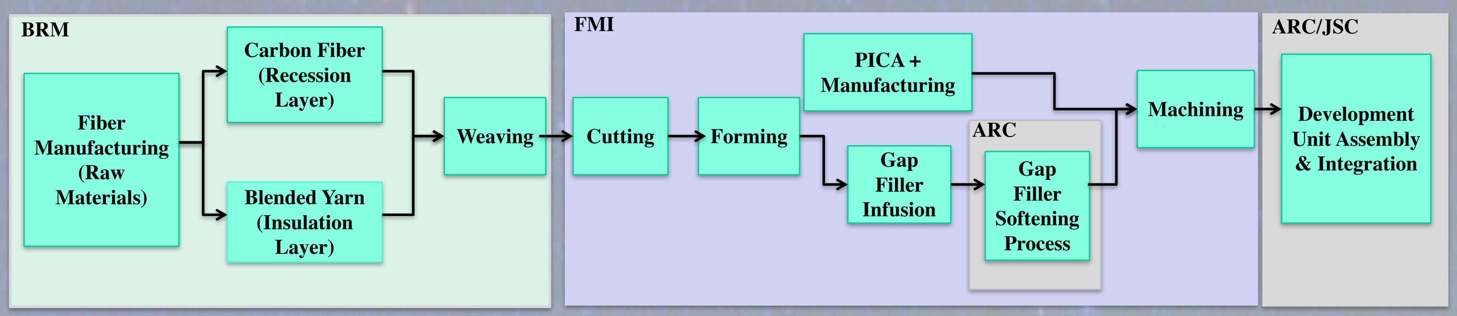
- HEEET extends beyond TPS material development and is maturing a system – therefore a system integration approach needs to be established and integration challenges addressed.
- HEEET is fabricating and testing a relevant scale (1m) Engineering Test Unit (ETU)
- ETU geometry, interfaces and testing conditions have to trace back to the mission requirements, loads and environments to the extent possible within ground facilities
  - Entry structural loads (pressure and deceleration loads)
  - Thermal environments (hot soak and cold soak)
  - Shock loads
  - Launch loads

ETU Tile Integration Approach

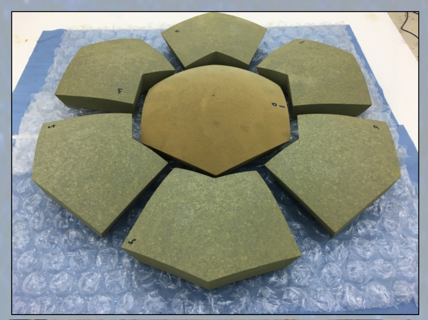
Multi step integration approach required:

- Woven preforms are molded, resin infused, cured and machined
- Individual tiles are bonded on to the carrier structure
- Channels along tile to tile joints are routed
- Seam material is bonded in place
- Outer mold line is machined

Integration development Units - used to develop and refine processes.

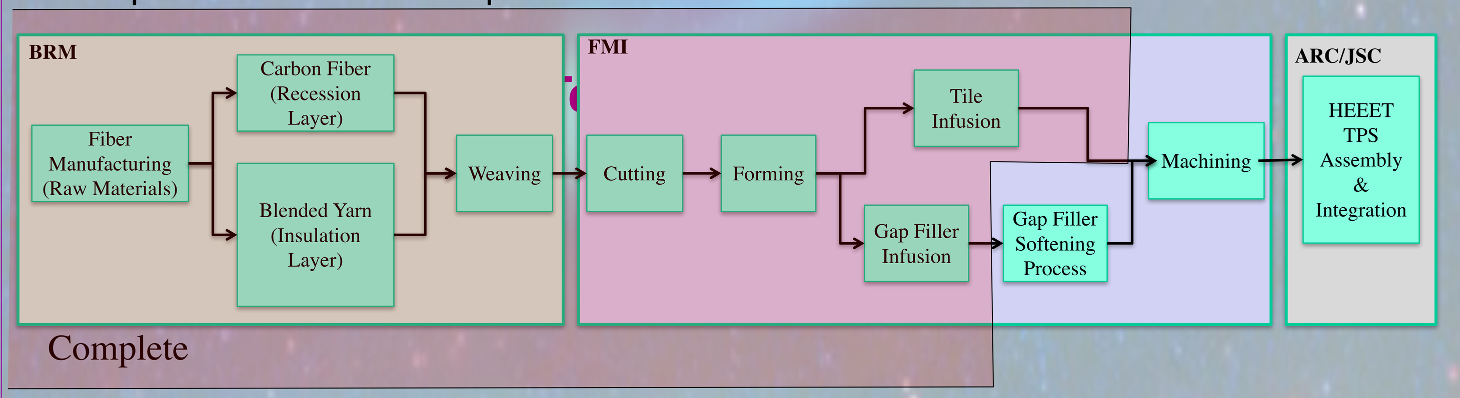


- Utilize PICA+ TPS surrogate (a higher density version of PICA) to simulate the carrier structure and the HEEET tiles
  - PICA+ has similar CTE as HEEET and carrier structure composite
- Individual PICA+ tiles were machined
- Worked through each integration step from tile bonding, channel routing, seam install and final OML machining
- Finalized integration procedures
- Full size ETU tiles were used, representing a nose cap and first ring of tiles



ETU Manufacturing Status

- Weaving, forming and infusion of tiles and gap filler are complete
- Carrier structure fabrication complete
- Tile machining in progress
- Gap Filler fabrication in process

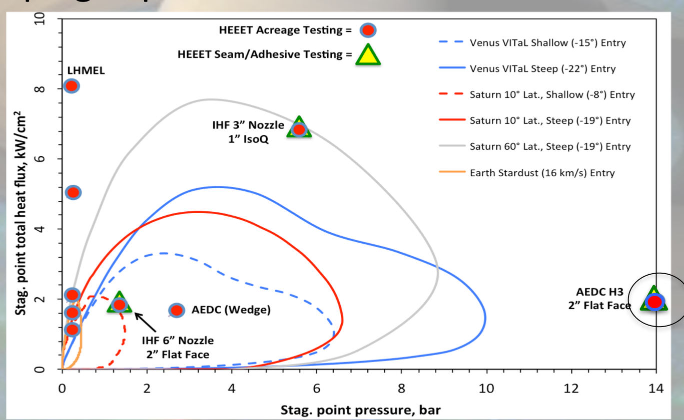


5: Thermal / Arc Jet Testing

HEEET is a capability development project and not tied to a single mission – challenging to complete ground testing needed to demonstrate the capability for all conditions of interest.

- HEEET testing is broader than any single mission/destination. HEEET team engaged stakeholders to ensure mission relevant heat flux / pressure environment testing
- The HEEET thermal / aerothermal test campaign spans four facilities and at least twelve test conditions
- Test range:

Heat Flux W/cm²	Pressure atm	Shear (Pa)
250 - 8000	0 – 14 atm	0 - 4000



- Test objectives:
  - Test acreage & seam to guide HEEET architecture down-select and requirements verification
  - Demonstrate applicability of chosen design under high heat flux, pressure and shear for relevant Venus and/or Saturn mission profiles (look for failure modes)
  - Develop a thermal response model for future proposers to use for TPS sizing and analysis

6: Structural Testing

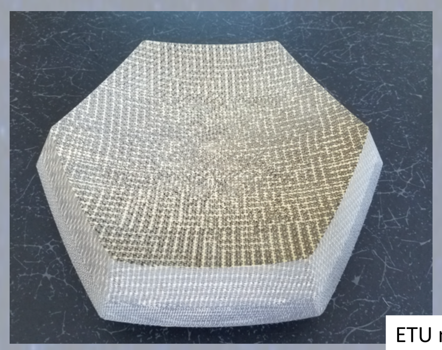
- Element, subcomponent, component and subsystem level testing are being performed to verify the structural adequacy of the ETU
  - Analytical work will be used to evaluate vehicles > 1-meter diameter
- Component Test Objectives:
  - Verify seam structural performance on a large scale with anticipated ETU representative stress levels
  - Verify entry stresses in seams under relevant thermal environments
- Subsystem Testing: ETU testing will verify the performance of the HEEET design for the given thickness under all mission loading events except acoustic environments and entry

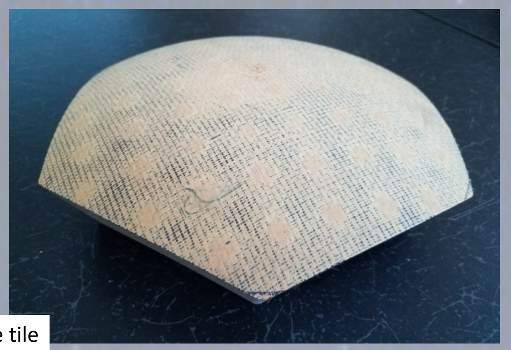
Level	Material/Test Description	Rationale	Simplified Requirements/Mission Phases: Vibe During Launch/Ascent	Acoustic During Launch/Ascent	Cold Soak	Hot Soak	Shock	Entry
Component	TTT Tension Test	Bondline Adhesive Allowable Development	T	T	T	T		T
	Seam Tension (1")	Seam tensile allowable development	T	T	T	T		T
	Seam Tension (2.1")	Seam tensile allowable development	T	T	T	T		T
	Flexure Test w/ Seam	Seam flexural allowable	T, A	T, A	T, A	T, A		T, A
	LHMEL Flexure Test w/ Seam	Flexural testing under entry heating	T, A	T, A	T, A	T, A		T, A, V
Subsystem	ETU	ETU Testing in 2017	T, A, V	A	T, A, V	T, A, V	T, V	T, A, V

T: Test
A: Analysis
V: Verification

7: Recent Accomplishments

1. **Manufacturing**
   - Weaving scaled up to 25-in width @ 2-in thickness
   - Successfully formed & infused all tiles to support ETU build
   - ETU tile machining in process


ETU nose tile

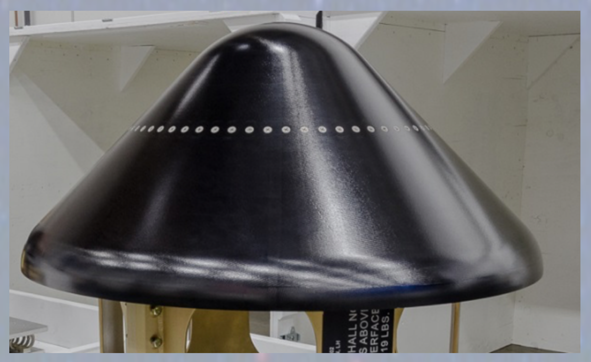


2. **Seams**
   - Completed seam arcjet testing @ AEDC facility (downselected integration approach used for coupon fabrication)
   - Completed LHMEL 4pt Bend testing
   - Matured Seam/Tile integration approach


Post-test Seam Arcjet Model

3. **ETU:** composite carrier structures fabricated

4. **HEEET Independent Reviews** (Reviewers: APL, Goddard, JPL, JSC, KSC, LaRC and UC Boulder)
   - ETU system requirements review (Sep 2014)
   - Design review (February 2015)
   - Thermal test plan review (June 2015)
   - Structural test plan review (February 2016)
   - Manufacturing and Integration review (March 2016)
   - Failure modes and margins review (Dec 2016)
   - ETU Manufacturing, Schedule and Future Work Review (Feb 2017)


Carrier Structure

8: Summary

- Woven TPS is a game-changing approach to designing, manufacturing, and integrating a TPS for extreme entry environments by tailoring the material (layer thicknesses) for a specific mission
- A comprehensive set of requirements have been developed which is guiding testing/analysis required for verification
- Given constraints on weaving technology a heat shield manufactured from the 3D Woven Material will be assembled from a series of panels, which results in seams between the panels
- Seam design needs to meet both structural and aerothermal requirements
- Down-selected use of Expanding Softened HEEET (ESH) as a gap filler in the seam design
- Seam approach has demonstrated excellent performance in the arcjet at > (5000 W/cm² heat-flux and 5 atmospheres of stagnation pressure)
- Project is currently on target to mature HEEET to TRL 6 in support of next New Frontiers for which it is incentivized

9: Acknowledgements

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