Heatshield for Extreme Entry Environment Technology (HEEET) Development and Maturation Status for NF Missions

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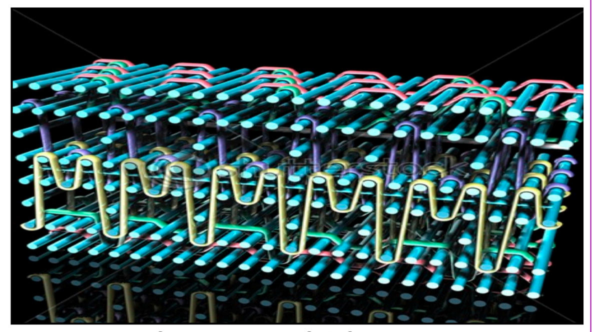
1. HEEET Background/NF Proposal Team Interaction

- HEEET is a game changing core-technology that is being designed with:
  - Broad mission applicability and long term sustainability
  - Substantial engagement with TPS community
  - HEEET goal is to develop a woven TPS technology to TRL 6 by the end of fiscal year 2017
  - HEEET leverages a mature weaving technology that has evolved from a well-established textile industry
  - Dual layer design allows some tailor-ability of TPS for mass efficiency across a wide range of entry environments



Complex 3D multi-layer weave

Interaction with NF-4 Proposal Teams

Recent New Frontiers Community Announcement of Opportunities states :

"NASA is also considering providing an increase to the PMMC cap for investigations utilizing the Heat Shield for Extreme Entry Environment Technology (HEEET), a woven Thermal Protection System."

Interaction with Proposal Teams:

- Provide in-depth briefing on HEEET technology development
  - Particular focus on carrier structure-TPS integration and analysis required for specific mission design
  - Conduct a Workshop targeted towards NF-4 Proposal teams planning to baseline HEEET
- HEEET Team anticipates participation in critical reviews to assess HEEET infusion and gaps
- HEEET Team anticipates reviewing proposal implementation approach of HEEET and to provide a credibility assessment report
- HEEET Team participation is limited to HEEET technology, and not to EDL in general

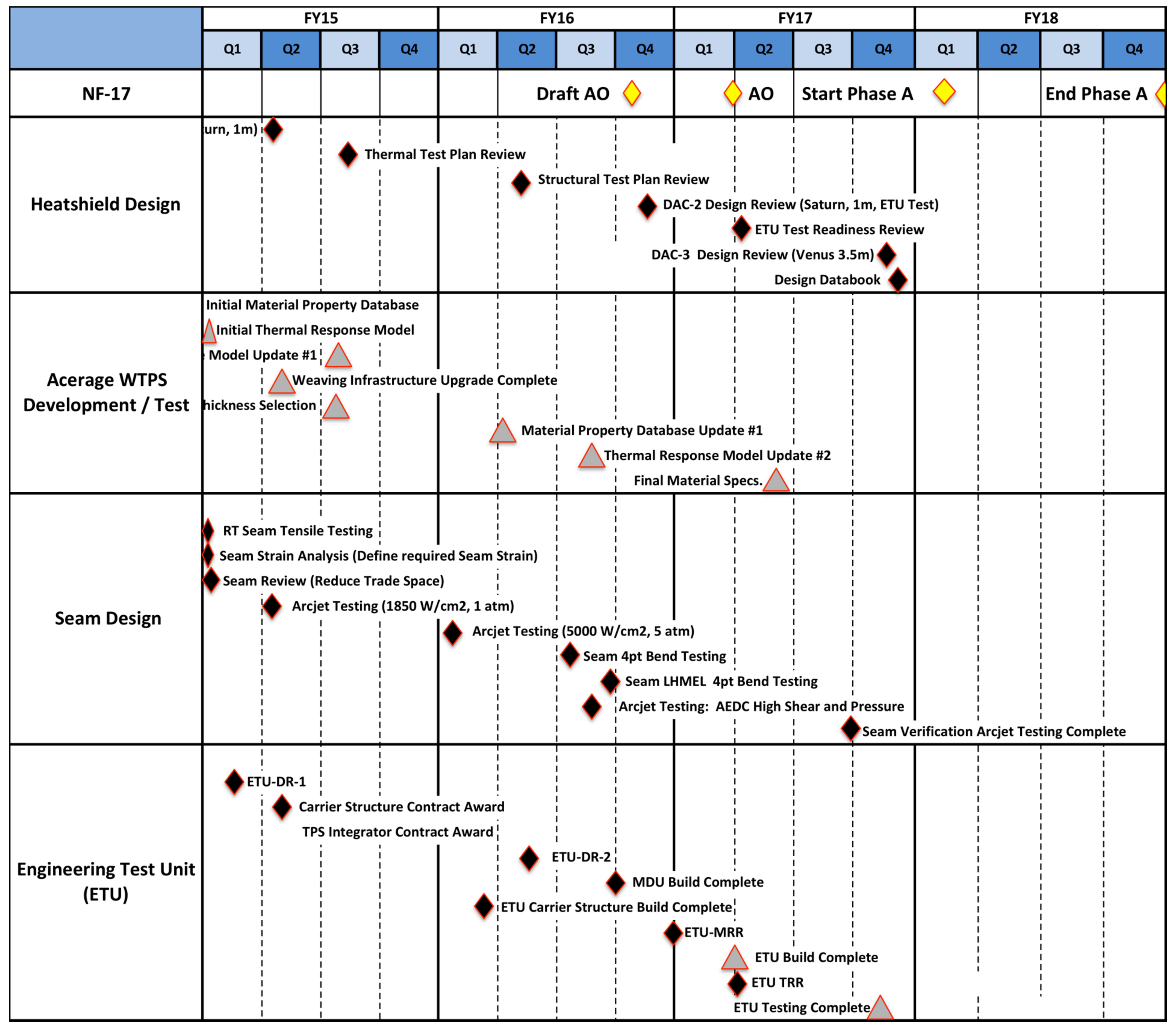
Proposal Team Responsibilities

- **Trajectory Analysis, Aeroheating (CFD), Payload and Compatible Aeroshell Sizing, Carrier Structure Design and Structure Costing, Engineering Science Instrumentation**
- **HEEET Design:**
  - HEEET team provides constraints on tile size and lessons learned from Saturn Probe Design
- **MDU/EDU and other required testing:**
  - Test Definition/Costing
  - HEEET team provides HEEET specific limited guidance on issues
- **HEEET Costing and schedule**
  - HEEET team provides background on manufacturing process, ID's sources for raw materials, vendors supporting manufacturing steps, but proposal team must negotiate directly with suppliers for detailed cost estimates and lead time and integrated schedule
- **# of heat shields**
  - Flight + spare + EDU + MDU, etc…
  - This coupled with testing requirements etc….will define how much woven material is required
    - Given the high cost of set-up would be advisable to set up loom only once and weave everything.
- **Proposal writing related to HEEET**

HEEET Team Responsibilities

- **Aerothermal constraints, TPS thickness constraints, TPS Sizing**
  - Constraints on trajectories based on manufacturing limitations
  - HEEET surface roughness estimates to be used by proposal team to compute roughness heating augmentation
  - HEEET Team will perform limited sizing for design trajectories
  - Guidance on margin policy for HEEET
- **Carrier Structure Guidance**
  - Seam strain level, Radius of curvature, Interface with payload, etc
  - ETU carrier design under development (Ref: Saturn Entry Probe)
- **Guidance on estimating implementation cost and schedule**
  - HEEET team will not conducted detailed cost estimates or develop implementation schedule.
  - Will provide vendors utilized for ETU build and detailed insight into integration
- **Guidance on HEEET specific implementation tasks (> TRL 6)**
- **Guidance on Risks/Challenges related to implementation of HEEET for specific proposal**
- **HEEET Implementation credibility review**
  - Will review final cost, schedule and technical aspects of HEEET implementation and provide a written report
  - Not an embedded design function
- **Engineering Science Instrumentation**
  - Provide lessons learned from ground based instrumentation. ESI is outside the scope of HEEET development

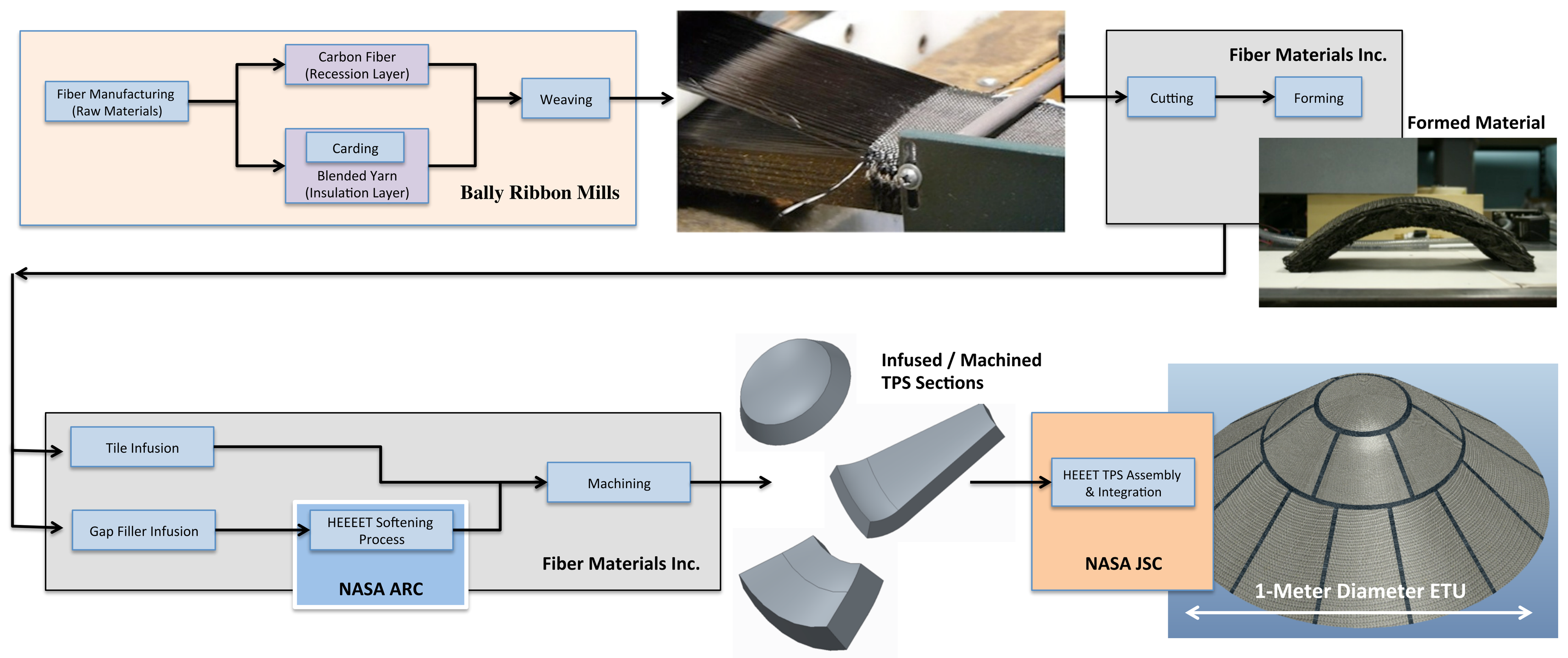
HEEET Project Schedule



- NF Target Dates: Phase A Down-select May 2019; KDP B August 2019 with PDR following

2. Architecture and Engineering Test Unit (ETU) Manufacturing Plan

- HEEET project has prioritized a dual layer TPS architecture for maturation - A layer-to-layer weave is utilized, which mechanically interlocks the different layers together in the thru-the-thickness direction
  - High density all carbon surface layer developed to manage recession
  - Lower density layer is a blended yarn to manage heat load
  - Woven architecture is then infused with an ablative resin

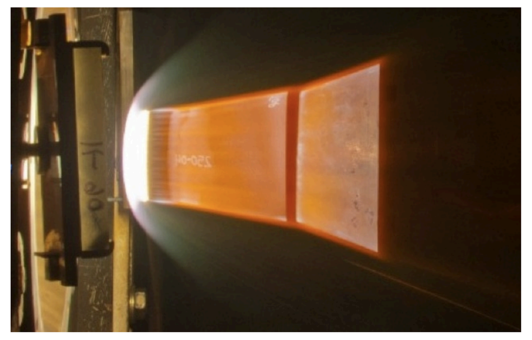


- ETU geometry, interfaces and testing conditions have to trace back to the mission requirements, loads and environments to the extent possible within ground facilities
  - Entry structural loads (pressure and deceleration loads)
  - Thermal environments (hot soak and cold soak)
  - Shock loads
  - Launch loads

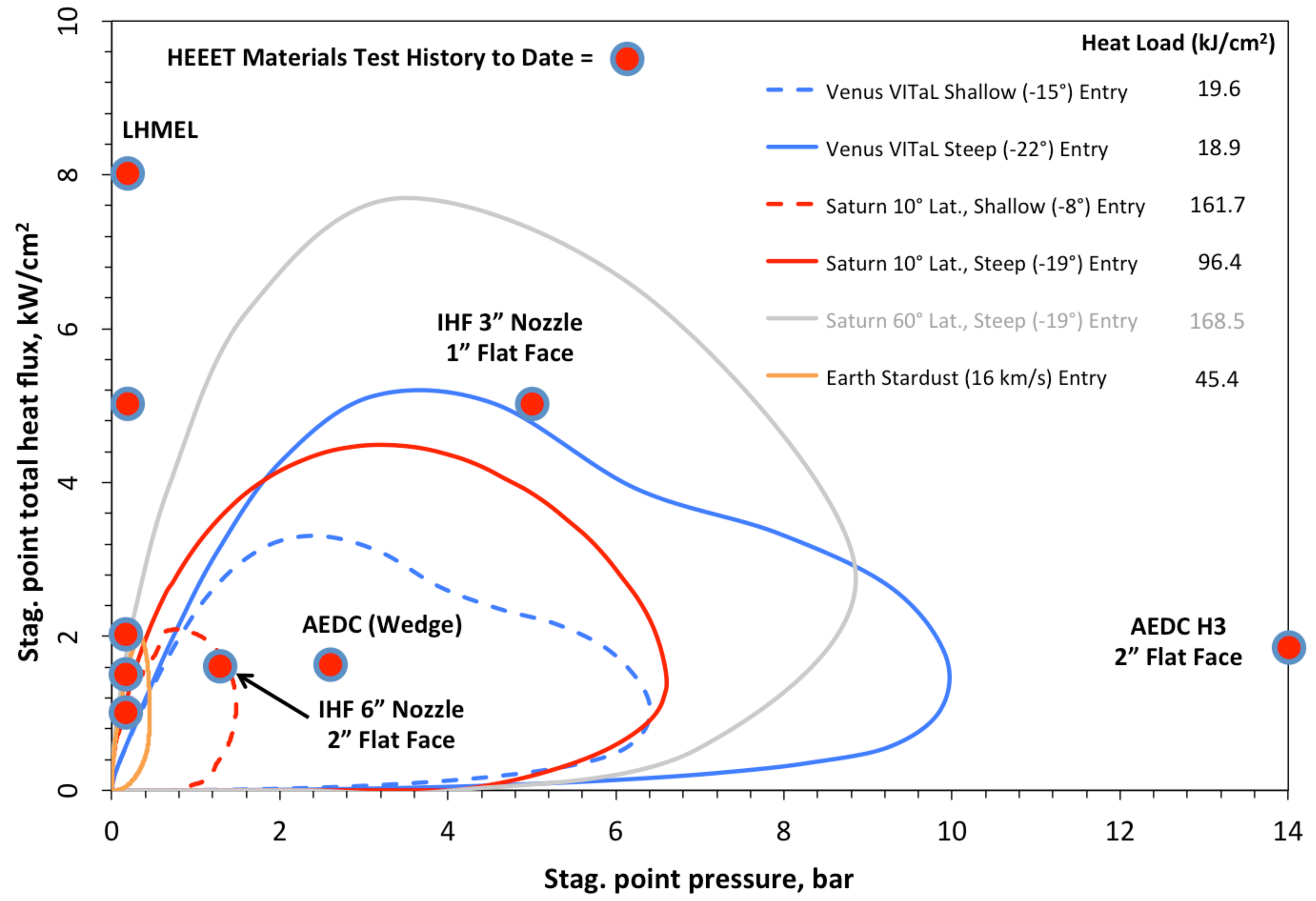
3. Thermal /Arcjet Test Plan

- The HEEET thermal / aerothermal test campaign spans four facilities and at least twelve test conditions
- Test range:

Heat Flux W/cm^2	Pressure atm	Shear (Pa)
250 - 8000	0 – 14 atm	0 - 4000



- Test objectives:
  - Test acreage and 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



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4. Structural Testing

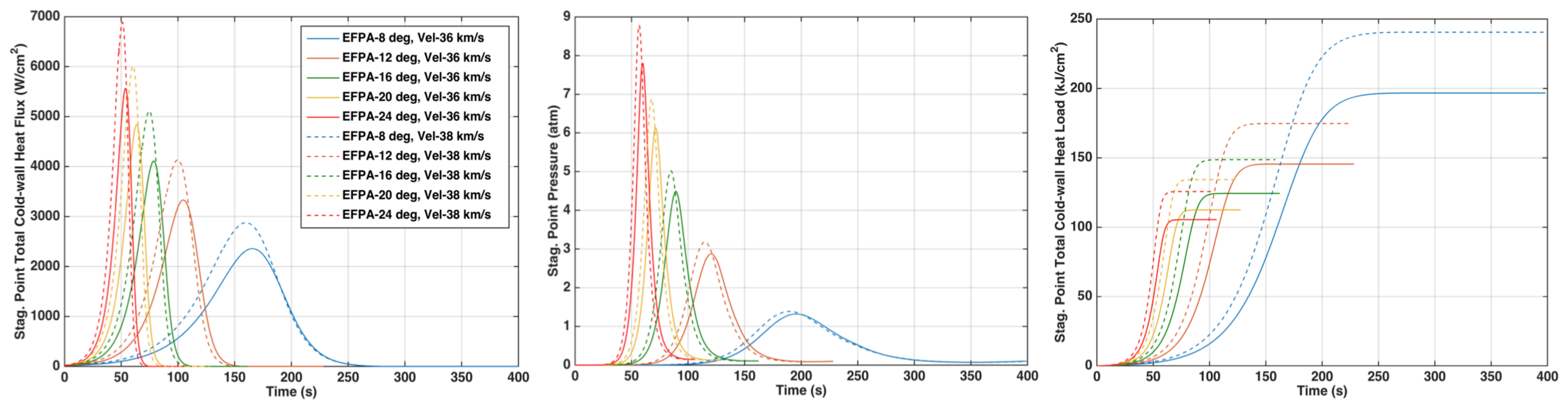
- Element, subcomponent, component and subsystem level testing are being performed to verify the structural adequacy of the ETU
  - Analytical work will be used to evaluate vehicles > 1-meter diameter
- Component Test Objectives:
  - Verify seam structural performance on a large scale with anticipated 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

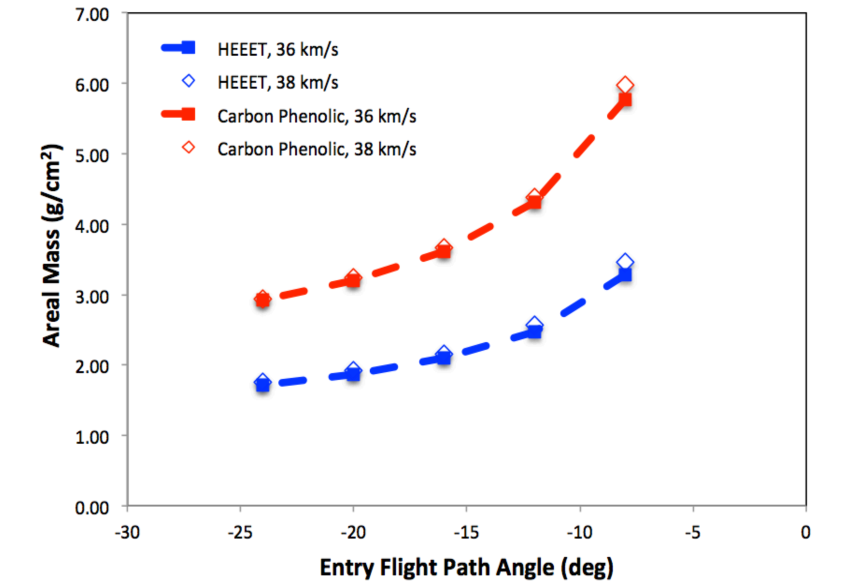
T: Test
A: Analysis
V: Verification

5. TPS Sizing for Saturn

- Stagnation point analysis
  - 200 kg, 1-meter diameter, 45-deg spherecone entry vehicle with a nose radius of 25 cm
  - Inertial entry velocities of 36 and 38 km/s. Entry flight path angles of -8, -12, -16, -20 and -24 deg
  - Equatorial entry in the eastern direction



- Areal mass of the 2-layer HEEET TPS is ~58% of the mass of fully dense carbon phenolic
  - Analysis holds true for a broad range of entry trajectories
- Sizing results are for zero margin utilizing preliminary thermal response model



6: Recent Accomplishments

1)Manufacturing
1) FMI under contract for Forming/Infusion for MDU
2) FMI completed machining study on Nosecap pathfinder

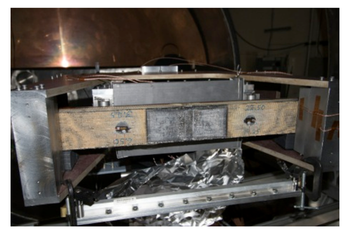
2)Seams
1) Completed seam arcjet testing @ >5000 W/cm^2 and 5 atm
2) Completed shakedown test on LHMEL 4pt Bend testing
3) Maturing Seam/Tile integration approach

3) MDU/ETU: composite carrier structure is in fabrication

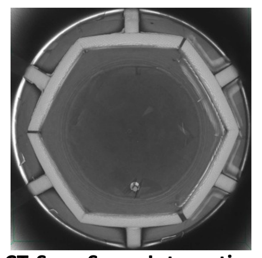
4) HEEET Independent Reviews (Reviewers: APL, Goddard & JPL)
1) ETU system requirements review (Sep 2014)
2) Design review (February 2015)
3) Thermal test plan review (June 2015)
4) Structural test plan review (February 2016)

Post Machined Nose Cap Pathfinder

Post-Test Seam Arcjet Model



Post-test Seam LHMEL 4pt Bend Evaluate seam structural performance under aero heating



CT-Scan Seam Integration Development Article

7: 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
- Baselined use of Softened HEEET (SH) as a gap filler in the seam design
- Seam approach has demonstrated excellent performance in the arcjet at >5000 W/cm^2 and 5 atm
  - Requires thin adhesive bond line between acreage tiles and SH gap filler
- Project is currently on target to mature HEEET to TRL 6 in support of next New Frontiers