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

D. Ellerby§, A. Beerman*, M. Blosser%, T. Boghozian*, J. Chavez-Garcia*, R. Chinnapongse§, M. Fowler§, P. Gage#, M. Gasch§, G. Gonzales*, K. Hamm§, C. Kazemba, J. Ma§, M. Mahzari§, F. Milos§, O. Nishioka§, K. Peterson*, C. Poteet%, D. Prabhu*, S. Splinter%, M. Stackpoole§, E. Venkatapathy§ and Z. Young§

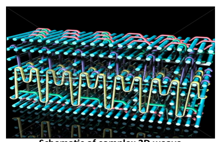
§ NASA ARC; %NASA LaRC; $NASA JSC; *ERC Inc.-Moffett Field, CA; #NEERIM Corp.-Moffett Field, CA

1: Background – Thermal Protection Systems

- In 2013 the NRC Decadal Survey Recommended
  - Probes to Venus, Saturn and Uranus
  - High-speed sample return missions
- Pioneer Venus & Galileo Jupiter probes used 2D Carbon Phenolic (CP)
  - CP is a very robust TPS
  - Heath shields made with CP require tape-wrapped & chop-molded CP
- There are significant challenges with using 2D "heritage-like" CP
  - Availability of constituents (Carbonized Avtex Rayon)
  - Chop-molded CP has not be used for TPS since 1980s and will need recertification for future NASA Missions (expensive)
  - CP is a poor insulator – and to be mass efficient typically drives to steep entry flight path angles resulting in high heat fluxes and high G-loads
- A broad category of both robotic and human exploration missions would benefit from a tailorable mid-density TPS
  - Greater efficiency means lower TPS mass fraction (more science!)
  - Enable lower entry angles & lower G-loads

2: 3D Woven TPS for Extreme Entry Environments

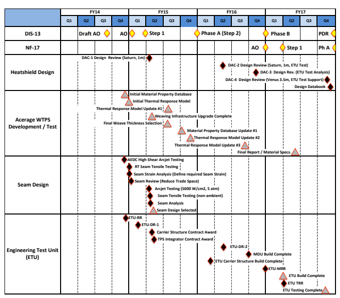
- HEEET is a game changing core-technology that is being designed with:
  - Broad mission applicability
  - Rapid mission insertion focus & substantial engagement with TPS community
  - Long term sustainability
- HEEET leverages a mature weaving technology that has evolved from a well-established textile industry



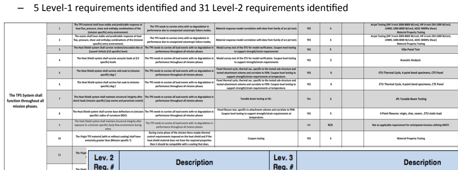
Schematic of complex 3D weave

- Dual layer design allows some tailor-ability of TPS for mass efficiency across a wide range of entry environments
- HEEET goal is to develop a woven TPS technology to TRL 6 by the end of fiscal year 2017
  - Will enable in-situ robotic science missions recommended by the NRC Planetary Science Decadal Survey

NASA's Science Mission Directorate encouraged the development of this new TPS technology by the community for mission infusion into the Discovery 2014 proposals
- **Risk of developing 3D Woven TPS on time would not impact proposal evaluation**
- **Adoption of HEEET was incentivized (Cost of 3D Woven TPS material up to $10M)**
- **NASA pays for HEEET team consulting and technology transfer**



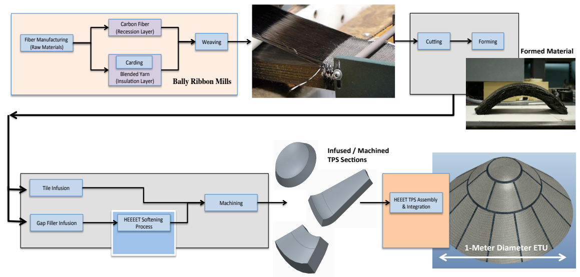
- HEEET team has developed a set of requirements from a mission performance perspective with the verification written as a project technology development goal
  - Have sought input from community on requirements via HEEET workshop
  - 5 Level-1 requirements identified and 31 Level-2 requirements identified



Lev. 2 Req. #	Description	Lev. 3 Req. #	Description
1	The acreage TPS material shall have predictable thermal response at heat flux, pressure, shear and enthalpy combinations of the (mission specific) entry environment.	1.1	The acreage material's recession depth shall be predictable by 50% (TBR)
		1.2	The thermal response model for acreage TPS material shall predict the temperature at the interface between recession and insulating layers within TBD K
		1.3	The thermal response model for acreage TPS material shall predict the temperature at the interface between TPS and substructure within TBD K
		1.4	The TPS material's thickness loss across acreage shall not vary by more than 50% (TBR) of the recession layer initial thickness for any given test article
2	TPS seams shall have predictable thermal response at heat flux, pressure, shear and enthalpy combinations of the (mission specific) entry environment.	2.1	The TPS material's thickness loss across seams shall not differ from adjacent acreage thickness loss by more than 50% (TBR) of the recession layer initial thickness for any given test article.

3: 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

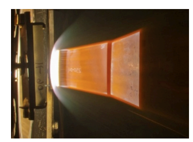


- ETU geometry, interfaces and testing conditions have to trace back to the mission requirements, loads and environments to the extent possible within ground facilities
  - Entry structural loads (pressure and deceleration loads)
  - Thermal environments (hot soak and cold soak)
  - Shock loads
  - Launch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

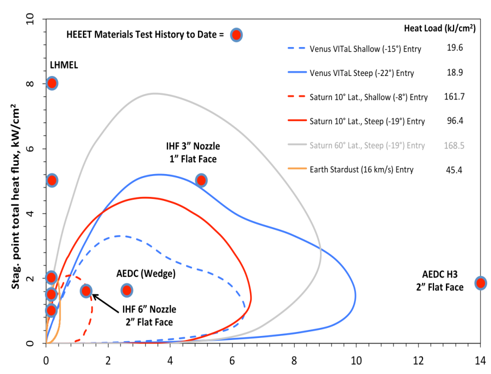
4: Thermal /Arcjet Test Plan

- 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 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



Acknowledgements

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- Authors would like to thank the center managements at ARC, LaRC and JSC for their continuing support

5: Structural Testing

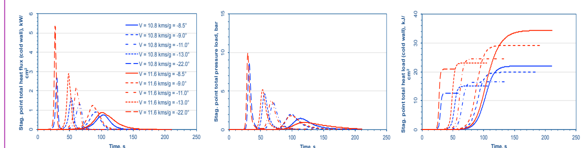
- Element, subcomponent, component and subsystem level testing are being performed to verify the structural adequacy of the ETU
  - Analytical work will be used to evaluate vehicles > 1-meter diameter
- Component Test Objectives:
  - Verify seam structural performance on a large scale with anticipated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

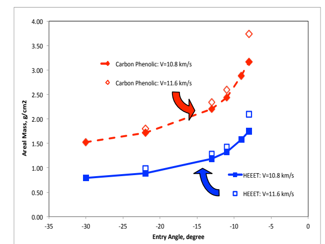
6: TPS Sizing for Venus

- Stagnation point analysis
  - Trajectories are terminated at Mach = 0.8 (+10 seconds after typical Mach termination)
  - Max Heat Flux: 5 kW/cm2 (V=11.6 km/s, H=22°)
  - Max Heat Load: 34 kJ/cm2 (V=11.6 km/s, H=8.5°)



Venus environments produced by Dinesh Prabhu with support from the EVT program

- Areal mass of the 2-layer HEEET TPS is ~ 50% 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



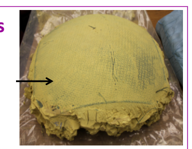
7: Recent Accomplishments

1)Manufacturing
1) Weaving scaled up to 12-in width @ 2-in thickness
2) Successfully formed & infused a nose cap for 1m vehicle with 12-in weave
3) MDU/ETU resin infusion vessel modification completed by FMI

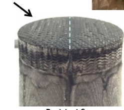
2)Seams
1) Completed seam arcjet testing @ 1850 W/cm² and 1.3 atm
2) Completed preliminary seam structural testing
3) Baselined seam design

3) MDU/ETU: composite carrier structure contract awarded

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



12-inch Diameter Resin Infused Molded Nose cap



Post-test Seam Arcjet Model

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
- Initial arc jet testing of the HEEET TPS indicates that the acreage material is very robust and performs as well as "heritage like" carbon phenolic materials
- 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
  - Substantial progress has been made on developing a Seam design that meets both structural and aerothermal requirements
- Project is currently on target to mature HEEET to TRL 6 by FY17