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| Title: Overview of Heatshield for Extreme Entry Environments Technology (HEEET) | | | Page #: 1 of 8 |

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## The Need

Venus probes and landers, Saturn and Uranus probes, and some high speed sample return missions have been highly ranked for their scientific value by the National Research Council (NRC) Planetary Science Decadal Survey (PSDS) committee. Due to their extreme entry environments, thermal protection system (TPS) options for these missions are limited to a single heritage material: Carbon Phenolic (CP). The HEEET project is developing a woven TPS technology that will provide an efficient and readily-manufacturable heat shield material for entries with heating rates between 1500 w/cm$^2$ and 8,000 W/cm$^2$ and stagnation pressure between 1.0 atm and 10 atm. If mission designers have the flexibility to keep environments towards the lower end of this range, the quality of performance verification that can be achieved in existing ground test facilities can be significantly enhanced (which also applies to qualification of a new CP material). Bringing this new TPS capability to TRL 5/6 will enable mission selection in competed NASA opportunities.

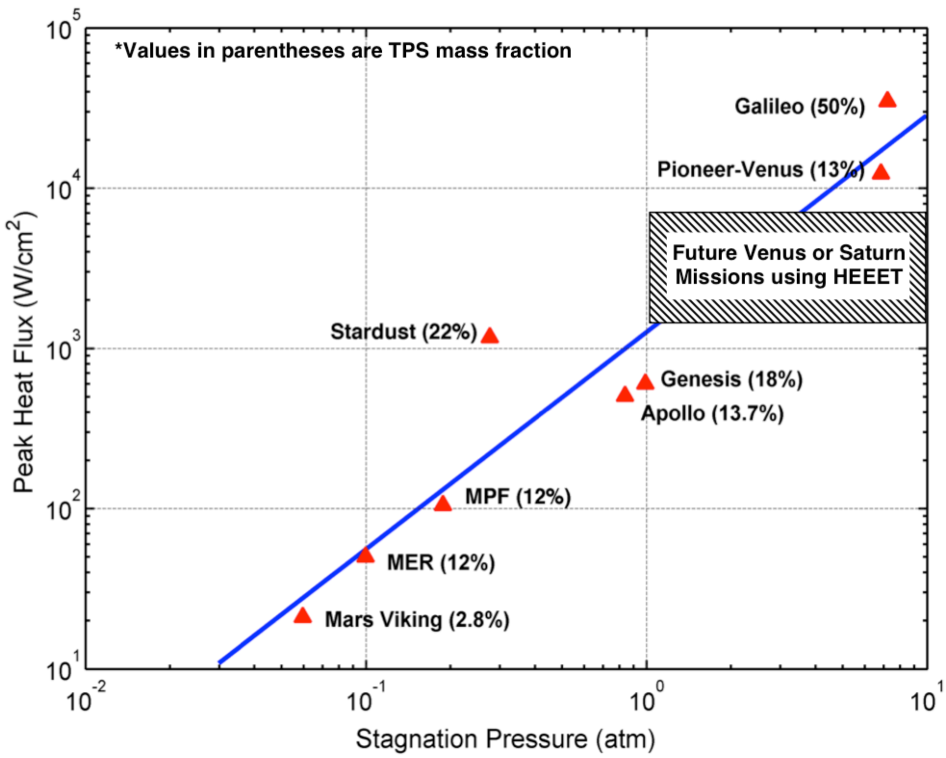


*Figure 1. The HEEET project will develop efficient and robust thermal protection material for extreme entry environments*

While CP is an excellent ablator that can withstand extreme heating rates, its high conductivity makes it inefficient for shallow entries that have high integrated heat loads. The HEEET material system is structured with a high density layer of carbon fibers at the surface designed to provide robust recession performance backed by a thicker layer of lower density blended yarns that provides insulation to the bondline between the TPS and the carrier structure. The superior insulating performance of this dual-layer structure can enable shallower entry (and lower inertial loads for the payload) or deliver significant TPS mass savings (so that more payload can be carried for the same entry mass).

Although CP has mission heritage from Pioneer Venus and Galileo, the heritage rayon based carbon fiber is no longer available and manufacturing processes require recertification. Exact reproduction of previously-flown CP is not possible, which increases uncertainty about the performance and reliability of a new CP product. In contrast, the HEEET material system employs readily-available carbon fibers that are produced for a range of other applications. Sustainable production is an explicit goal for the HEEET project.

In order to make a blunt heat-shield, for NASA applications, two different manufacturing techniques are needed for carbon phenolic in the nose and flank regions. The tape-wrapped version that is suitable for the flank is used extensively for Department of Defense rocket nozzle applications. The chop-molded form of CP, which has been used on the nose of NASA vehicles and is NASA unique for entry applications, has displayed a spallation failure mode in some ground tests. The three-dimensional weave employed in HEEET materials improves robustness, so that recession is more controlled in similar aerothermal environments.

*Figure 2. The woven TPS at right shows no indication of mechanical loss of material, in contrast with the chop-molded CP at left.*

## Technology Concept

The weaving industry has made dramatic progress on automated techniques in recent years. They now control accurate placement of fibers of different composition to manipulate material composition, density and fiber orientation. A TPS material with distinct functional layers is now achievable. Near the surface, carbon fibers are woven layer to layer, so that loss of fibers binding layers together does not cause simultaneous loss of multiple layers. This weave architecture should mitigate ply lift and delamination failure modes inherent in 2-D carbon phenolic.

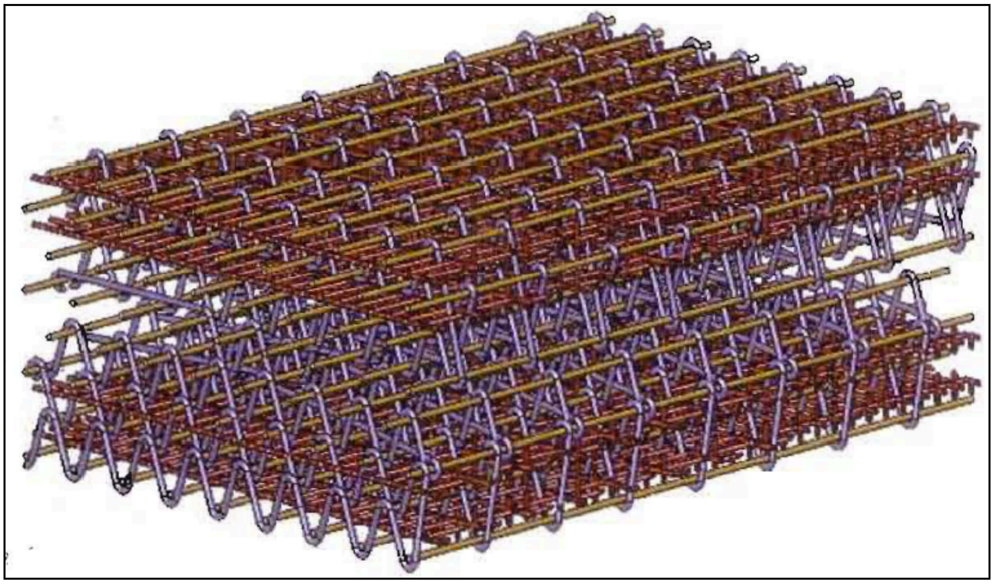

*Figure 3. Three dimensional weave avoids simultaneous loss of multiple layers, and permits through-the-thickness tailoring of density.*

In the insulating layer, a blended yarn that combines carbon and phenolic fibers is used, to reduce fiber conductivity. In this layer the fiber density is lower, to further reduce conductivity. Figure 3 shows a schematic of a generic 3D layer to layer weave that shows the ability to vary density and composition. In this case there is a higher density top layer, a lower density middle section and a higher density bottom section (however the HEEET material is only a dual layer).

Near-term HEEET development will concentrate on a specific weave architecture suitable for harsh environments, but it is possible to tailor the weave to achieve densities between that of Carbon Phenolic and PICA, without changing the manufacturing technique. Three-dimensional weaving is already being developed for Orion compression pad and for deployable heatshields. A family of robust materials can be developed in the future to support atmospheric entry at multiple destinations.

The woven material comes off the loom at constant width: the HEEET project is working with a commercial vendor to develop a loom capable of weaving 24” wide and up to 3” thickness. A large heatshield must therefore be constructed from several panels, which are cut to shape and joined to each other. The material is formed to the heatshield shape while it is dry, and then infused with phenolic using a technique similar to that developed for PICA. There are several options for joining heatshield pieces together and attaching them to the structural substrate. Seam design is a current focus for the project, with thermal and structural testing of the options already in progress. Selection of a preferred implementation is planned within 12 months, to support timely construction of technology demonstrator hardware.

## Current Status

The potential benefits of a woven TPS for harsh entry environments have been identified in mission studies, where sizing results for HEEET materials are compared with heritage carbon phenolic for similar entries. The properties assumed for HEEET materials are still being confirmed through testing, but sensitivity analysis shows that mass benefits are significant for all plausible properties. Lighter heatshields are predicted for all destinations that have been evaluated, and for all entry profiles. The benefit is most pronounced for shallow entries, which have lower heating rates and lower deceleration levels.

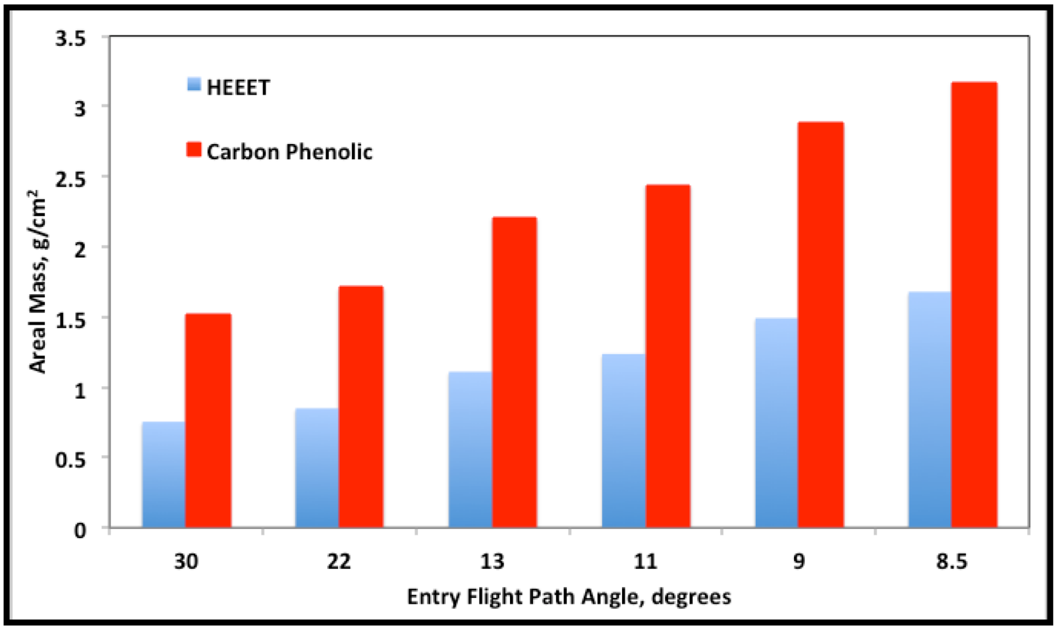


*Figure 4. Thickness sizing results (zero margin) for a 45 degree sphere cone, 3.5 m diameter, for Venus entry at 10.8 km/s, entry mass 2000 kg.*

The primary function of TPS is to survive entry loads and protect the payload from intense heating, so early testing in the HEEET project focused on thermal performance. Figure 5 shows that tests have been conducted at conditions relevant for both Venus and Saturn. Material performance, both with and without seams, has been impressive. Ongoing testing will support development of material response models to predict TPS sizing for relevant missions.

The HEEET project is structured to deliver verification of mission-focused TPS requirements. In addition to entry performance, manufacturing and certifiability are addressed, along with operability in all mission phases, and requirements for interfacing with other subsystems are included.

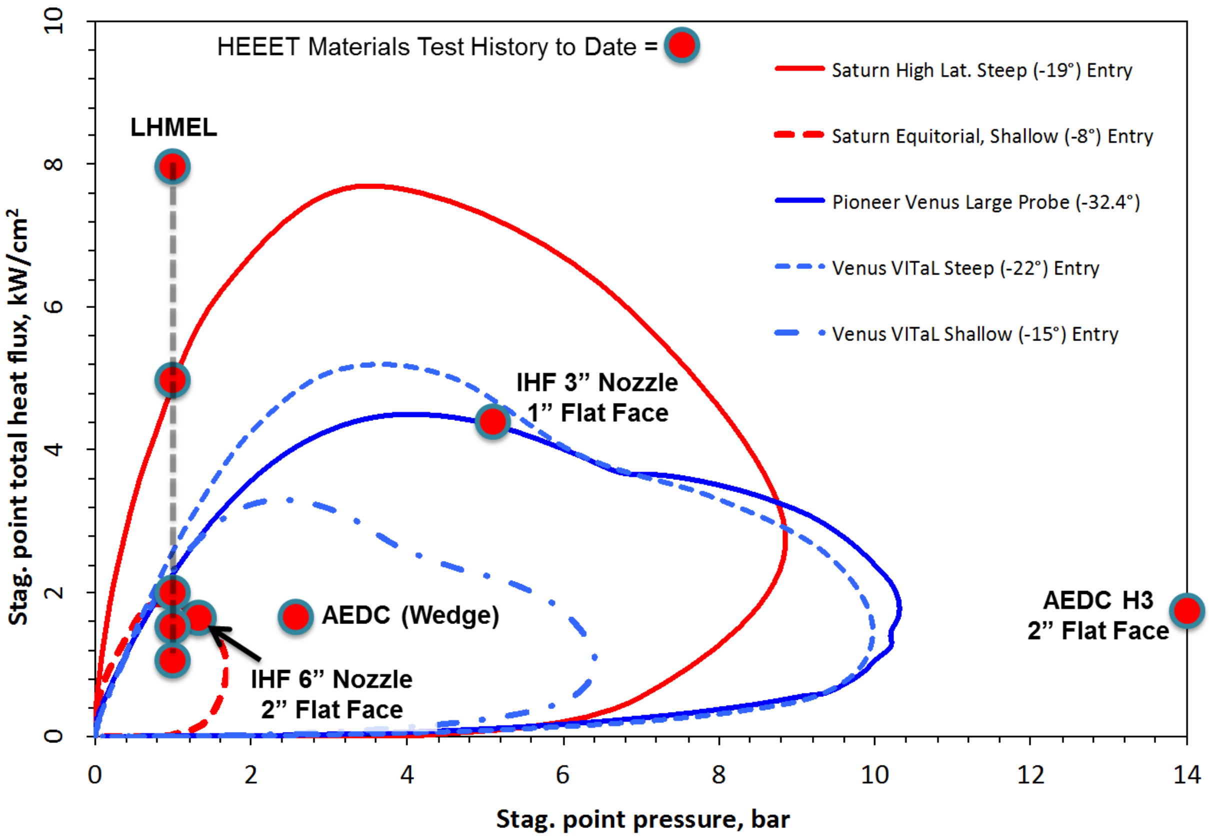


*Figure 5. HEEET materials have been tested in mission-relevant conditions, and at extremes of pressure and heating rate. Failure modes have not been observed to date.*

The set of requirements shown in Table 1 is derived from previous vehicle development, including MSL, Stardust and Orion. The requirements have been refined through interaction with mission designers. Verification statements for each requirement are established, and HEEET project tasks are aligned with each verification. Table 1 also shows that all Level 1 requirements are at or above TRL 3. Wherever the new technology differs from heritage CP and PICA systems, coupon or subscale testing has been conducted to confirm performance is consistent with analytical studies.

## Development Plan

The HEEET project is in the early stages of a 4-year development effort, which was initiated after earlier development efforts established the thermal and structural capability of the woven and infused material. The final product of this project is hardware that demonstrates manufacturing at relevant scale and supports test demonstration of hardware operability in all mission environments. This hardware is scheduled to complete testing during Phase B of Discovery 13, which is consistent with the required schedule for achieving TRL 6.

Figure 6 shows key milestones in each year of the project which support design and manufacturing implementation decisions for the hardware.

| TRL Level | Hardware description | Level 1 Requirements | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Function thermally** | **Function structurally** | **Be operable** | **Be manufact-urable** | **Interface with vehicle** | **Be Certifiable** |
| 3 | **Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.** | Mission studies indicate feasible thicknesses and good TPS mass fractions. | Strength requirements established from analysis of mission-relevant loads. | Analogy with other TPS systems involving carbon and phenolic: benign for dust, out-gassing, etc | Trade studies on candidate manufacturing flows | Concepts for penetrations and closeouts are established | Integrated inspection and repair study is in work. Traceability from ground test to flight similar to previous TPS |
| 4 | **A low fidelity system/ component breadboard is built and operated to demonstrate basic functionality and critical test environments,** | Tests of acreage material and candidate seam concepts in range of arc-jet environment | Coupon tests of woven material and candidate seams indicate adequate strength is feasible. | | Weaving, cutting, bonding, infusion, seam production demonstrated at subscale. | | Flaw detection in weave, infusion and seams demonstrated at subscale. |

*Table 1. For key functional requirements, performance has been demonstrated at coupon scale.*

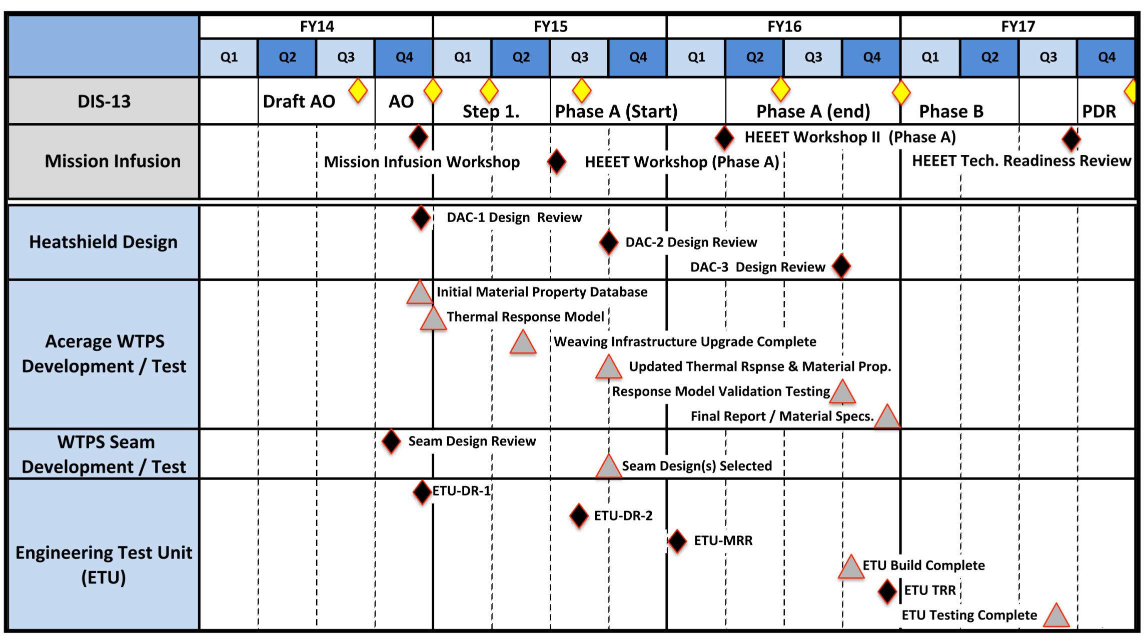


*Figure 6. The HEEET project will culminate with fabrication and testing of heatshield hardware at mission-relevant scale.*

## Summary

Successful development of a new woven thermal protection material will provide a capability that enables entry missions at Venus and Saturn. Sizing studies indicate that the HEEET material it is more mass-efficient than heritage CP material.

The HEEET project has demonstrated functional performance at coupon scale. Weave architecture and infusion level have been downselected for full-scale manufacturing.

Design trade studies are in progress to select an implementation strategy for forming panels and attaching them to heatshield structure and to each other.

A heatshield will be built at mission-relevant scale to achieve TRL 6 for this technology on a schedule that supports Discovery 13 competitive selection.