



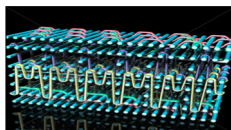
# Heatshield for Extreme Entry Environment Technology (HEET) TPS for Ice Giants Probe Missions

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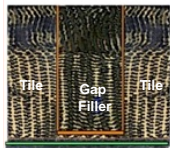
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## 1. HEET Background

- HEET is a game changing technology that is being designed to enable in-situ robotic science missions recommended by the NASA Research Council (NRC) Planetary Science Decadal Survey
- HEET leverages a mature weaving technology that has evolved from a well-established textile industry
- 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
- Primary technical challenge was developing a manufacturable seam that meets aerothermal (reentry heating) and thermal structural requirements
  - Seam = Gap Filler + Adhesive
  - Adhesive utilized to bond gap filler to adjacent arecage tiles (Adhesive bond thickness = 0.010-inch)

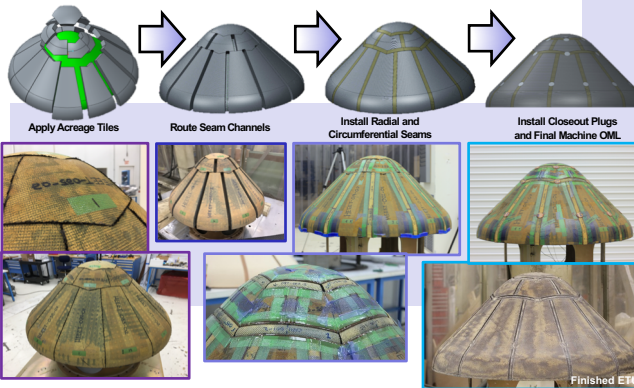
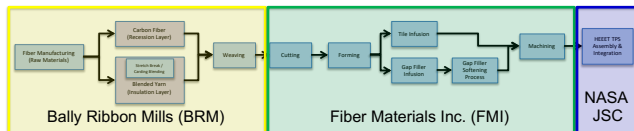


Complex 3D multi-layer weave



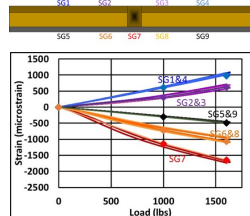
## 2. Architecture and Engineering Test Unit (ETU) Manufacturing

- All manufacturing and integration operations have been demonstrated at mission-relevant scale
- All basic manufacturing steps have been transferred to industry to establish supply chain for future missions

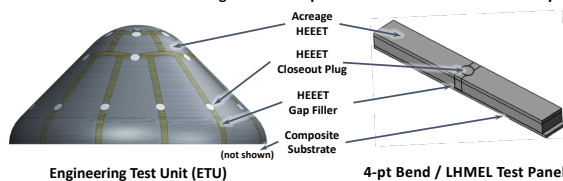


## 3. HEET Ground Testing – Structural and Aerothermal

- Flexural testing was conducted at LARC at cold temperatures (-250F), room temperature, and hot temperatures (+250F)
  - Testing was completed in late October 2017
- Thermal structural analyses were performed to correlate the Finite Element Model that would be used in ETU pre-test predictions.
  - Thick seam predictions are within 10% for all specimens that had no known defects prior to the test
  - Closeout plug predictions are within 17% of FEM



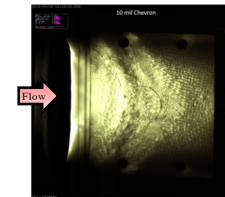
- Element, subcomponent, component and subsystem level testing are being performed to verify the structural adequacy of the ETU
  - Analytical work will be used to evaluate vehicles > 1-meter diameter
- Component Test Objectives
  - Verify seam structural performance on a large scale with anticipated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



- May 2018: Completed first of 2 HEET aerothermal test campaigns in a wedge shear configuration at Arnold Engineering Development Center (AEDC)
  - Test objectives are to evaluate ETU seam design features in high heat flux, pressure and shear environments

### Test conditions:

Test Campaign	Heat Flux W/cm <sup>2</sup>	Pressure atm	Shear (Pa)
AEDC H3	1650	2.6	4000-6000
IHF 3-in Nozzle	6500	5.5	0

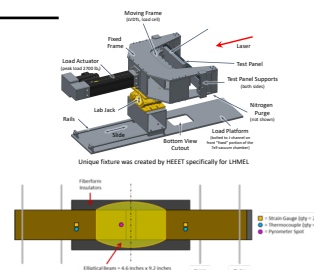


Close out plug / circumferential ESH intersection with 10-mil seam during during arjet testing

- Recession predicted by FIAT tool, using roughness-augmented heat flux, was similar to measured recession on test hardware

### Combined Thermal-Structural Testing was performed at the Air Force Research Lab LHMEI II facility

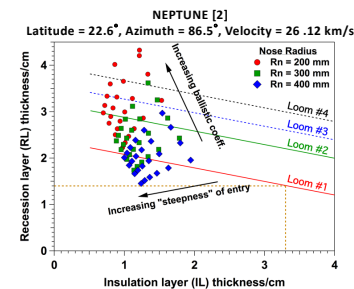
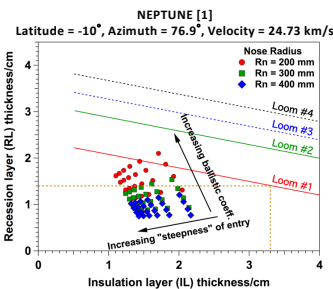
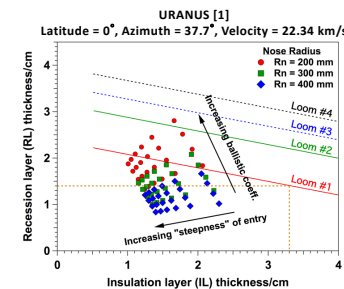
- Tests conducted in the 7 x 9 foot vacuum chamber using the 20 kW Fiber Laser
- LHMEI panels were the same as four-point bend panels tested at NASA Langley
- HEET's novel fixture for combined loading has been adopted by Orion project for thermomechanical testing of Avcoat



## 4. HEET Application to Ice Giant Missions

A range of ballistic coefficients, entry flight path angles, and nose radii of 45° sphere-cone geometries explored such that HEET solutions can be woven within the limits of the first two looms

- Step #1: For given entry state (velocity, latitude & azimuth [1,2]) compute 3DOF trajectories using TRAJ [3]**
  - Ballistic coefficient range: 200–350 kg/m<sup>2</sup> (in steps of 50 kg/m<sup>2</sup>)
  - Inertial entry flight path angle range that covers deceleration loads between 50 and 200 g
    - Uranus: -16.5° to -36.5° Neptune: -16° to -26°
    - no pressure and/or heat flux constraints imposed
  - Inertial entry velocity: Uranus: 23 km/s Neptune: 26 km/s
  - Stagnation point convective heating estimates obtained from correlations based on freestream density and velocity; radiative heating likely to be small at both destinations
  - All trajectories terminated at flight Mach number of 0.8 (heatshield jettison)
- Step #2: Size HEET using FIAT [4] to stagnation point aerothermodynamic environments estimated in Step #1**
  - Planet-specific 'B' tables for material thermal response, and a margins policy [5] that accounts for uncertainty in environments & material properties
  - Thicknesses determined with: (a) initial temperature of -10°C, and (b) a maximum allowable back face temperature of 250 °C
- Step #3: Adjust stagnation point sizing from Step #2 to margin against turbulent heating on the conical flank**
  - Flank heating can be as high as stagnation point heating, but at a lower (=50%) pressure level – increased material recession
  - Current solution: Scale up stagnation point recession layer thickness by 1.2, and scale down insulation layer thickness by 1.2
- Step #4: Add manufacturing margins to estimates of flank thicknesses (recession and insulation layers)**
  - Manufacturing margins: 0.51 cm for the insulation layer, and 0.38 cm for the recession layer



- There are several possible HEET solutions that fall within the manufacturing capabilities of Looms 1 and 2, i.e., no upgrade is required beyond the present loom capability
- The entry flight path angle will be limited by the ability to demonstrate material performance in ground-test facilities, e.g., arc jets
- In addition to limiting the ballistic coefficient to lie between 200 and 250 kg/m<sup>2</sup>, it is better to keep the nose radius between 300 and 400 mm