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

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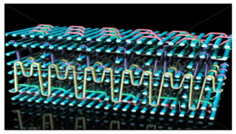
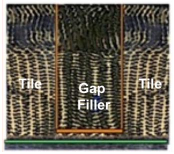
1. HEEET Background

- **HEEET 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**
- **HEEET 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 acreage tiles (Adhesive bond thickness = 0.010-inch)

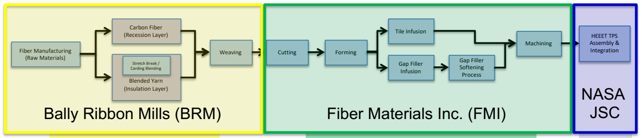


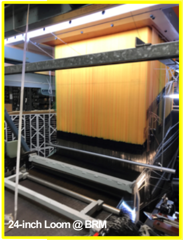
Complex 3D multi-layer weave

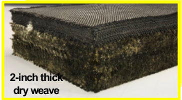


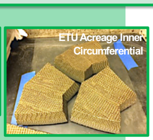
2. Architecture and Engineering Test Unit (ETU) Manufacturing

- **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**

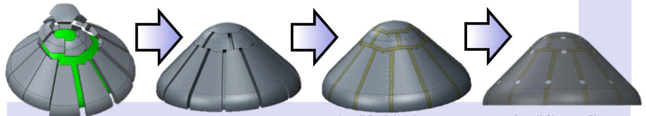








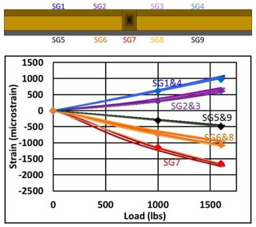
ESH Gap Filler



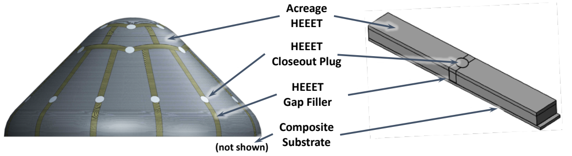
Apply Acreage Tiles → Route Seam Channels → Install Radial and Circumferential Seams → Install Closeout Plugs and Final Machine OML

3. HEEET 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 HEEET design for the given thickness under all mission loading events except acoustic environments and entry**

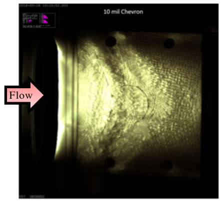


Engineering Test Unit (ETU) **4-pt Bend / LHMEL Test Panel**

- **May 2018: Completed first of 2 HEEET 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/cm²	Pressure atm	Shear (Pa)
AEDC H3	1650	2.6	4000-6000
IHF 3-in Nozzle	6500	5.5	0

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



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

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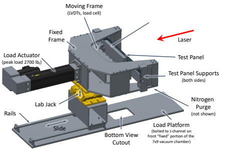
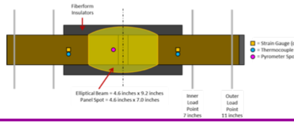
- **Combined Thermal-Structural Testing was performed at the Air Force Research Lab LHMEL II facility**
  - Tests conducted in the 7 x 9 foot vacuum chamber using the 20 kW Fiber Laser
- **LHMEL panels were the same as four-point bend panels tested at NASA Langley**
- **HEEET's novel fixture for combined loading has been adopted by Orion project for thermomechanical testing of Avcoat**



Unique fixture was created by HEEET specifically for LHMEL

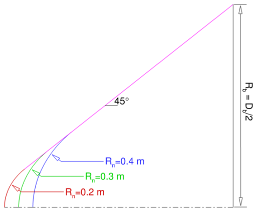


4. HEEET Application to Ice Giant Missions

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

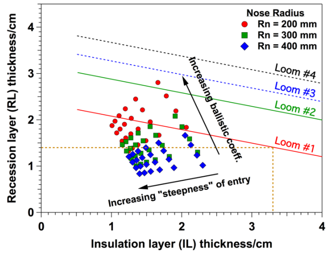
- **Step #1: For given entry state (velocity, latitude & azimuth [1,2]) compute 3DOF trajectories using *TRAJ* [3]**
  - Ballistic coefficient range: 200–350 kg/m^2 (in steps of 50 kg/m^2)
  - Inertial entry flight path angle range that covers deceleration loads between 50 and 200 g
    - Uranus: -16.5° 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 HEEET 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

References:
[1] Hwang, H., *et al.*, (2018), *15th IPPW*, Boulder, CO, June 11–15. [2]Ice Giants: Pre-Decadal Survey Mission Study Report (2017), JPL D-100520. [3] Allen, G. A., Jr., Wright, M. J., and Gage, P. J. (2005) NASA/TM-2005-212847. [4] Milos, F. S. and Chen, Y.-K. (2013) *J. Spacecraft and Rockets*, 50(1), pp.137-149. [5] Mahzari, M. and Milos, F. (2018), *15th IPPW*, Boulder, CO, June 11–15.

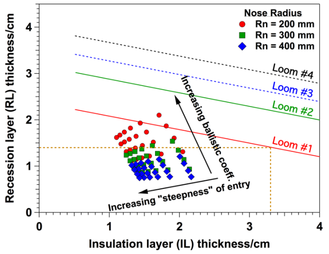


- **Nose radius: 200, 300, or 400 mm**
  - Choices cover past/proposed missions
    - Galileo nose radius was 220 mm
  - Smaller nose radius ⇒ higher convective heating, but lower radiative heating
  - Turbulent heating likely on the conical flank

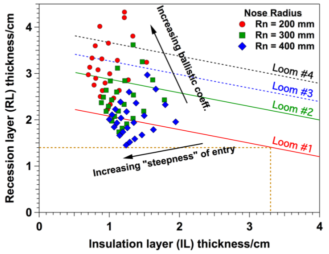
URANUS [1]
Latitude = 0°, Azimuth = 37.7°, Velocity = 22.34 km/s



NEPTUNE [1]
Latitude = -10°, Azimuth = 76.9°, Velocity = 24.73 km/s



NEPTUNE [2]
Latitude = 22.6°, Azimuth = 86.5°, Velocity = 26 .12 km/s



All sizing has been performed assuming a 3.8 mm thick layer of HT-424 adhesive and 3.2 mm thick Al-2024 structure to which HEEET is bonded. The structural component can be easily switched to another material

- **There are several possible HEEET 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^2, it is better to keep the nose radius between 300 and 400 mm**