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 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 stressing requirements
  – Seam = Gap filler + Adhesive
  – Adhesive utilized to bond gap filler to adjacent acreage tiles (Adhesive bond thickness = 0.010-inch)

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

1. HEEET Background

2. Architecture and Engineering Test Unit (ETU) Manufacturing

3. HEEET Ground Testing – Structural and Aerothermal

Flexural testing was conducted at LARC at room temperatures (~250°F), and hot temperatures (~250°F)

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% of all specimens that had no known defects prior to the test

Component Test Objectives

• Verify structural adequacy of the ETU
  – Analytical work will be used to evaluate vehicles > 1 meter diameter

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 3D0 flight trajectories using Thru(3)
  – Ballistic coefficient range: 200–350 kg/m² (in steps of 50 kg/m²)
  – Inertial entry flight path angle range that covers deceleration loads between 50 and 200 g
  – Uranus: -18.5° to -36.5°  Neptune: -10° to -18°
  – No pressure and/or heat flux constraints imposed
  – Inertial entry velocity: 20 km/s  Neptune: 26 km/s

Flexural testing was conducted at LARC at cold temperatures (+250F), room temperature, and hot temperatures (+250F), to correlate the Finite Element Model that test predictions.

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 (AFRL) with ETU Test campaigns in a wedge shear configuration at Arnold Engineering Development Center (AEDC)

• Test objects are to evaluate ETU seam design features in high heat flux, pressure and shear environments

5. 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:

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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 (heatsield jettison)

• Step #2: Size HEEET using Thru(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

• Step #3: Adjust stagnation point sizing from Step #2 to margin against turbulent heating on the conical flank

  – Hot gas heating can be as high as stagnation point heating, but at a lower (~50%) pressure level
  – Flexural testing was conducted at LARC at cold temperatures (+250F), room temperature, and hot temperatures (+250F), to correlate the Finite Element Model that test predictions.

• Step #4: Add manufacturing margins to estimates of flank thicknesses (recession and insulation layers)

  – Manufacturing margins: 0.55 cm for the insulation layer, and 0.38 cm for the recession layer

  – Current solution: Scale up stagnation point recession layer thickness by 1.2, and scale down insulation layer thickness by 1.2

• Step #5: Add manufacturing margins to estimates of flank thicknesses (recession and insulation layers)

  – Manufacturing margins: 0.55 cm for the insulation layer, and 0.38 cm for the recession layer

  – Current solution: Scale up stagnation point recession layer thickness by 1.2, and scale down insulation layer thickness by 1.2

Defining parameters used for the ETU nose piece design:

• ETU Nose Piece

  – ETU Nose Piece

  – ETU Acreage Shoulder Flank

  – ETU Acreage Inner Flank

  – ETU Acreage Outer Flank

  – ETU Acreage Should Flank

  – ETU Acreage Inner Flank

  – ETU Acreage Shoulder Flank

  – ETU Acreage Final Machine OML

  – ETU Acreage Shoulder Flank

  – ETU Acreage Outer Flank

  – ETU Acreage Shoulder Flank

  – ETU Acreage Inner Flank

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