Heatshield for Extreme Entry Environment Technology (HEEET) Development Status

Presented by Don Ellerby

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  - Jacobs Technology Inc.
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- **Neerim Corp:**
  - Peter Gage

- **NASA ARC, AEDC, LaRC and LHMEL test facilities and their crews**

- **Bally Ribbon Mills:**
  - Weaving

- **Fiber Materials Inc. (FMI):**
  - Forming/Resin Infusion/Machining: Acreage and Gap Fillers
Outline

- Introduction to HEEET Project
- HEEET Material: Dual Layer 3D Woven TPS Material
- TPS Sizing: Saturn and Venus
- Engineering Test Unit Design: Saturn Probe
- HEEET Manufacturing/Integration
- Thermal Testing
- Structural Testing
  - LHMEL 4pt Bend (Entry Performance)
  - Engineering Test Unit (ETU)
- Summary
Goal: Mature HEEET system in time to support New Frontiers – 4 opportunity (mission infusion)
- Target missions include Saturn Probe and Venus Lander
- Capable of withstanding extreme entry environments:
  - Peak Heat-Flux >> 1500 W/cm²; Peak Pressure >> 100 kPa (1.0 atm)
- Scalable system from small probes (1m scale) to large probes (3m scale)
- Sustainable – avoid challenges of C fiber availability that plague Carbon Phenolic
- Development of the whole Integrated system, not just the material (includes seams)
  - Culminates in testing 1m Engineering Test Unit (ETU)
    - Integrated system on flight relevant carrier structure
HEEET Material

- Dual-Layer 3-D woven material infused with low density phenolic resin matrix
  - Recession layer
    - Layer-to-layer weave using fine carbon fiber - high density for recession performance
  - Insulating layer
    - Layer-to-layer weave: blended yarn - lower density/lower conductivity for insulative performance

- **Material Thickness:**
  - 2.1 in (5.3 cm) thick material [0.6 in (1.5 cm) recession layer, 1.5 in (3.8 cm) insulating layer]

- **Material Width:**
  - Currently manufacturing 13 in (33 cm) wide material
  - Weaving scale-up in progress for 24 in (61 cm) wide material
  - Weaving limitations drive need for a tiled system
Saturn Entry Probe
Areal Mass Comparisons

- Stagnation point analysis
  - 200 kg, 1-meter diameter, 45-deg sphere cone, nose radius of 25 cm, Ballistic Coeff = 252 kg/m²
  - Inertial entry velocities of 36 and 38 km/s. Inertial entry flight path angles between -8 and -24 deg
  - Equatorial entry in the eastern (prograde) direction

- Saturn entry is extreme - very high heat-flux and pressure and long flight duration results in extreme heat-load (75 - 250 kJ/cm²)

- Areal mass of the 2-layer (HEEET) system has the potential for > 40% mass savings relative to heritage Carbon Phenolic
  - Sizing results are for zero margin utilizing preliminary thermal response model
Venus Entry Probe
Areal Mass Comparisons

- Stagnation point analysis
  - 2750 kg, 3.5-meter diameter, 45-deg spherecone, nose radius of 87.5 cm, Ballistic Coeff = 272 kg/m$^2$
  - Inertial entry velocities of 10.8 and 11.6 km/s. Inertial entry flight path angles between -8.5 to -22 deg
- Venus (12-36 kJ/cm$^2$) has lower heat loads than Saturn (75-250 kJ/cm$^2$)
- Areal mass of the 2-layer (HEEET) system has the potential for > 40% mass savings relative to heritage Carbon Phenolic
  - Sizing results are for zero margin utilizing preliminary thermal response model
- Mass efficiency of HEEET may enable shallower EFPA than feasible with CP, resulting in lower g – loads
Missions to Saturn generally require a thicker TPS than Venus missions due to higher heat load

- Recession layer thickness for Saturn missions is 0.2-0.4 inches while for Venus missions is 0.05-0.15 inches
  - Actual recession is 2/3 of the margined recession layer thickness
- Insulation layer thickness for Saturn missions is 0.6-1.4 inches while for Venus missions is 0.4-0.8 inches
- Total thickness: Saturn = 0.9 – 1.7 inches; Venus = 0.5 – 0.9 inches
- Added margins accounting for trajectory and aerothermal uncertainties may increase the required thickness
- Differences in atmospheric composition (Venus CO$_2$ vs Saturn H$_2$/He) is accommodated via modeling
  - Current arcjet test capability at extreme entry environments is limited to air
Weaving size limitations require use of a tiled TPS

- Acreage Tiles
- Gap Fillers

Gap filler between tiles performs two primary functions:

- Provide structural relief for all load cases
  - Achieved by relatively high compliance of gap filler compared to acreage tiles
  - Required strain accommodation by gap filler is driven in part by stiffness of carrier structure (coupled design)

- Provide an aerothermally robust joint, “aerothermally monolithic seam”
  - Recession performance in family with acreage material
  - Achieved by:
    - Gap Filler composition similar to acreage material
    - Very thin adhesive widths between gap filler and acreage tiles
HEEET Seam Aerothermal Performance
(~7000 W/cm² and 5 atm)

- IHF 3” nozzle arcjet testing (~ 7000 W/cm² and 5 atm) of HEEET seam designs completed
- Feasibility of seam design demonstrated
- Test articles showed aerothermally “monolithic” behavior
  - Seam and acreage showed similar recession behavior
ETU Architecture & Part Nomenclature

Tiles
• Shoulder Radius: 5.65” OML
• Tile Thickness (1.65”)

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<tr>
<th>Tile Type</th>
<th>Tile Color</th>
<th>Tile Quantity for 1x Tile Set</th>
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HEEET Manufacturing Overview

NASA ARC

Dry Woven HEEET

Flat Panel Infusion

Cutting

Forming

Nose Cap Cutting

Forming

Nose Cap Infusion

NASA ARC (During Development)

Machining

Softened HEEET Test Articles

Structural Test Coupon Tiles: 4-Point Bend & TTT

ArcJet Test Coupons & Misc. Structural Testing

MDU Tile Set

ETU Tile Set

Nose Cap Path Finder

HEEET Gap Filler

NASA ARC

Fiber Materials Inc. (Development)

Rough Cutting

Tile Infusion

Gap Filler Infusion

Bally Ribbon Mills

NASA – Johnson Space Center (JSC)

Integration

Tile & Seam Test Coupon Set

Manufacturing Demonstration Unit (MDU)

Engineering Test Unit (ETU)

NASA – Langley Research Center (LaRC)

Test Program

Coupon/Material Testing

NDT

ETU Testing

AASC Deliverables

4-Point Bend Substrate

TTT Substrate

Carrier Structure 1

Carrier Structure 2

Material Procurement

Ply Design

Tooling Design

Layup/Cure/Assembly

Applied Aerospace Structures Co. (AASC)
Stagnation point environments from Venus, Saturn and Earth entry missions

- High latitude Saturn entry has the highest heat flux
- Venus steep entry has the highest surface pressure loading
- Saturn missions have the highest heat load (TPS thickness)
Element, subcomponent, component and subsystem level testing are being performed to verify the structural adequacy of the ETU
- ETU design assumes a 1m Saturn Probe mission
- Analytical work will be used to evaluate vehicles > 1-meter diameter (Venus)

Element Level Testing:
- Recession and Insulating Layers
- -175F – RT – 350+F
- Warp, Fill, Thru The Thickness (TTT)
- Tension, Compression and Shear

Sub-Component Level Testing:
- Seam Tension Testing
- TTT Tension Test: TPS Bonded to Carrier
  - Verify failure occurs in Insulating Layer first
- 4pt Bend Testing
  - Acreage, seams, curved specimens
- LHMEL 4pt Bend Testing
  - Seam structural performance during entry phase
- Pyroshock test will be performed at the coupon level

ETU Testing
Test Configuration:

- Heat Flux Nominally 200 W/cm²
- Spot size covered a rectangular area 7” wide by 3” high
- Target plane for requested spot size was just inside the outer load points of the HEEET TPS 4 Point Bend Test Fixture
- 7x9-foot vacuum chamber was pumped down to 1 torr, held for 1 minute, and back filled with active nitrogen purge and chamber pumping to a pressure between 300 and 500 torr
- 12 inch knife edge nitrogen flow across the sample face to prevent beam blockage due to ablation products
Engineering Test Unit (ETU) Testing Overview

- MDU and ETU Carrier Structure Proof tests to serve as precursor to ETU testing and Static Mechanical testing
- Testing to focus on random vibration (launch/ascent), thermal vacuum (on orbit/transit), static mechanical (entry), and pyroshock (separation) tests
- ETU tests planned for NASA Langley Research Center

MDU Carrier Structure Proof Test
ETU Carrier Structure Proof Test
Pre-Integration

Integrate TPS on Carrier Structure

Random Vibration

Thermal-Vacuum

Static Mechanical

NDE (CT)

Vibration Test

ETU In Cal-Rod Cage of T-Vac Test

ETU with Rigid Plate Closeout (Inverted)
Feasibility of HEEET Gap Filler has been demonstrated in High Heat Flux Arcjet Testing (~7000 W/cm² and 5 atm) and in initial structural testing

HEEET manufacturing has progressed well:

- **Weaving:**
  - >125 ft of 13” wide x 2.1” thick material
  - Scale up to 24” width in progress

- **Forming/Resin Infusion/Machining:**
  - FMI has modified resin infusion vessel to support HEEET infusion
  - FMI fabricated MDU tile set and demonstrated machining

Integration approach has been baselined and feasibility demonstrated at coupon/breadboard level

1m Manufacturing Development Unit (MDU) will be completed in mid-FY17

HEEET maturation on target to support New Frontiers
HEEET technology maturation project is supported by SMD and STMD’s Game Changing Development Program.

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