Heatshield for Extreme Entry Environment Technology (HEEET) Development Status

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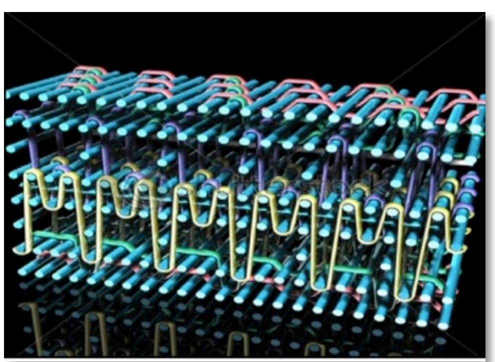
- **NASA ARC, AEDC, LaRC and LHMEL test facilities and their crews**
- **Bally Ribbon Mills:**
  - Weaving
- **Fiber Materials Inc. (FMI)**
  - Forming/Resin Infusion/Machining: Acreage and Gap Fillers

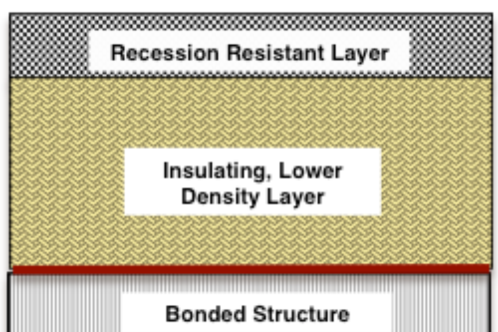
Outline

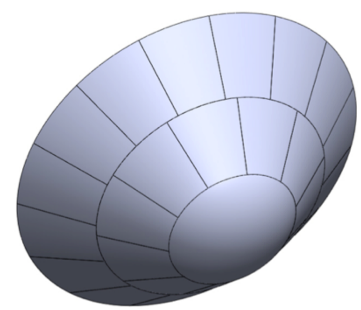
- **Introduction to HEEET Project**
- **HEEET Material: Dual Layer 3D Woven TPS Material**
- **TPS Sizing: Saturn and Venus**
- **Engineering Test Unit Design: Saturn Probe**
- **HEEET Manufacturing/Integration**
- **Thermal Testing**
- **Structural Testing**
  - LHMEL 4pt Bend (Entry Performance)
  - Engineering Test Unit (ETU)
- **Summary**

Heatshield for Extreme Entry Environment Technology (HEEET) Project

- **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/cm^2; 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

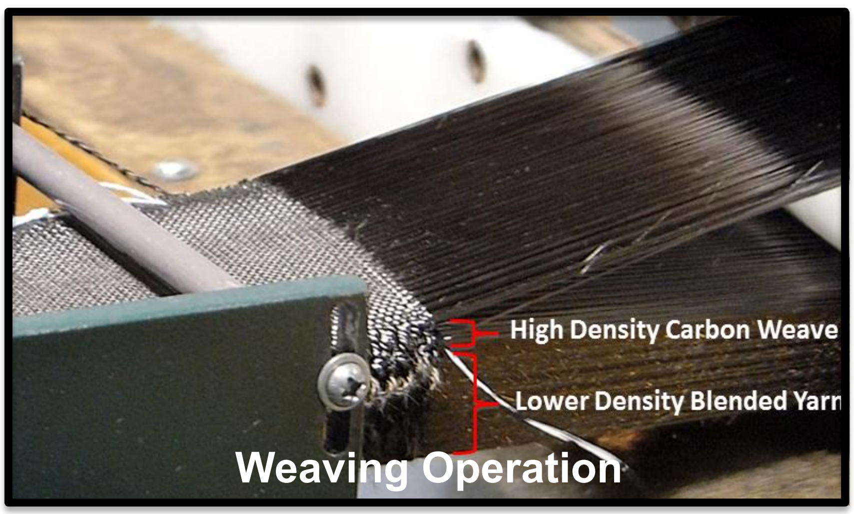


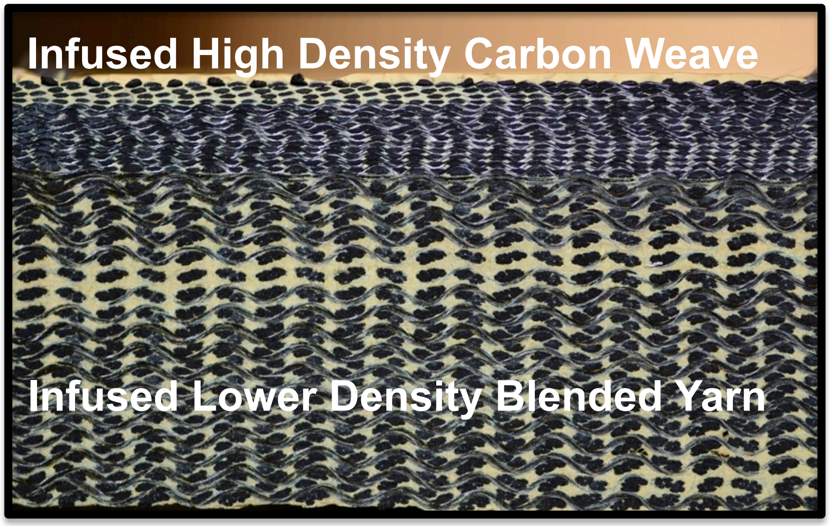




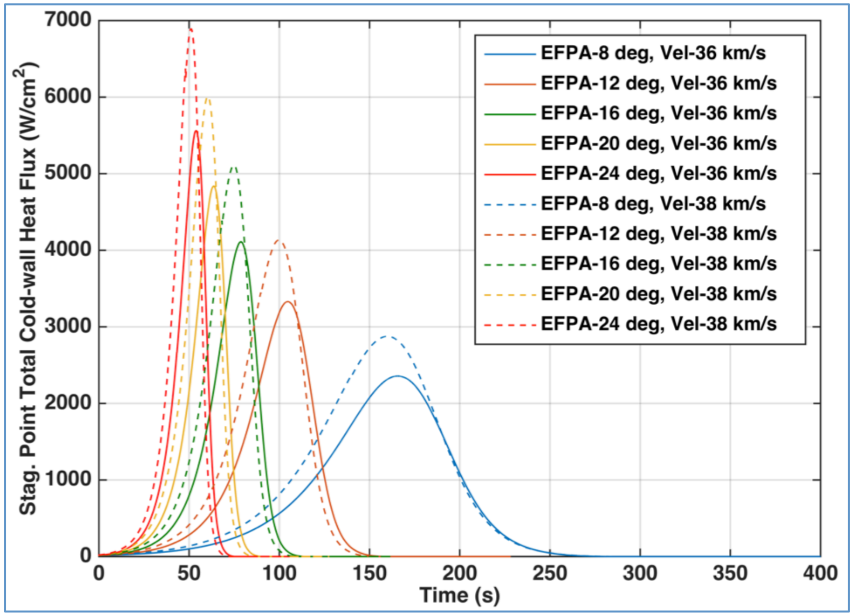
HEEET Material

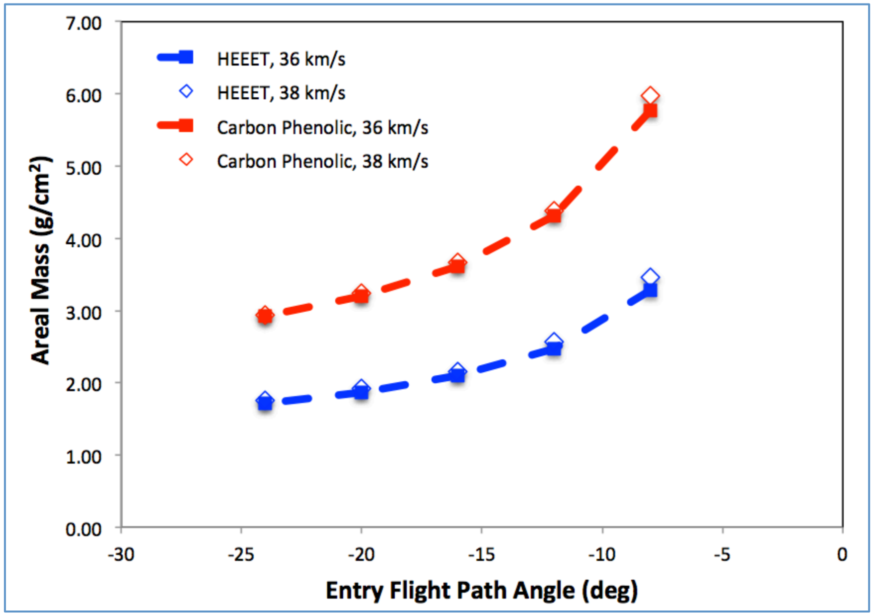
- **Dual-Layer 3-D woven material infused with low density phenolic resin matrix**
  - Recession layer
    - Layer-to-layer weave using fine carbon fiber - high density for recession performance
  - Insulating layer
    - Layer-to-layer weave: blended yarn - lower density/lower conductivity for insulative performance
- **Material Thickness:**
  - 2.1in (5.3 cm) thick material [0.6in (1.5cm) recession layer, 1.5in (3.8cm) insulating layer)]
- **Material Width:**
  - Currently manufacturing 13in (33cm) wide material
  - Weaving scale-up in progress for 24in (61cm) wide material
  - Weaving limitations drive need for a tiled system





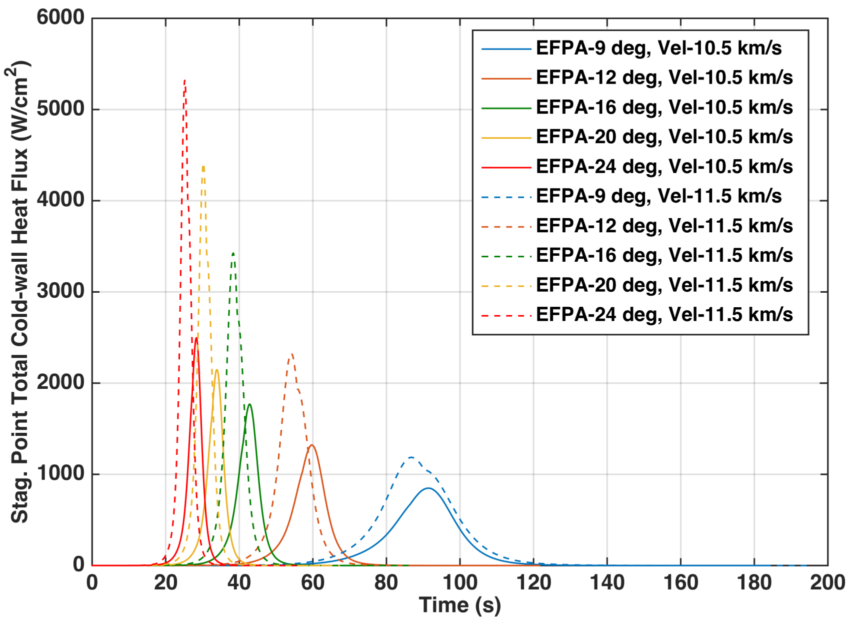
Saturn Entry Probe
Areal Mass Comparisons

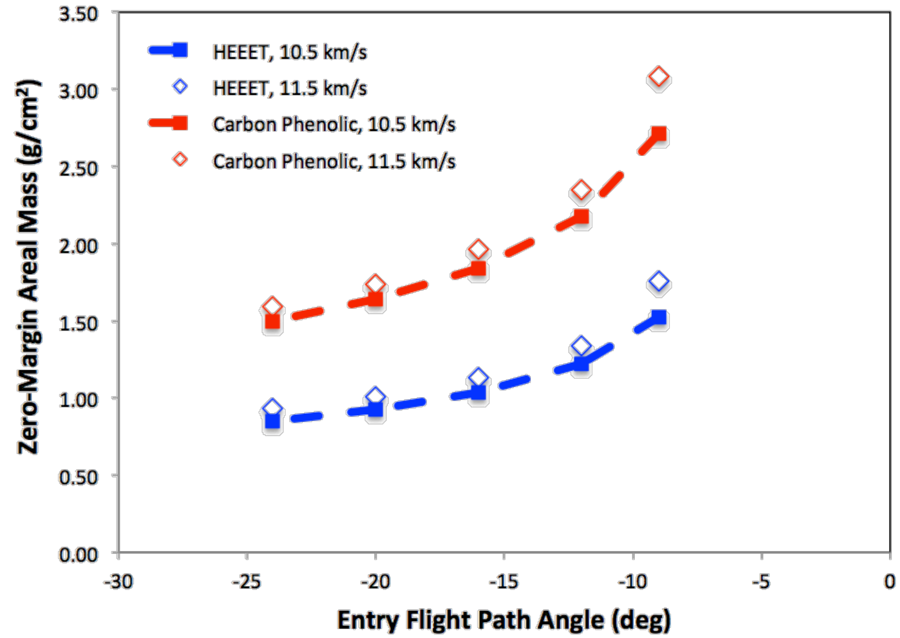




- Stagnation point analysis
  - 200 kg, 1-meter diameter, 45-deg sphere cone, nose radius of 25 cm, Ballistic Coeff = 252 kg/m^2
  - Inertial entry velocities of 36 and 38 km/s. Inertial entry flight path angles between -8 and -24 deg
  - Equatorial entry in the eastern (prograde) direction
- Saturn entry is extreme - very high heat-flux and pressure and long flight duration results in extreme heat-load (75 - 250 kJ/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

Venus Entry Probe Areal Mass Comparisons



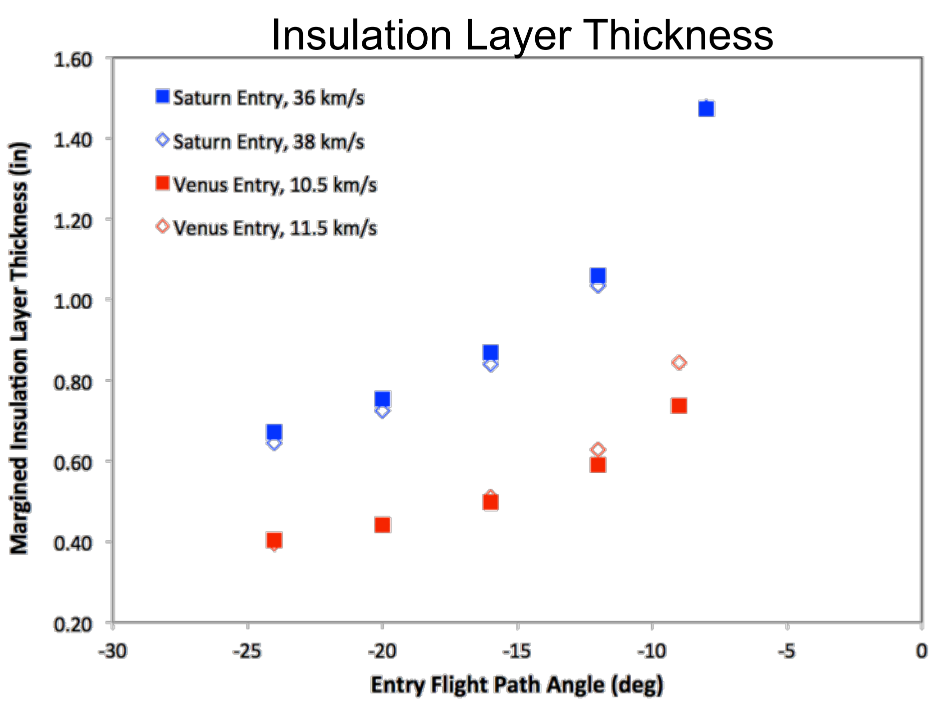


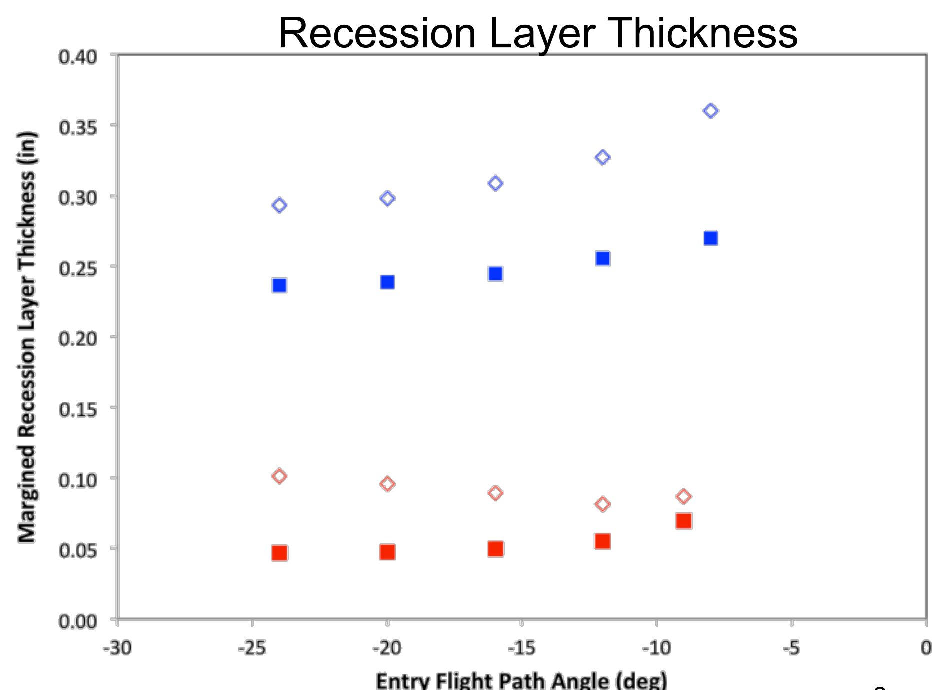
- Stagnation point analysis
  - 2750 kg, 3.5-meter diameter, 45-deg spherecone, nose radius of 87.5 cm, Ballistic Coeff = 272 kg/m^2
  - Inertial entry velocities of 10.8 and 11.6 km/s. Inertial entry flight path angles between -8.5 to -22 deg
- Venus (12-36 kJ/cm^2) has lower heat loads than Saturn (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

HEEET Thickness for Reference Missions

Missions to Saturn generally require a thicker TPS than Venus missions due to higher heat load

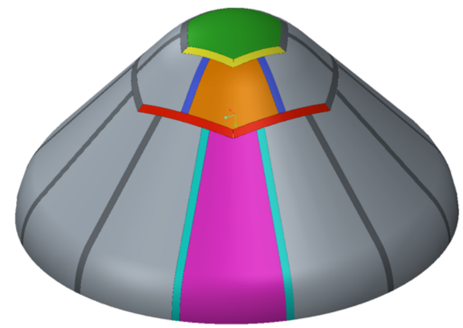
- Recession layer thickness for Saturn missions is 0.2-0.4 inches while for Venus missions is 0.05-0.15 inches
  - Actual recession is 2/3 of the margined recession layer thickness
- Insulation layer thickness for Saturn missions is 0.6-1.4 inches while for Venus missions is 0.4-0.8 inches
- Total thickness: 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



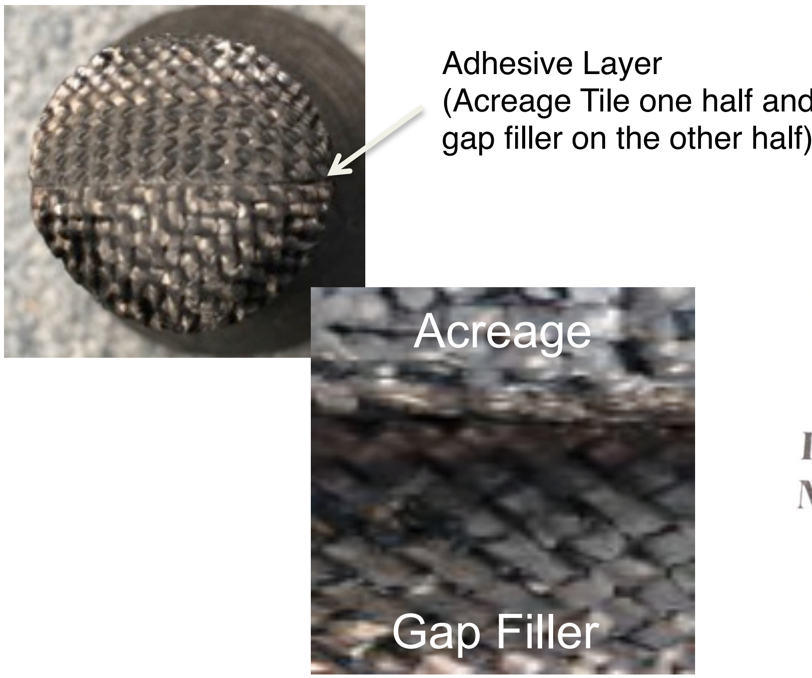


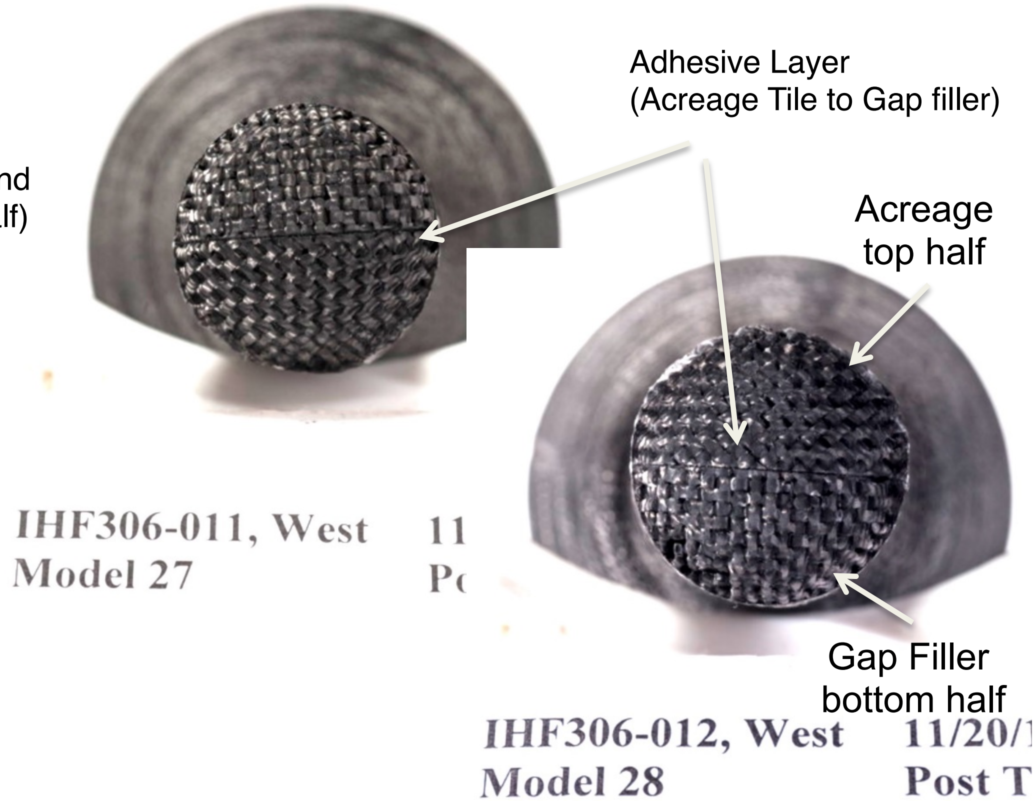
HEEET Gap Filler

- **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)

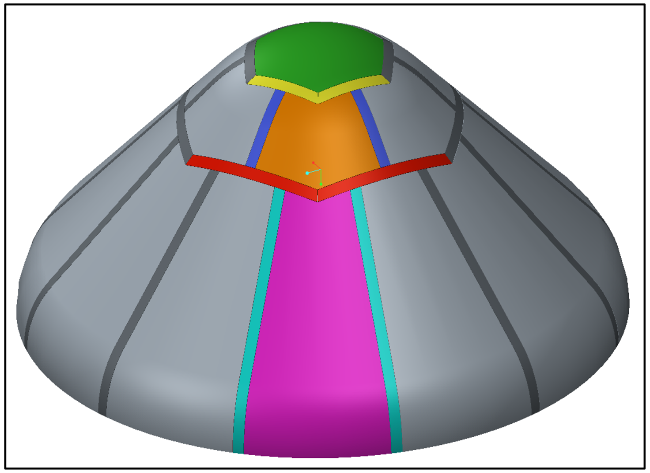


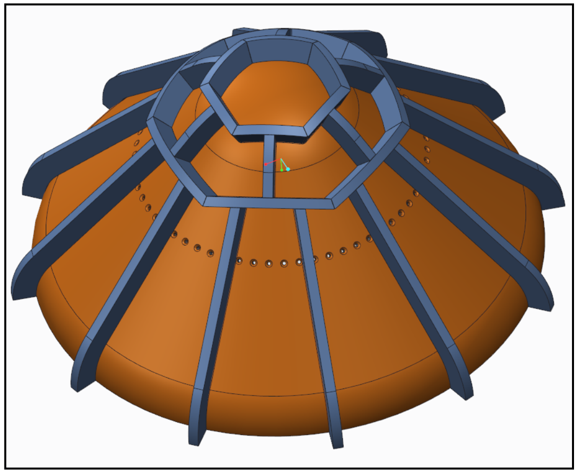


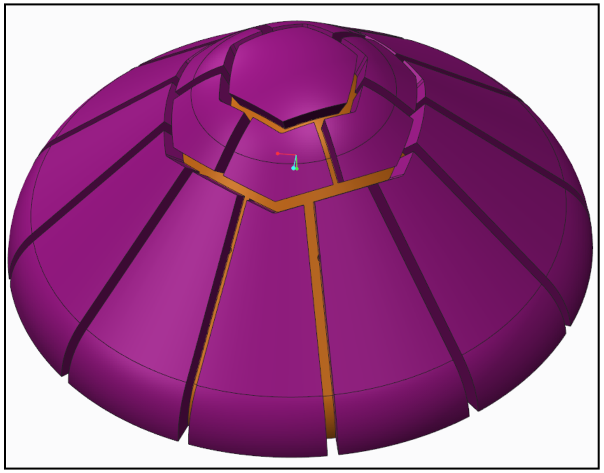
- **IHF 3” nozzle arcjet testing (~ 7000 W/cm² and 5 atm) of HEEET seam designs completed**
- **Feasibility of seam design demonstrated**
- **Test articles showed aerothermally “monolithic” behavior**
  - **Seam and acreage showed similar recession behavior**

HEEET 1m Engineering Test Unit (ETU)
Saturn Probe Reference Mission

ETU Architecture & Part Nomenclature


Complete ETU

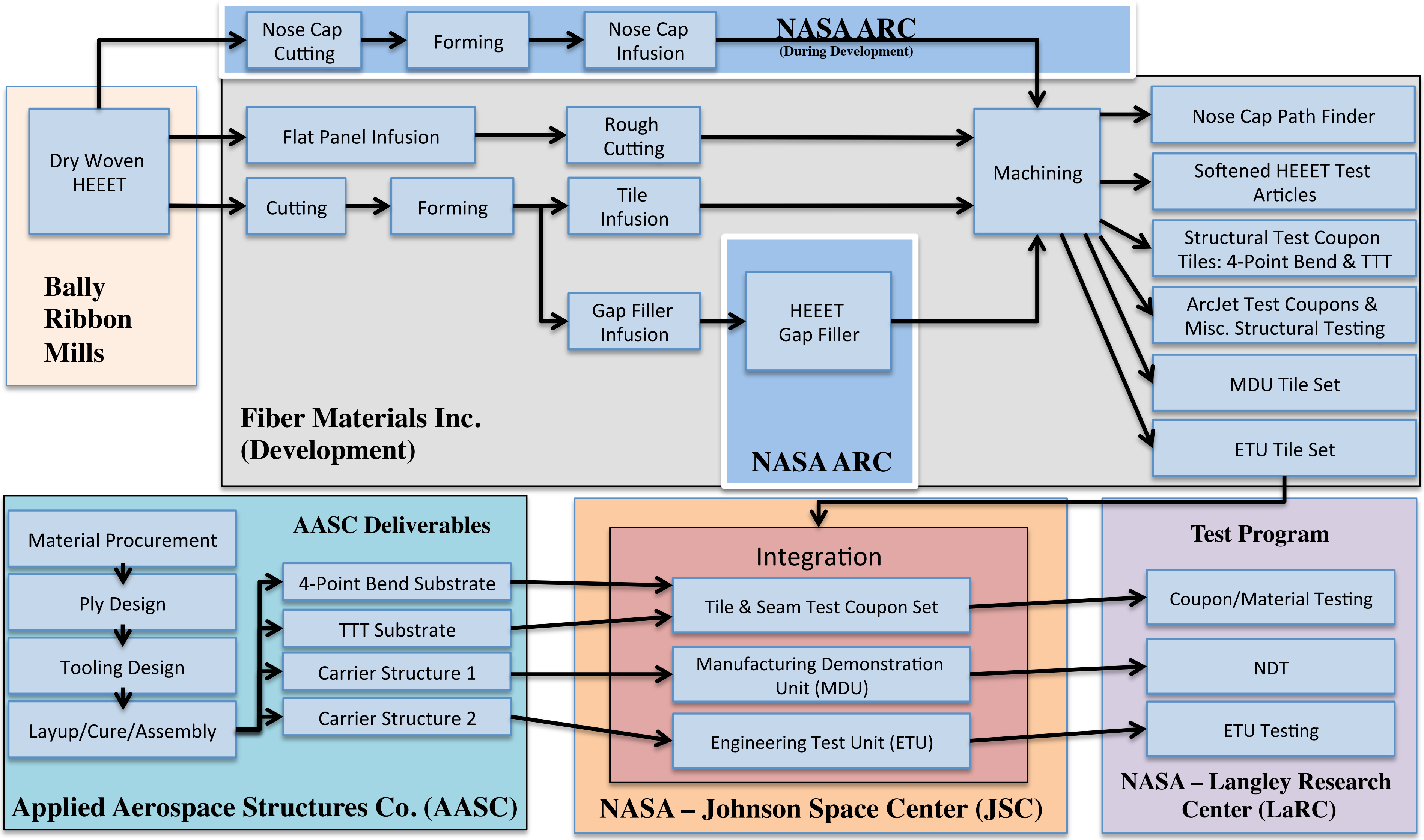

ETU – Gap Fillers Only


ETU – Acreage Tiles Only

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

Tile Type	Tile Color	Tile Quantity for 1x Tile Set
Nose Cap		1
Inner Circumferential Gap Filler		6
Inner Radial Gap Filler		6
Inner Tile		6
Outer Circumferential Gap Filler		6
Outer Radial Gap Filler		12
Outer Tile		12

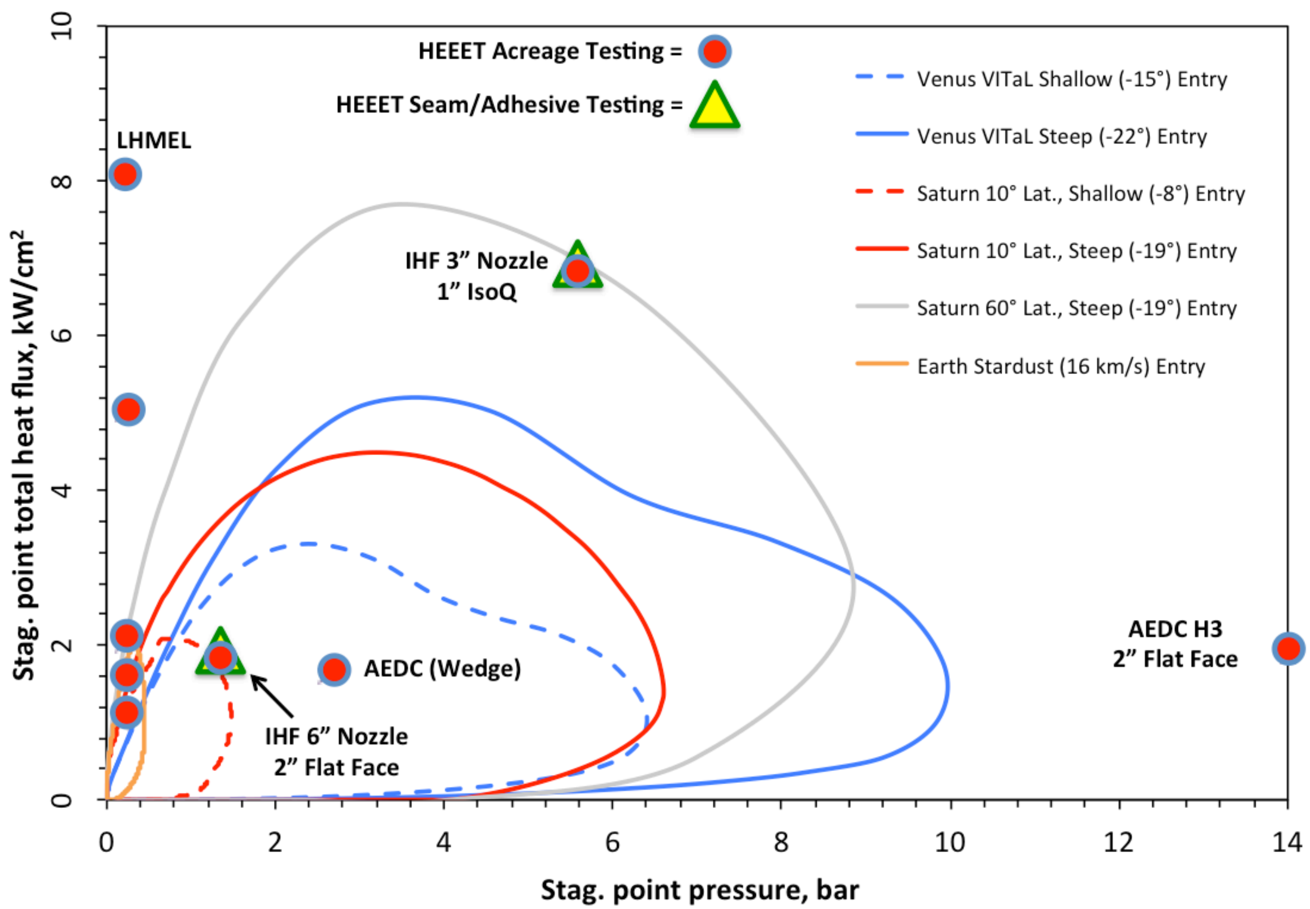
HEEET Manufacturing Overview



Mission Relevant Heat Flux and Pressure Environment Testing

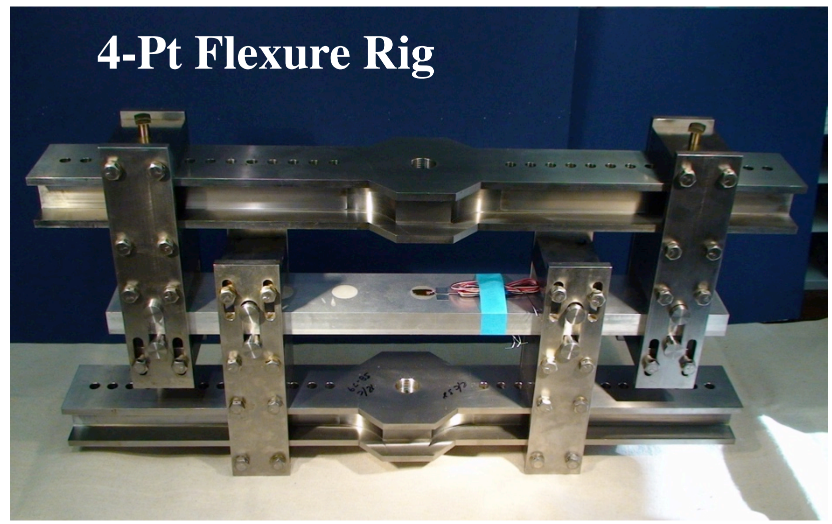
- **Stagnation point environments from Venus, Saturn and Earth entry missions**

  - 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)



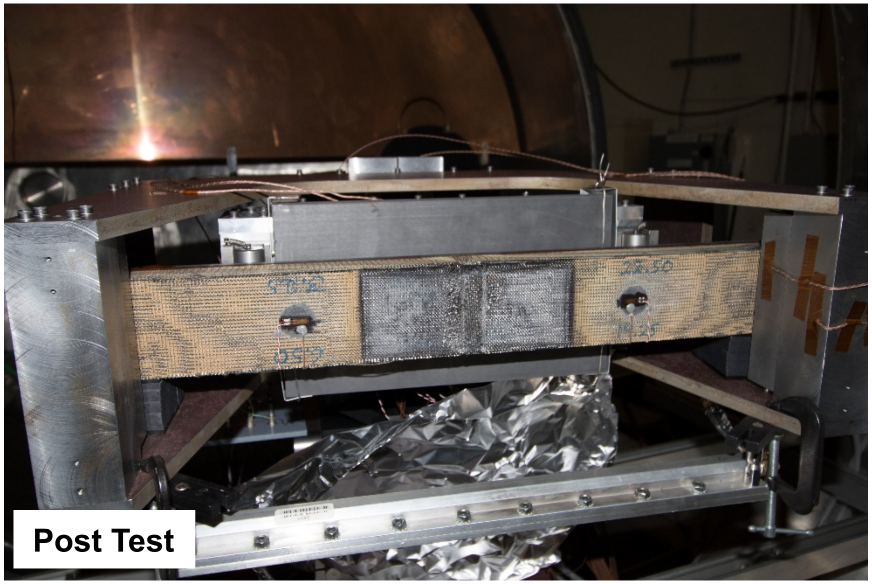
Structural Testing

- **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**



LHMEL 4pt Bend Testing

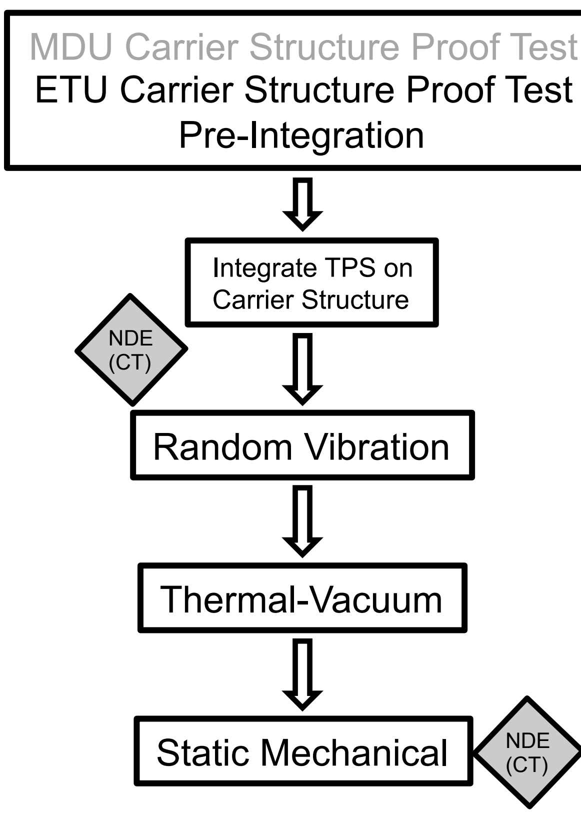
- Test Configuration:
  - Heat Flux Nominally 200 W/cm^2
  - Spot size covered a rectangular area 7” wide by 3” high
  - Target plane for requested spot size was just inside the outer load points of the HEEET TPS 4 Point Bend Test Fixture
  - 7x9-foot vacuum chamber was pumped down to 1 torr, held for 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

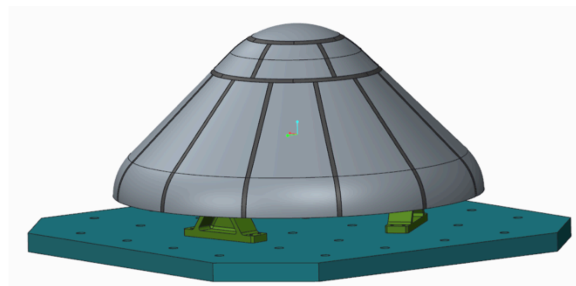

Post Test


7’x9’ LHMEL II Vacuum Chamber

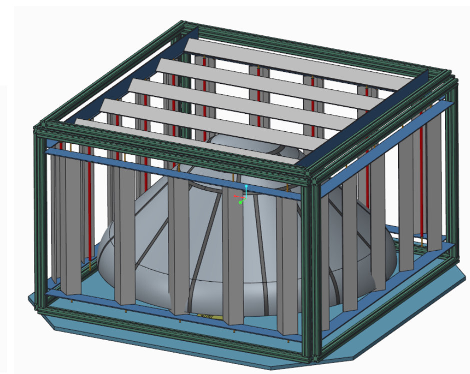
ETU Testing

- **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

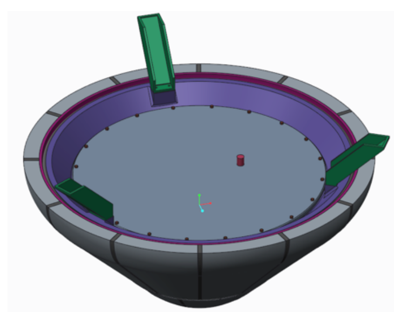


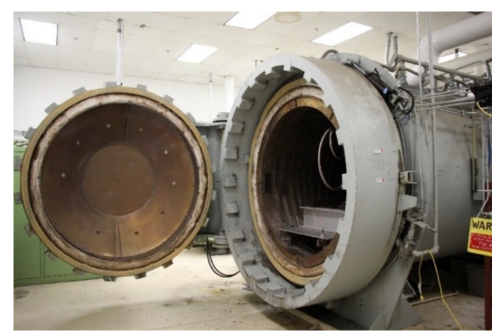


Vibration Test



ETU In Cal-Rod Cage of T-Vac Test





ETU with Rigid Plate Closeout (Inverted)

Summary

- **Feasibility of HEEET Gap Filler has been demonstrated in High Heat Flux Arcjet Testing (~7000 W/cm^2 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**

Acknowledgements

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- Support by SBIR program is gratefully acknowledged
- Support by NASA Ames Center Investment Funds during formulation of 3-D Woven TPS and internal investments by Bally Ribbon Mills are gratefully acknowledged.