National Aeronautics and
Space Administration

Overview of Heatshield for Extreme Entry Environment Technology (HEEET)

Presented by:
Don Ellerby
NASA Ames Research Center

International Conference on Flight Vehicles, Aerothermodynamics and Re-entry Missions & Engineering, 30 September – 3 October 2019, Monopoli, Italy

HEEET Team

NASA ARC:

- Dave Driver (Retired)
- Marianne Shelley (Retired)
- Ron Chinnapongse (Retired)
- Don Ellerby
- Matt Gasch
- Cole Kazemba
- Milad Mahzari
- Frank Milos
- Owen Nishioka
- Keith Peterson
- Margaret Stackpoole
- Ethiraj Venkatapathy
- Zion Young
- Peter Gage
- Tane Boghozian
- Jose Chavez-garcia
- Greg Gonzales
- Ben Libben
- Ruth Miller
- Grant Palmer
- Dinesh Prabhu
- Joseph Williams
- Alexander Murphy

NASA JSC:

- Mike Fowler
- Charles Kellermann

NASA LaRC:

- Carl Poteet
- Scott Splinter
- Sarah Langston
- Kevin Mclain
- Gregory Shanks
- Jacob Tury
- Stewart Walker
- Kelvin G. Boston
- Joshua S. Beverly
- Elora K. Frye
- Wayne D. Geouge
- Joseph J. O’Connell
- Teresa L. O’Neil
- Mark Thornblom
- Kevin L. Bloxom
- Dwight L. Duncan
- William M. Johnston
- Louise O’Donnell
- Mark C. Roth

HEEET Independent Review Board (IRB)

- Bobby Braun (UC-Boulder, IRB Chair)
- Micheal Amato (GSFC)
- Stan Bouslog (JSC)
- Robin Beck (ARC)
- Anthony Calomino (LaRC)
- Steve Gayle (LaRC)
- Ken Hibbard (APL)
- Pam Hoffman (JPL)
- Joy Huff (KSC)
- Michelle Munk (LaRC)
- Christine Szalai (JPL)

NASA Facilities:

- Ames:
  - Arcjet Complex
  - STAR Lab
  - EEL
  - Main Shop
- JSC:
  - ES4/Manufacturing
- LaRC
  - James H. Starnes, Jr., Structures and Materials Laboratory
  - Light Alloy Lab
  - Materials Research Lab
  - Model Shop
  - Systems Integration and Test Branch Laboratory

External Partners:

- Bally Ribbon Mills
- Fiber Materials Inc.

External Test Facilities:

- Laser Hardened Materials Evaluation Laboratory (LHMEL)
- Arnold Engineering Development Center (AEDC)
- NTS

External NDE:

- Hadland
- NSI
- VJ Technologies

Carrier Structures:

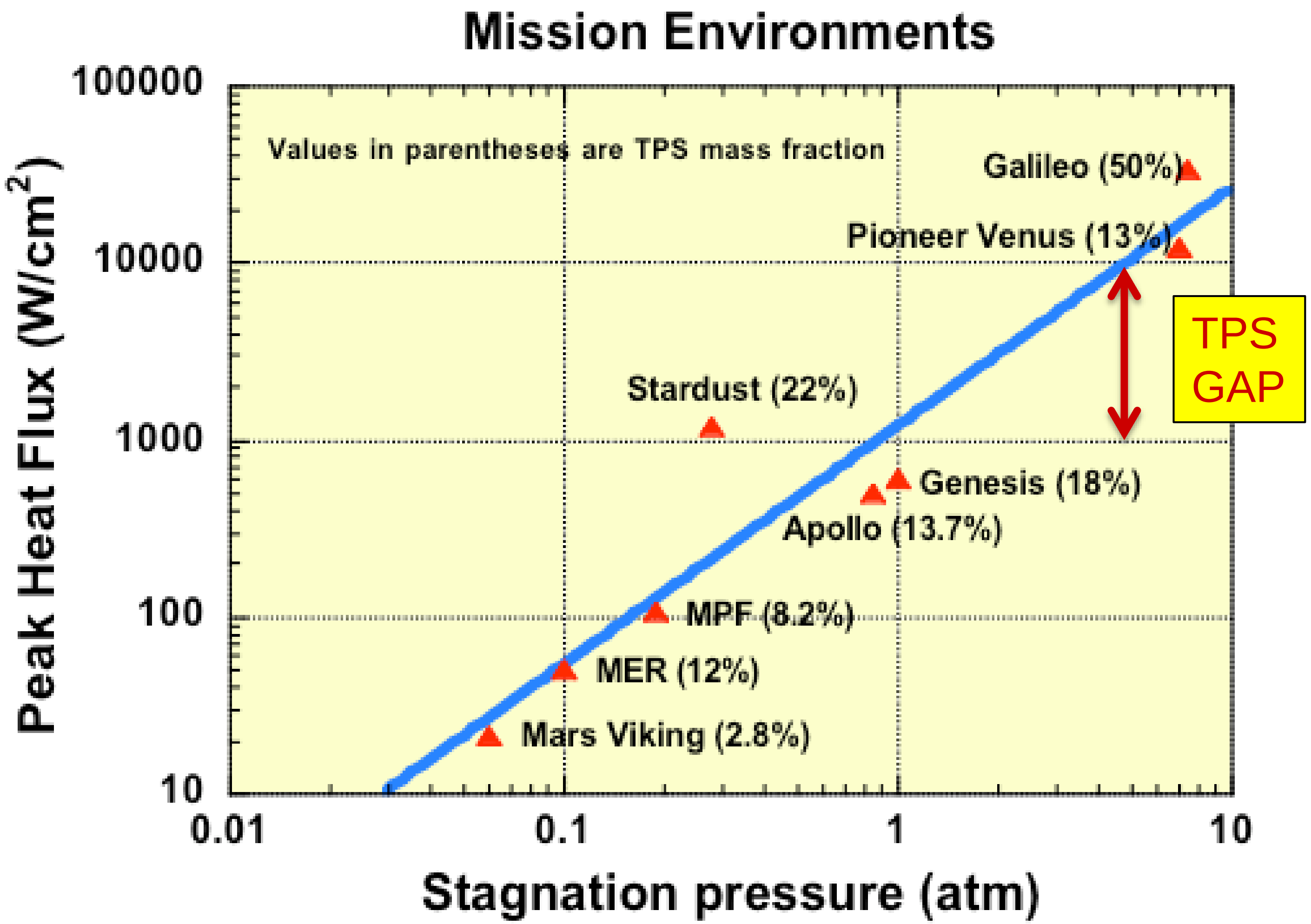
- AASC

Outline

- **HEEET = Heatshield for Extreme Entry Environment Technology**
- **Motivation for HEEET**
- **Implementation (2014 – 2019)**
  - Requirements
  - Manufacturing
  - Aerothermal
  - Structural
- **Documentation**
  - Design Data Book
- **Final TRL Assessment**

Motivation for HEEET

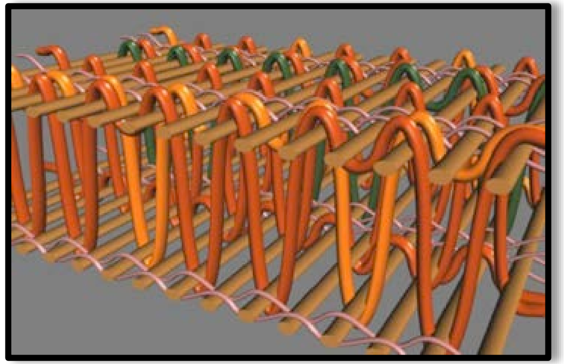
- **Address a shortfall in available TPS to meet NASA's needs for planetary science missions with very high heating entry environments**
- **Desire to develop a system that would avoid some of the sustainability challenges related to "heritage" TPS (i.e. Carbon Phenolic)**



What is the HEEET Material?

Mid-density 3D woven dual layer carbon phenolic

- 3D layer to layer weave
- Dual Layer:
  - OML Layer = Recession Layer (RL) – manages recession
    - Higher density all carbon fiber weave, exposed to entry environment
  - IML Layer = Insulation Layer (IL) – manages heat load
    - Lower density, lower thermal conductivity, blended carbon/phenolic yarn
  - **2 layers are integrally woven together,**
    - **mechanically interlocked (not bonded)**
- Woven material has medium density phenolic resin infusion
  - Higher phenolic loading than PICA
  - Open porosity

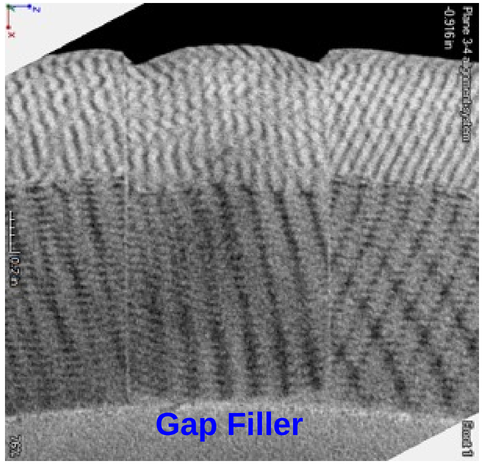


3D Weave

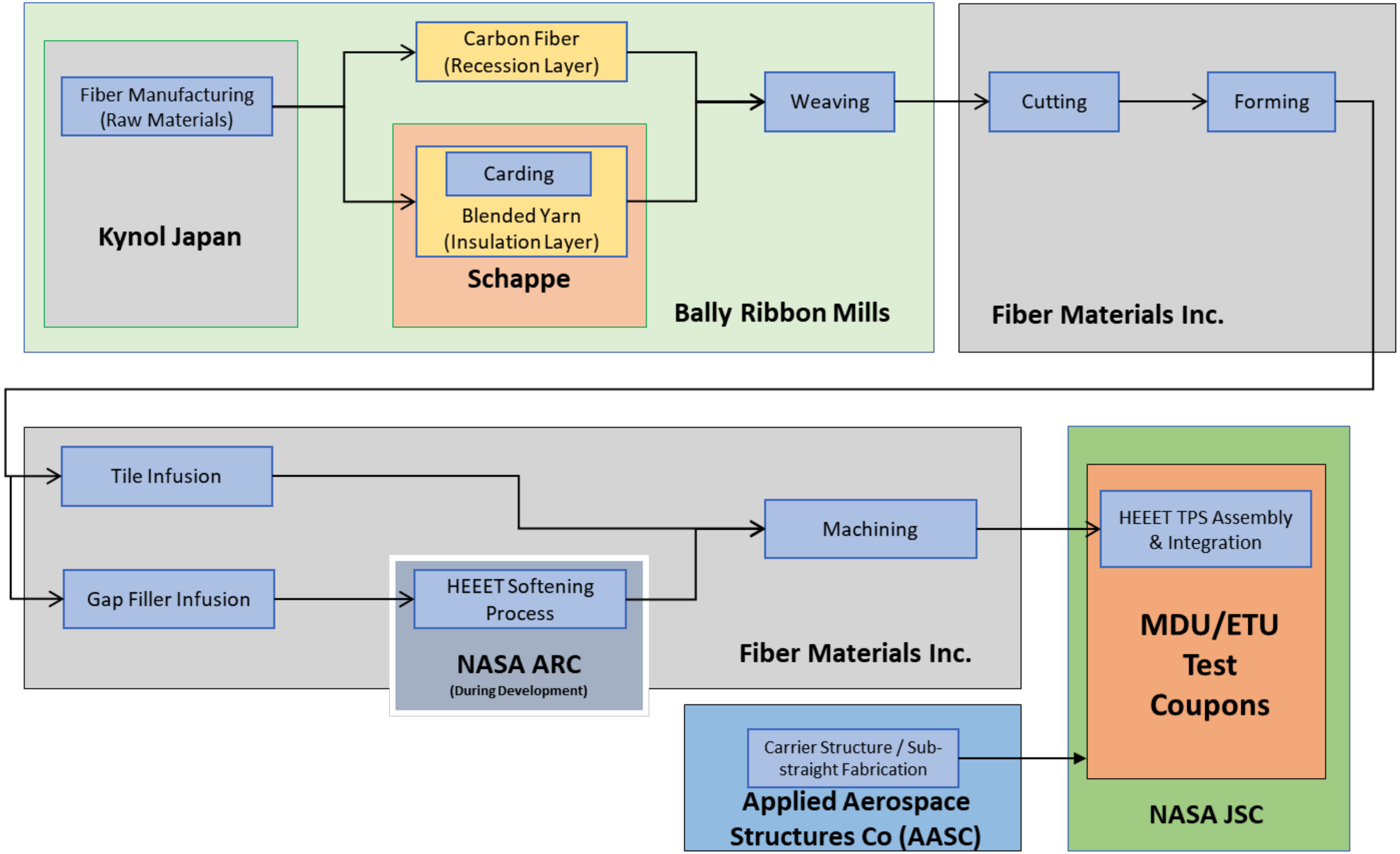
Dual Layer Weave

Seams in the HEEET Architecture

- **Target vehicle sizes range from <1m – >3.5m base diameter**
- **A tiled heatshield design is required due to weaving width limitations**
  - Results in seams between tiles – **the most challenging part of HEEET development**
- **The HEEET project has baselined a gap filler between tiles to perform two primary functions:**
  - Provide structural relief for all load cases by increasing compliance in the joint
  - Provide an aerothermally robust joint
- **Two factors inherent to the HEEET material and its mission applications drive requirements at the seams in the system.**
  - Aerothermal environments for HEEET mission architectures require unsupported adhesive joint widths be minimized to prevent runaway failure at the seam
    - IHF 3” nozzle testing at ~3500 W/cm^2 and 5 bar suggest joints ≤ 0.010” are required
  - HEEET in-plane modulus is high
    - As the carrier structure deflects the HEEET architecture must have sufficient compliance to maintain compatibility with the carrier without inducing excessive stress in the system



HEEET Manufacturing Overview



Fiber Manufacturing (Raw Materials)

Kynol Japan

Carbon Fiber (Recession Layer)

Carding

Blended Yarn (Insulation Layer)

Schappe

Weaving

Bally Ribbon Mills

Cutting

Forming

Fiber Materials Inc.

Tile Infusion

Gap Filler Infusion

HEEET Softening Process

NASA ARC

(During Development)

Machining

Fiber Materials Inc.

HEEET TPS Assembly & Integration

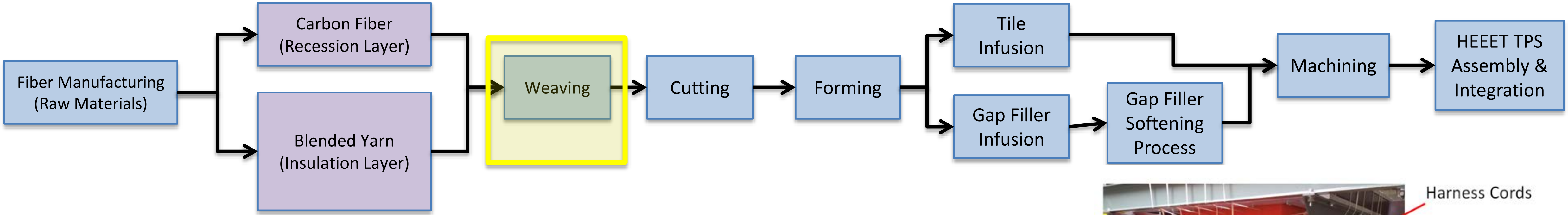
MDU/ETU Test Coupons

NASA JSC

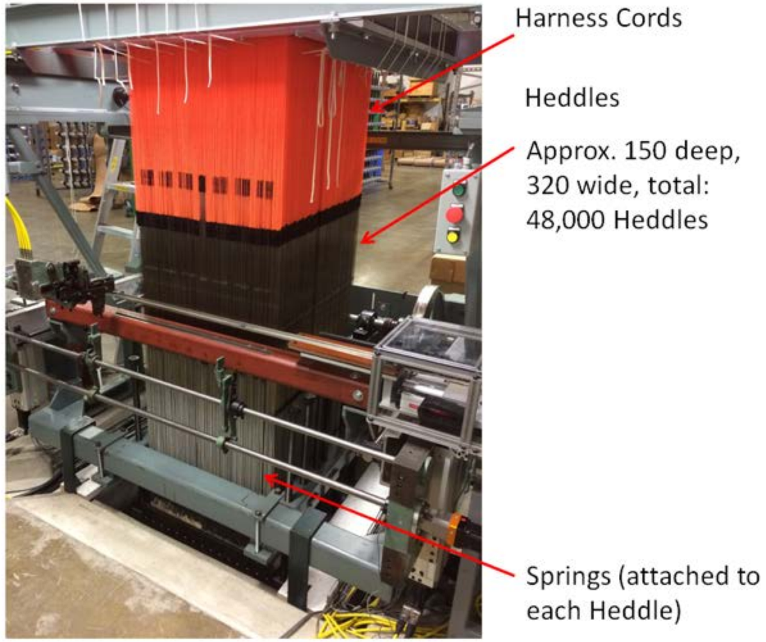
Carrier Structure / Sub-straight Fabrication

Applied Aerospace Structures Co (AASC)

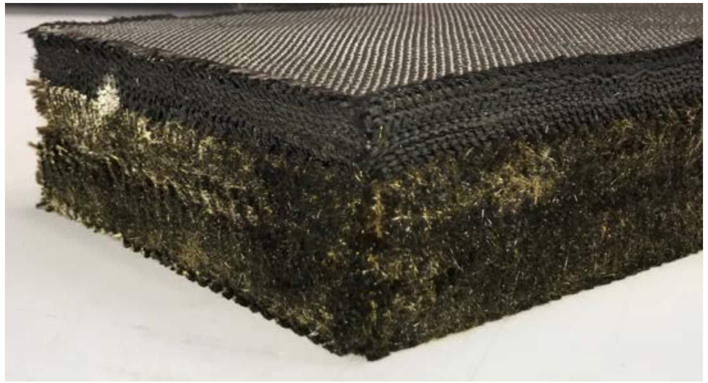
Bally Ribbon Mills (BRM) Weaving



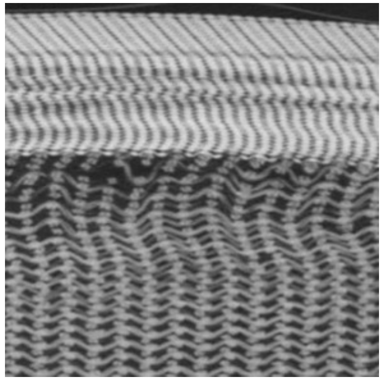
- **2 Phase scale up in weaving capability**
  - Phase 1: From 1” thickness x 6” width to 2.1” thickness x 13” width
  - Phase 2: Increased width to 24” (2.1” thickness)



24” Loom

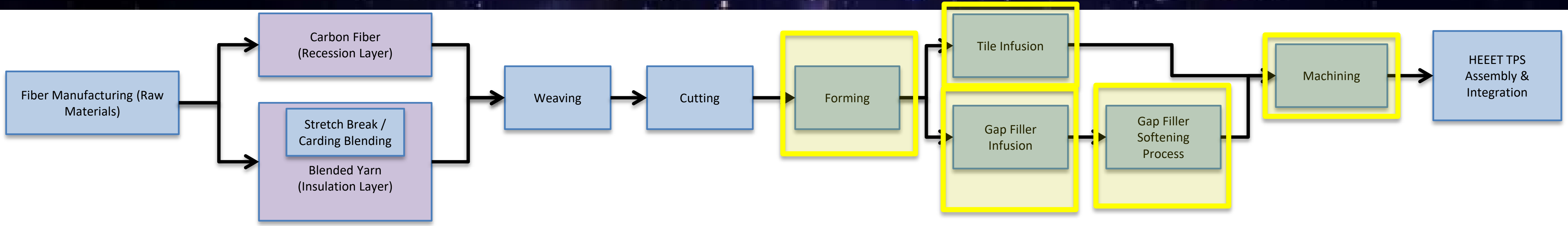


Dual Layer HEEET Weave



CT Scan HEEET Weave

Acreage Tile and Gap Filler Manufacturing


Fiber Manufacturing (Raw Materials)

Carbon Fiber (Recession Layer)

Stretch Break / Carding Blending

Blended Yarn (Insulation Layer)

Weaving

Cutting

Forming

Tile Infusion

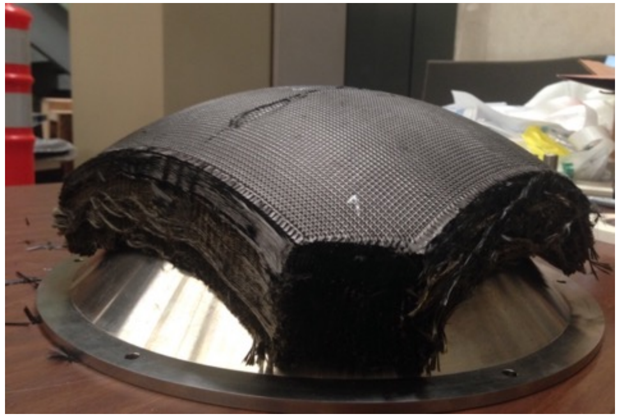
Gap Filler Infusion

Gap Filler Softening Process

Machining

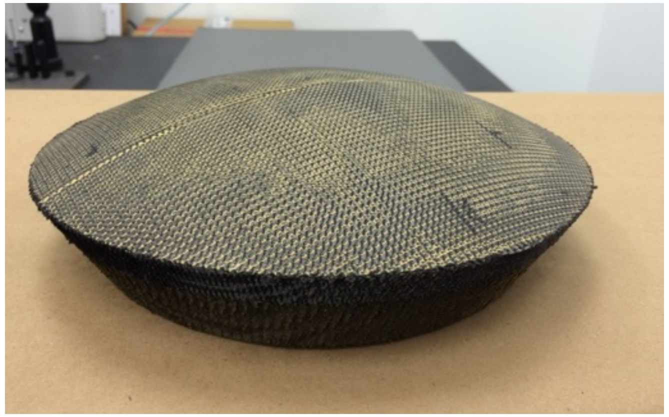
HEEET TPS Assembly & Integration

- **Forming, resin infusion and machining processes were initially developed in-house**
- **Established processes were Tech Transferred to Fiber Materials Inc. (FMI)**
- **FMI performed an upgrade to Infusion Vessel to support HEEET infusion process**
- **FMI successfully fabricated acreage tiles and gap fillers for the ETU**

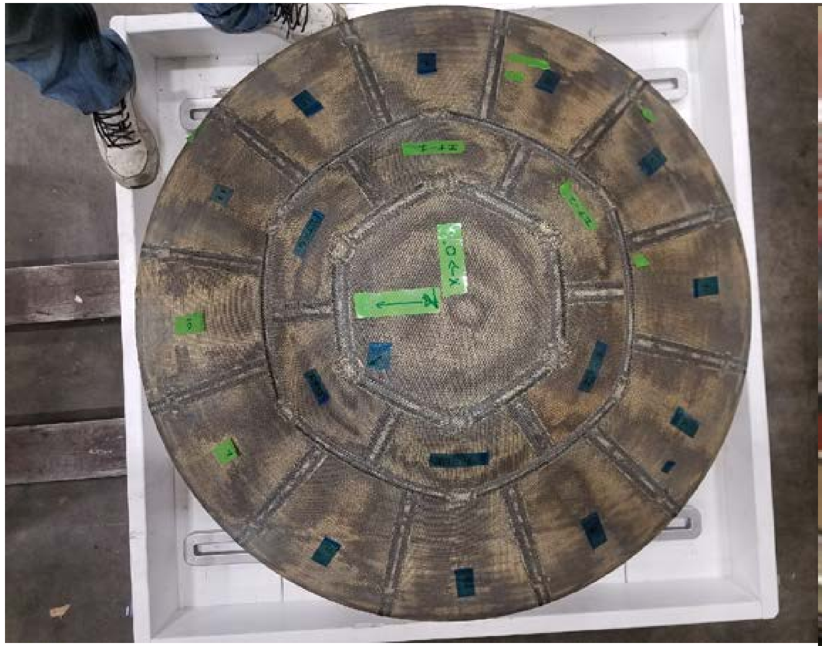

Forming

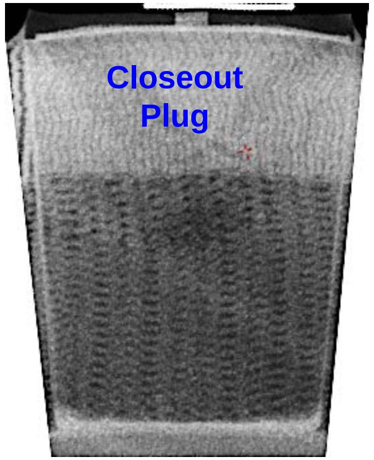

Resin Infusion: Tooling

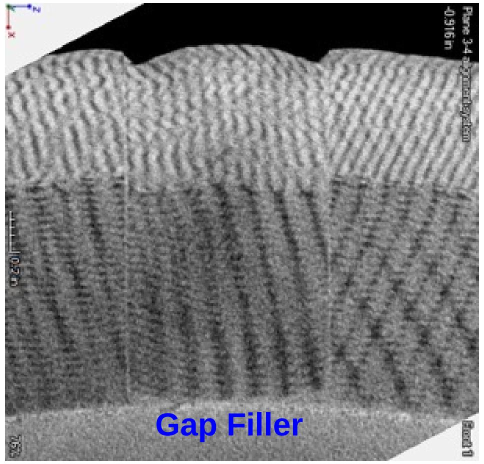

Infused Part

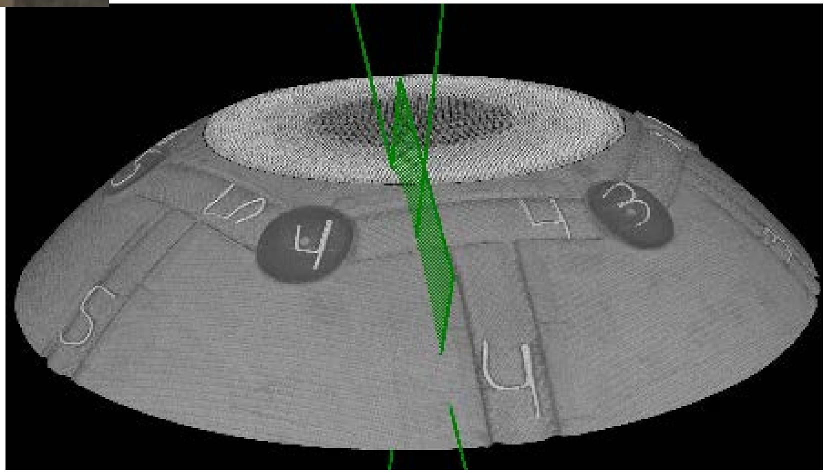

Machined Part

1m ETU Successfully Built and Inspected by CT Scan







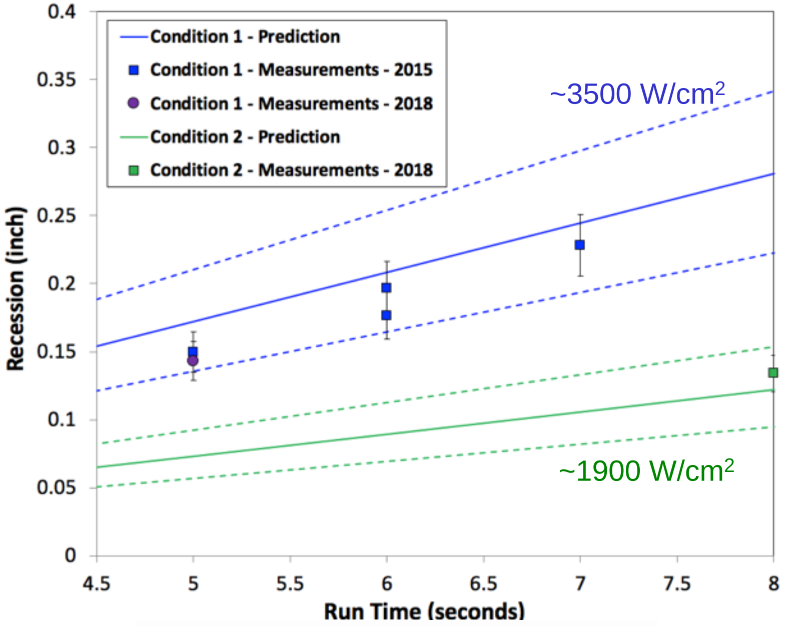


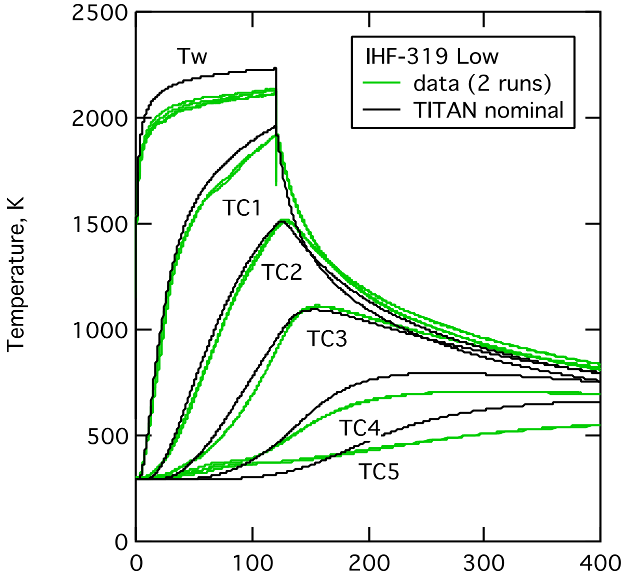
Aerothermal Test Campaign

Objectives for aerothermal test campaign:

1. Support development and validation of the TPS sizing tools
2. Exercise the system (acreage and seams) under mission relevant conditions to establish system capability
    - Looking for failure modes

- 12 arcjet test series conducted
- >140 coupons tested
- First testing in the IHF 3” nozzle
    - 3500 W/cm^2 and 5 bar
- First NASA testing in AEDC H3 facility
    - 4000 Pa shear
- FIAT code adapted to support dual layer TPS sizing
- Novel dual layer margins policy developed

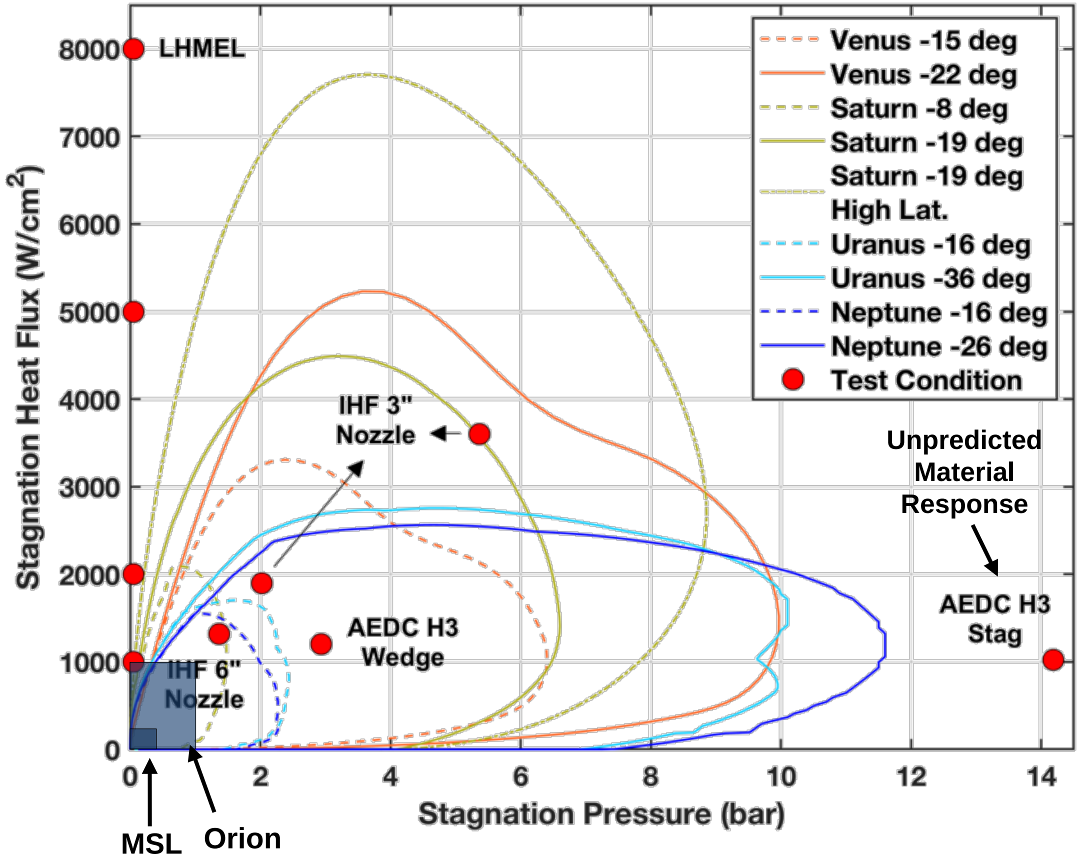




IHF 3”:
Hot Wall Heat Flux: 3500 W/cm^2
Pressure: 5 bar

AEDC Shear Testing:
Hot Wall Heat Flux: 1200 W/cm^2
Pressure: 2.9 bar/Shear: ~4000Pa

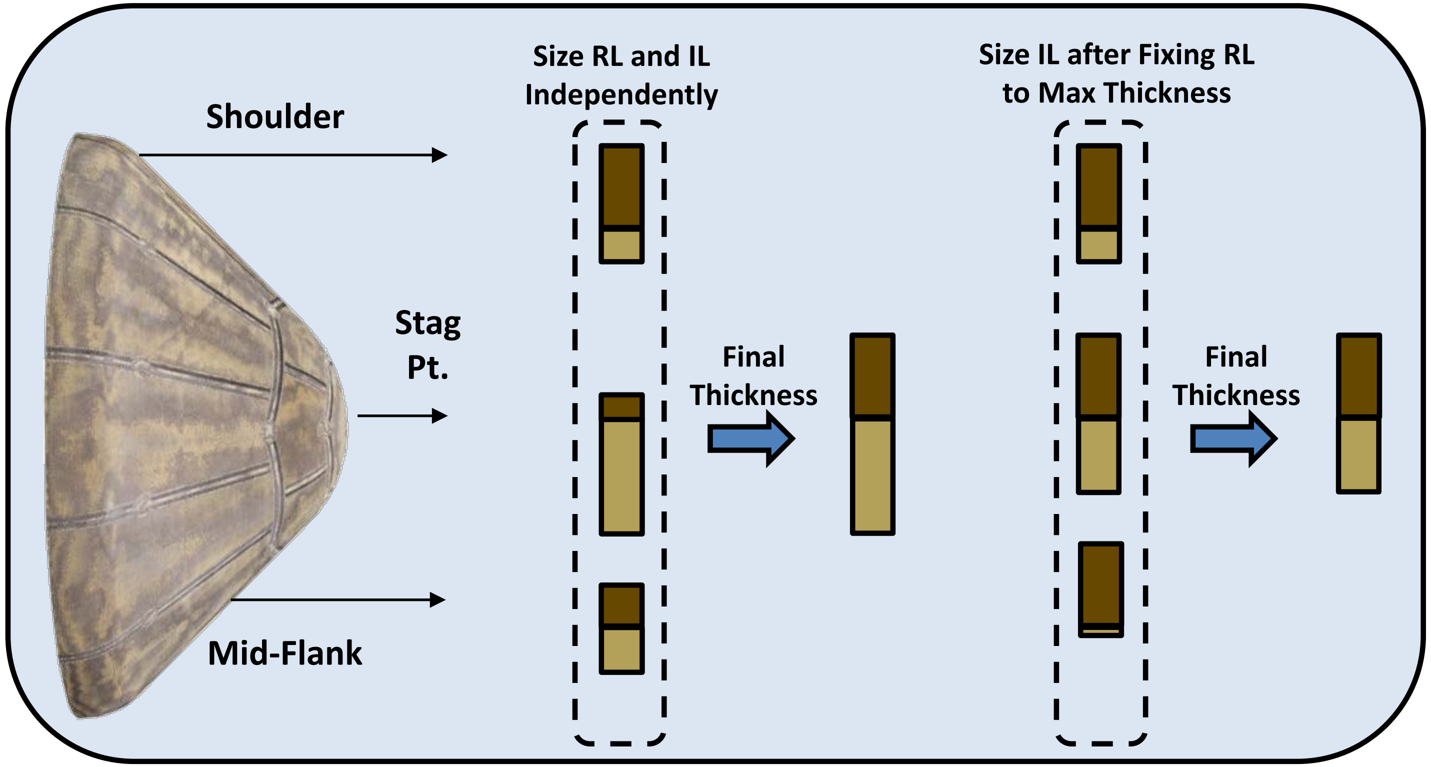
HEEET Arcjet Testing Covers Some Mission Options for All Target Destinations



Limits in ground based test facilities to achieve relevant conditions for some steep and high latitude entries. This issue applies to any TPS concept, not just HEEET.

Dual Layer TPS Sizing

- **TPS sizing is the process for determining the thickness of the TPS**
- **Bondline is the interface between the inner surface of the TPS (IML) and the structure to which it is typically adhesively bonded**
- **For single layer TPS the constraint is not to allow the bondline, to exceed temperature limit of adhesive or structure**
- **Dual Layer TPS introduces a new constraint, not to allow the insulation layer to be exposed**
- **Current HEEET implementation requires uniform TPS thickness for both layers**
- **Max thickness for each layer may occur at different body points and trajectories**
- **Sizing RL and IL independently and then stacking max RL thickness from one location on max IL thickness from another location is not mass efficient**
  - Excess RL at some locations can serve as insulation
- **More mass efficient to size IL after fixing RL to max sized thickness across all locations**



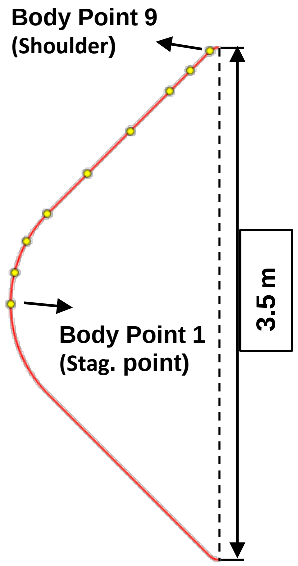
Example Sizing from a Venus Reference Mission

Sizing done at 9 locations on the heatshield

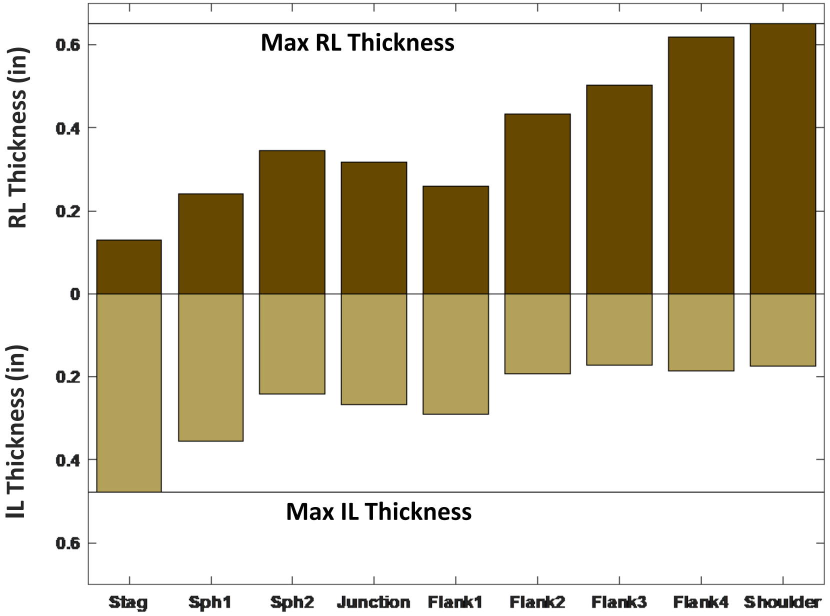
- Figure on left: RL and IL sized independently
- Figure on right: RL sized first; then IL sized while for fixed RL thickness

Taking advantage of the nonessential portion of RL thickness at locations that don’t drive RL sizing provides mass benefits

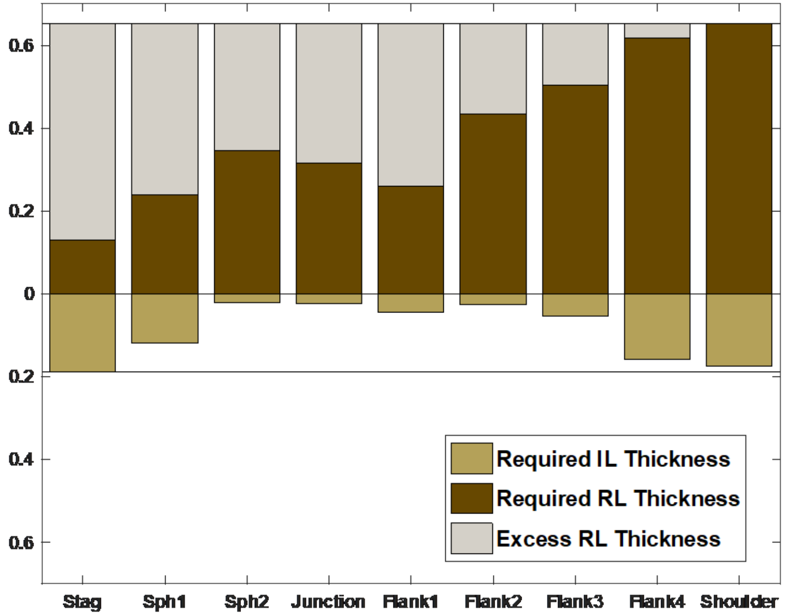
- 62% reduction in IL thickness, 19% reduction in areal mass



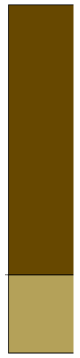
RL and IL Sized Independently
(Not taking advantage of excess RL)



IL Sized after Fixing RL to Max Thickness
(Taking advantage of excess RL)



Final Thickness

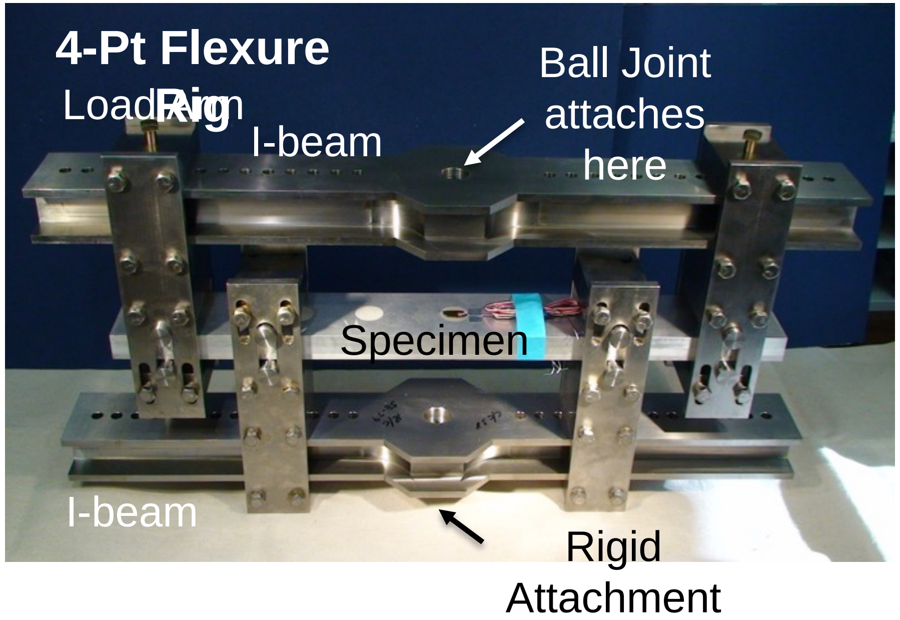


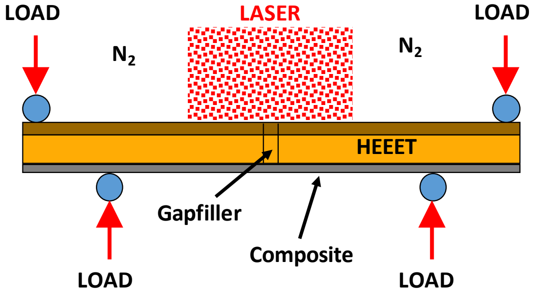
---

*Sizing and Margin Methodology for Dual-Layer Thermal Protection Systems, Mahzari and Milos, 15th International Planetary Probe Workshop

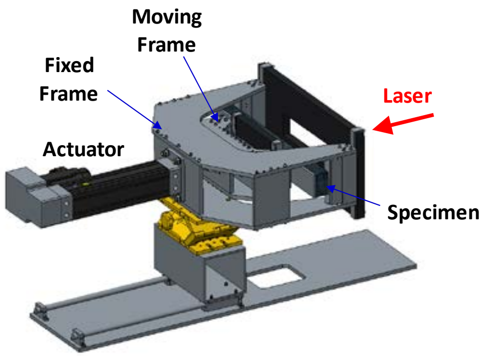
Structural Test Campaign

- **Element Level Testing**
  - Material Properties and allowables
    - Different Layers
    - Gap Filler
    - Adhesives
    - Composite structure
- **Component Level Testing**
  - 4-pt Bend (LaRC)
  - LHMEL 4pt-Bend
    - Developed novel test approach
    - Adopted by Orion
  - Shock Testing (NTS)
- **Subsystem Testing (LaRC)**
  - 1m Engineering Test Unit (ETU)



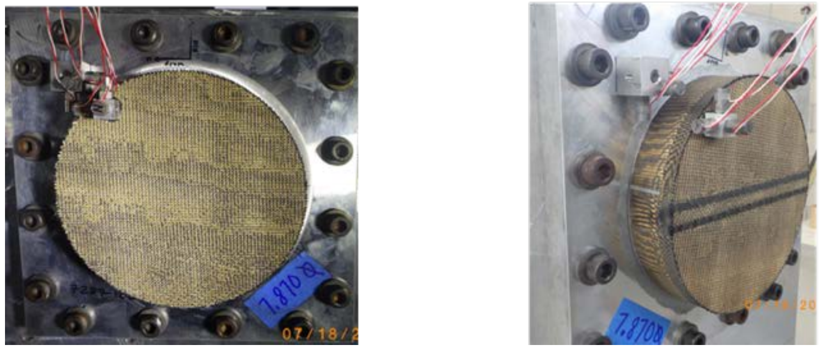


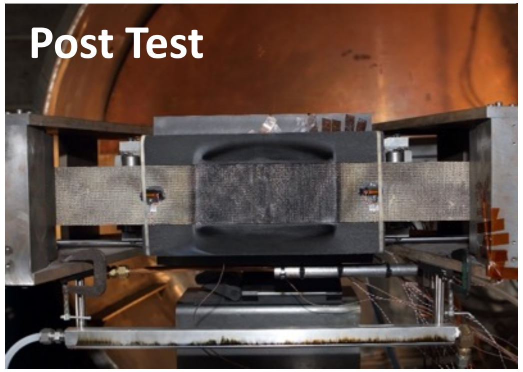
Schematic of LHMEL Structural Panel Test



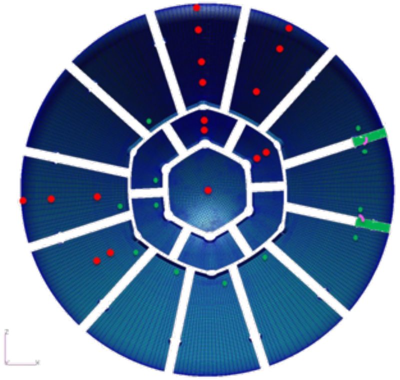
Load Application Apparatus

Shock Testing





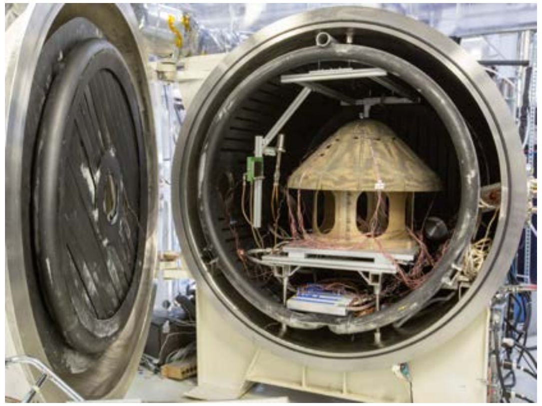
Subsystem (ETU) Testing Overview



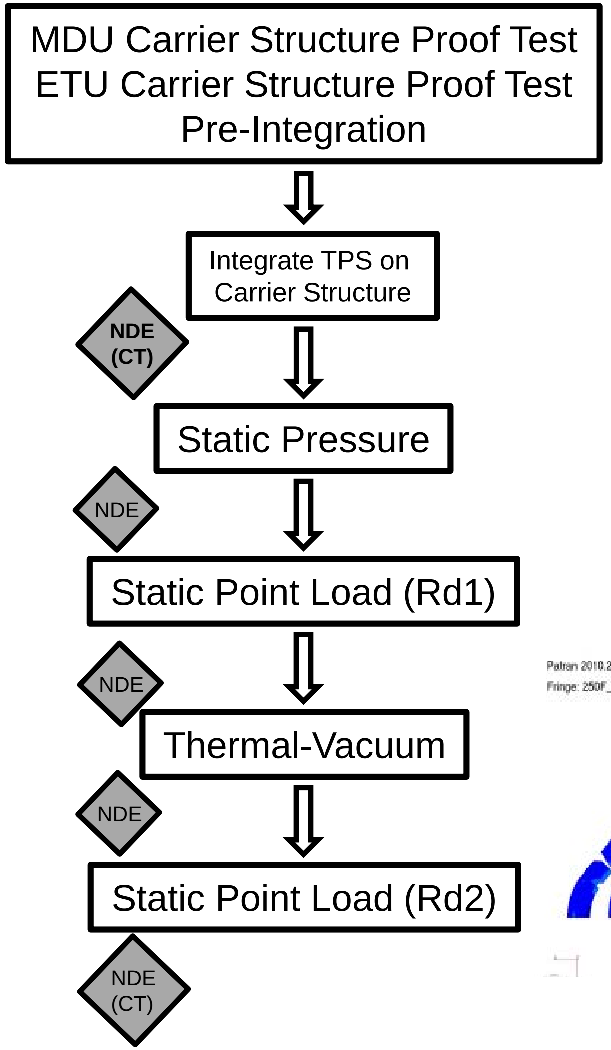
79 Total Strain Gages
For Test:
- 24 Biaxial
  - 17 on Recession layer
  - 7 on Composite
- 17 Uniaxial
  - 14 on Composite
  - 3 on Ring

For Defect Tracking: 14 Uniaxial

Static Pressure Test in Autoclave



ETU in Thermal Vac Chamber



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

⇩

Integrate TPS on Carrier Structure

NDE (CT)

⇩

Static Pressure

NDE

⇩

Static Point Load (Rd1)

NDE

⇩

Thermal-Vacuum

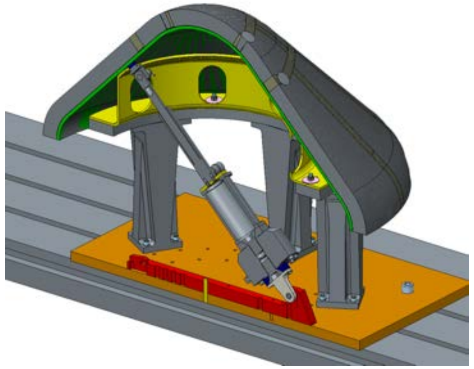
NDE

⇩

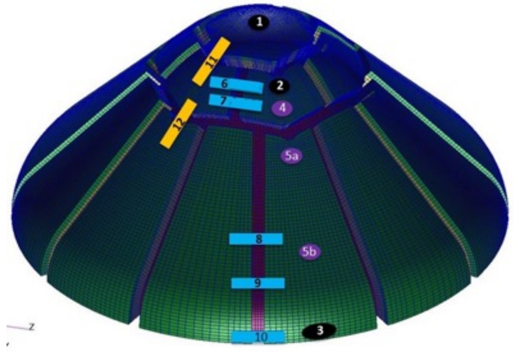
Static Point Load (Rd2)

NDE (CT)

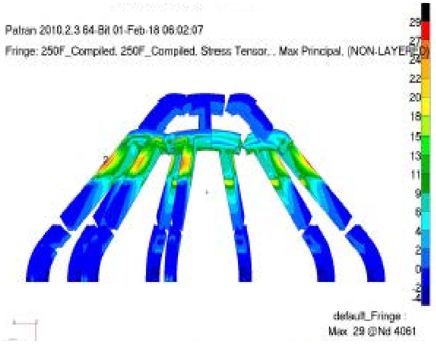
Static Point Load Configuration

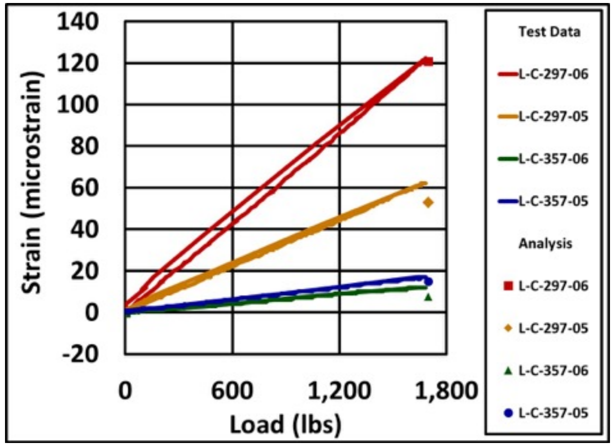


Point Load Locations



12 load locations are shown
23 total tests, 2 at each location minus nosecap





Pt 12: Under Closeout Plug

Final Technical Readiness Level (TRL) Self Assessment

Have we built high-fidelity prototypes that address scaling issues? Yes

Have we operated in relevant environments?

- Aerothermal (arc-jets) Yes
- Thermostructural (combined loading of flexures at LHMEL) Yes
- Structural (pressure, thermal-vacuum and point loads on 1 m ETU) Yes

Have we documented test performance demonstrating agreement with analytic predictions? Yes

HEEET system is assessed to be at TRL 6

Limitations

- Not at TRL 6 for thickness much greater than 2”
- Not at TRL 6 for applied environments above 5 bar and 3500 W/cm2
- No mission opportunity (except Jupiter) appears to require these levels

But don’t just take our word for it - HEEET Independent Review Board (IRB) Assessment:

- “The IRB concurs […] that the overall objective of achieving TRL 6 has been completed”

Any Questions?