Heatshield for Extreme Entry Environment Technology (HEEET) Development and Maturation Status

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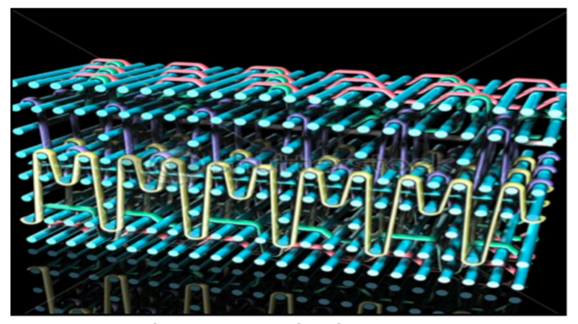
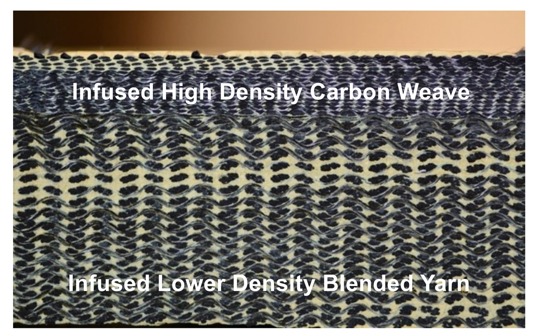
1. HEEET Background

- HEEET is a game changing technology that is being designed with:
  - Broad mission applicability and long term sustainability
  - Substantial engagement with TPS community
  - Will 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
  - Dual layer design allows tailor-ability of TPS for mass efficiency across a wide range of entry environments

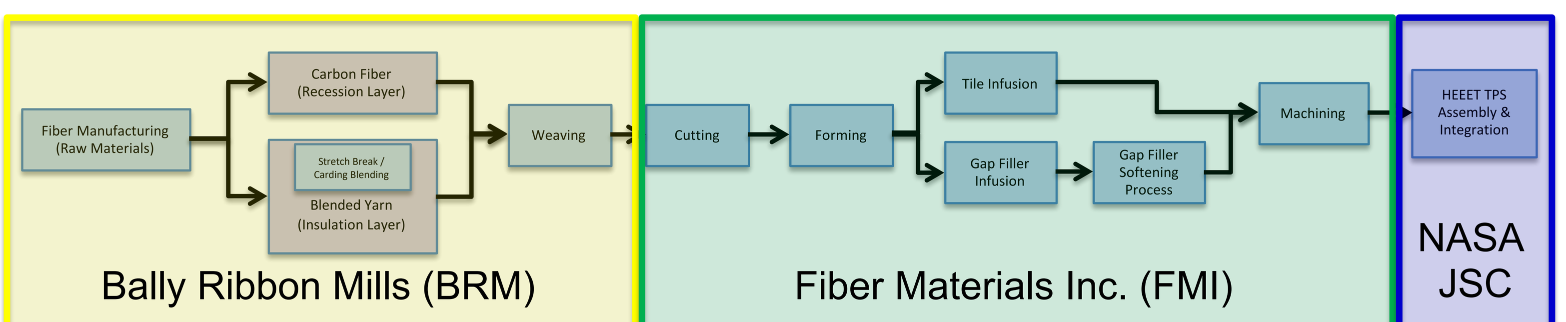


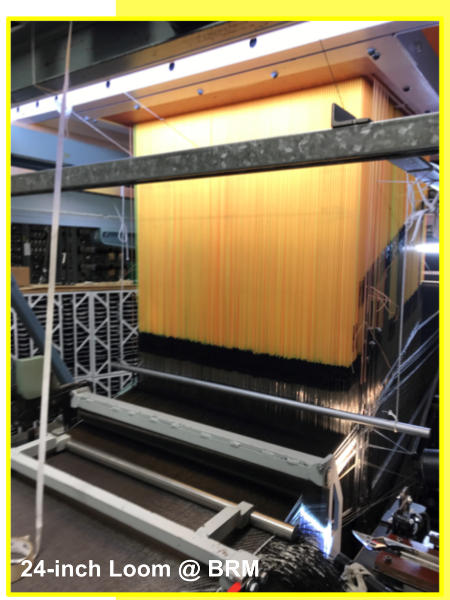
Complex 3D multi-layer weave

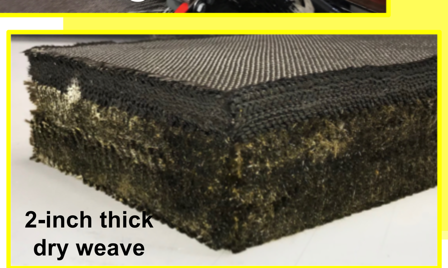


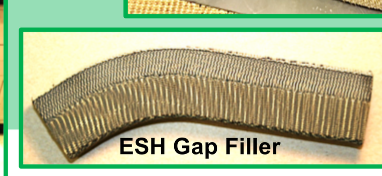
2. Architecture and Engineering Test Unit (ETU) Manufacturing

- 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









3. Arcjet Testing

- Completed initial HEEET aerothermal test campaign in a wedge shear configuration at Arnold Engineering Development Center (AEDC)
  - Test objectives were to demonstrate applicability of chosen seam design under combined high heat flux, pressure and shear conditions
- Test conditions:

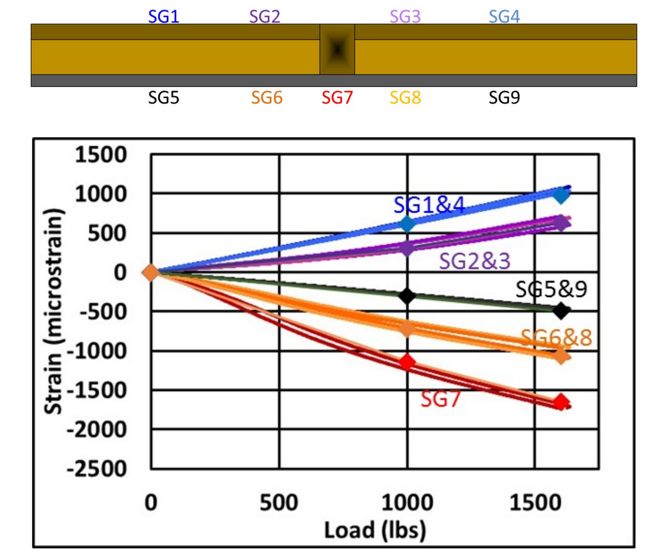
Heat Flux W/cm²	Pressure atm	Shear (Pa)
1650	2.6 atm	4000-6000

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

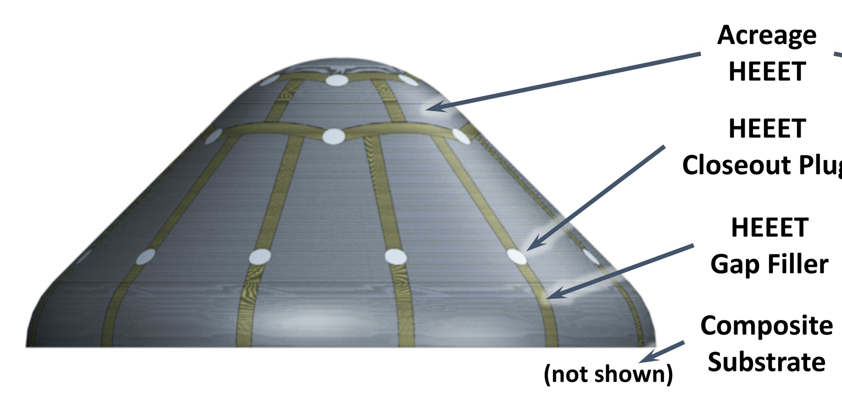
Seam Model Post-Test

4. Structural Testing

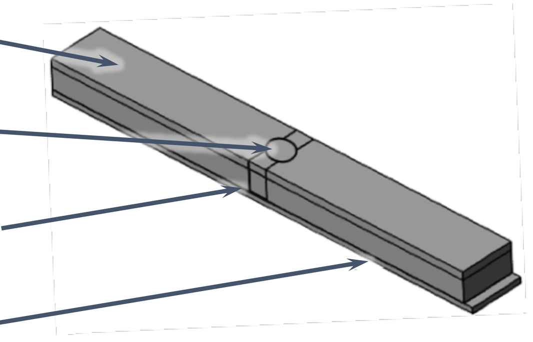
- Flexural testing was conducted at LARC at cold temperatures (-250F), room temperature, and hot temperatures (+250F)
  - Testing was completed in late October 2017
- Thermal structural analyses were performed to correlate the Finite Element Model that would be used in ETU pre-test predictions.
  - Thick 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



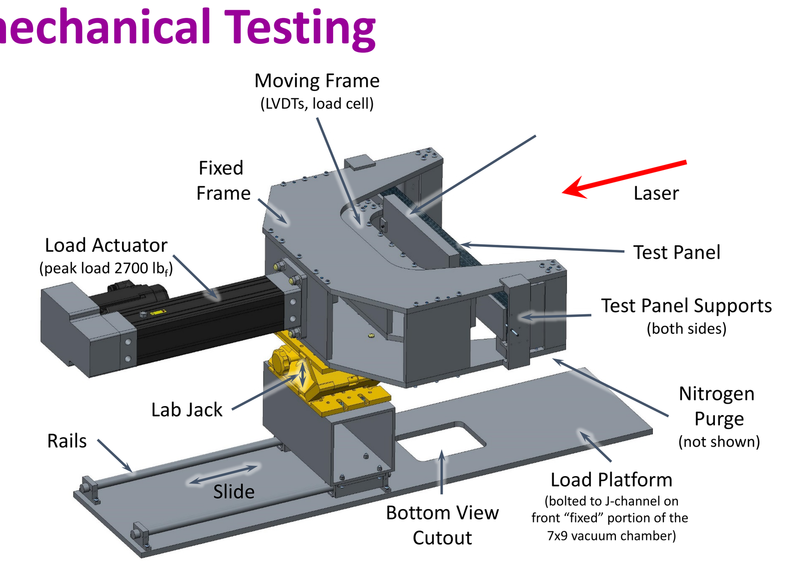
Engineering Test Unit (ETU)



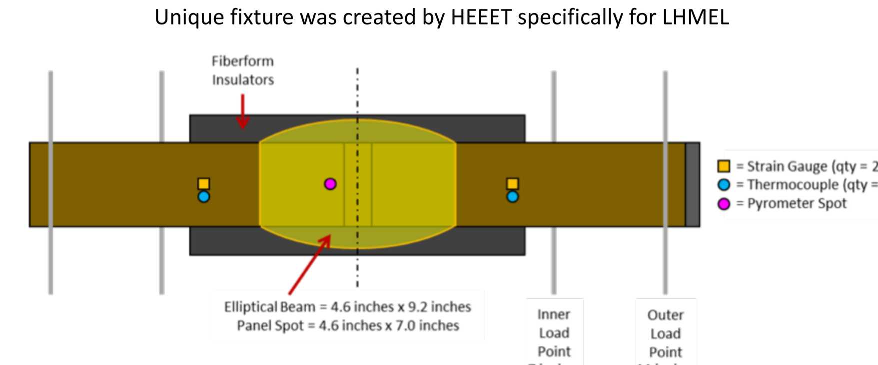
4-pt Bend / LHMEL Test Panel

5. Thermomechanical Testing

- 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 Test Objectives
  - Investigate the capability of the HEEET system under combined bending and extreme heating rate environments
  - Generate high quality experimental data for verification and validation of models
- 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

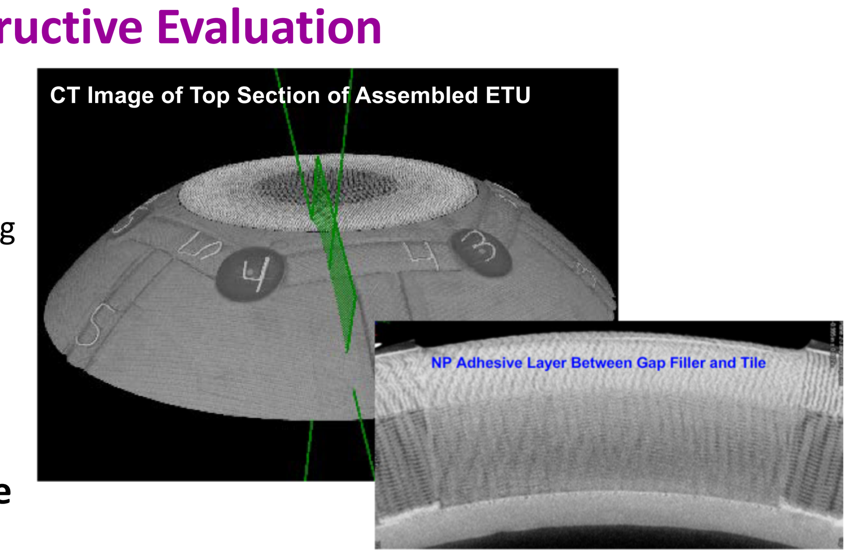


Unique fixture was created by HEEET specifically for LHMEL



6. Non-Destructive Evaluation

- CT Scanning of ETU underway at VJ Technologies
  - CT imaging provides a quantifiable means to evaluate the success of the ETU manufacturing and integration
  - Characterizes the ETU state prior to testing enabling the team to identify any flaws that may be introduced during testing and/or measure changes in pre-existing defects
- Preliminary look at data indicates that the integration methodology was successful



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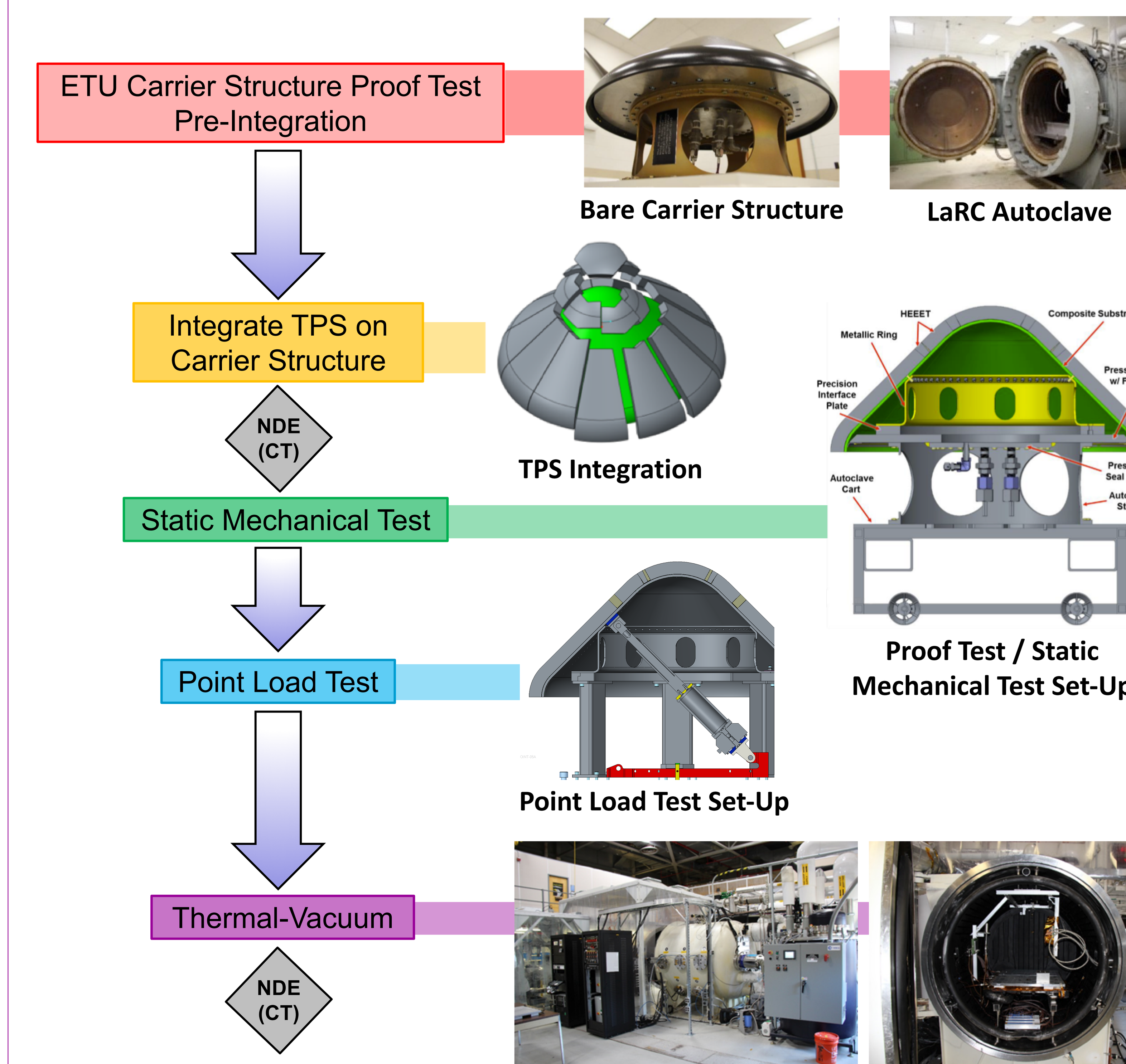
- Authors would like to thank the center managements at ARC, LaRC and JSC for their continuing support

7. ETU Testing

- ETU geometry, interfaces and testing conditions trace back to proposed mission requirements, loads and entry environments to the extent possible within ground facilities
  - Entry structural loads (pressure and deceleration loads)
  - Thermal environments (hot soak and cold soak)
  - Launch loads
- All ETU tests to be conducted at NASA Langley Research Center



8: HEEET TRL and Forward Work for Outer Planet Missions

- By FY18, HEEET will be at TRL 5+ for missions needing recession layer thickness up to 0.4-in
  - Sufficient for Venus and higher speed sample return missions but not for OP missions
- Recent mission studies indicate that a thicker recession layer will be required for Outer Planet missions (Saturn, Uranus, and Neptune)
- Ice-Giant missions have challenging environments, especially high peak pressure
  - Difficult to test at fully-relevant pressure to retire risks due to seam related features
- Lessons learned provides opportunity to improve seam design and also gain mass efficiency
  - Current seam configuration recedes faster than acreage and as a result, thickness margin for acreage and seam have to be increased (results in mass penalty)
  - Seams require testing of specific features and test capability limitation increases risk
- Plans for closing the TRL gap for Outer Planet missions will be presented to SMD-PSD
  - Establish HEEET capability with thicker recession layer adequate for OP missions
  - Reduce risk for Saturn and Ice-Giants
  - Improve mass efficiency

9: Summary

- Woven TPS is a game-changing approach to designing, manufacturing, and integrating a TPS for extreme entry environments that allows tailoring the material (layer thicknesses) for a specific mission
- Given constraints on weaving technology a heat shield manufactured from the 3D Woven Material will be assembled from a sets of panels, with seams between the panels
  - Seam design needs to meet both structural and aerothermal requirements
  - Project has baselined use of Softened HEEET (SH) as a gap filler in the seam design
- Project has completed several different structural and thermal-structural component tests at various NASA and DoD facilities
  - Data from component tests will be used to correlate the Finite Element Model that will be used to analyze ETU pre-test predictions
- Project is currently on target to mature HEEET to TRL 6 by the end of FY 2018
- OPAG advocacy is needed to develop thick HEEET to meet the needs of future Outer Planet missions, and to ensure HEEET is available for the next New Frontiers and Flag-ship mission considerations