Heatshield for Extreme Entry Environment Technology (HEEET) Development and Testing

D. Ellerby[§], T. Boghozian*, D. Driver[§], J. Chavez-Garcia*, M. Fowler[$], P. Gage[#], M. Gasch[§], G. Gonzales*, C. Kazemba~, C. Kellermann[$], S. Langston[%], B. Libben*, M. Mahzari [§], F. Milos[§], A. Murphy^, O. Nishioka[§], G. Palmer*, K. Peterson [§], C. Poteet[%], D. Prabhu*, S. Splinter[%], M. Stackpoole[§], E. Venkatapathy[§] , J. Williams*, and Z. Young[§]

[§] NASA ARC; [%]NASA LaRC; [$]NASA JSC; *AMA.-Moffett Field, CA; [#]NEERIM Corp.-Moffett Field, CA ; ^Millennium Engineering & Integration Co.-Moffett Field, CA; ~Science & Technology Co. Moffett Field, CA

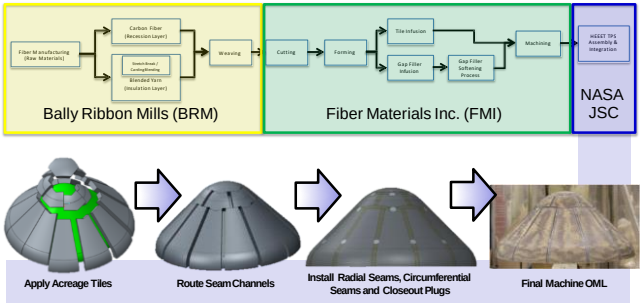
1. HEEET Background

- HEEET is a game changing technology that is being designed to enable in-situ robotic science missions recommended by the National Academies of Sciences, Engineering and Medicine
- HEEET leverages a mature weaving technology that has evolved from a well-established textile industry
- A layer-to-layer weave mechanically interlocks the different layers together in the thru-the-thickness direction
  - High density all carbon surface layer manages recession
  - Lower layer manages heat load with low-density blended yarn

Complex 3D multi-layer weave

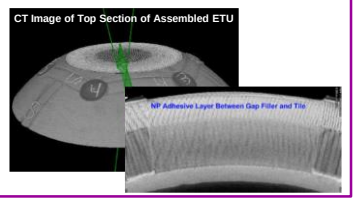
2. Architecture and Engineering Test Unit (ETU) Manufacturing

- All manufacturing and integration operations have been demonstrated at mission-relevant scale
- All component manufacturing steps have been transferred to industry to establish supply chain for future missions and vendors certified to manufacture parts to NASA specs



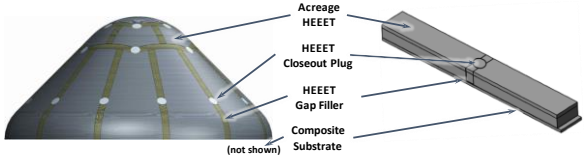
3. Non-Destructive Evaluation

- CT Scanning of ETU performed at VJ Technologies (1-meter scale)
  - CT imaging provides a quantifiable means to evaluate the success of the ETU manufacturing and integration
  - Characterizes the ETU state before and after testing to enable identification of any flaws introduced during testing and/or measurement of changes in pre-existing defects



4. Structural & Thermostructural Testing

- Flexural testing conducted at LaRC at cold temperatures (-250F), room temperature, and hot temperatures (+250F)
- Element, subcomponent, component and subsystem level testing verify the structural adequacy of the system
  - Analytical work will be used to evaluate vehicles > 1-meter diameter
- Subsystem Testing: ETU testing will verify the performance of the HEEET design for the given thickness under mission relevant loads except acoustic environments and entry
- Combined Thermal-Structural Testing is 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
  - Used to verify structural performance during entry
- Shock testing completed (June 2018) at 7.5dB above design requirement



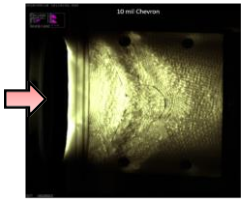
Engineering Test Unit (ETU) 4-pt Bend / LHMEL Test Panel

5. Arcjet Testing

- Arcjet testing performed at NASA and AEDC (2015-2017) established viability of acreage, seams and provided data for thermal response model development
- January 2018: Completed first round of shear aerothermal test campaign in a wedge configuration at Arnold Engineering Development Center (AEDC)
  - Test objectives were to evaluate ETU seam design features in high heat flux, pressure and shear
- Test conditions:

Test Campaign	Heat Flux W/cm²	Pressure atm	Shear (Pa)
AEDC H3	1650	2.6	4000-6000

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

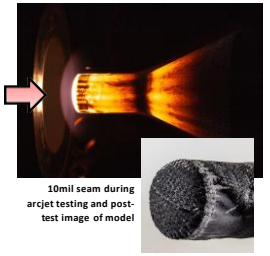


Close out plug / circumferential ESH intersection with 10-mil seam during arcjet testing

- June 2018: Completed stagnation aerothermal test campaign in the IHF 3-inch nozzle using 1-inch diameter stagnation coupons
  - Test objectives were to evaluate ETU seam design features in high heat flux and pressure
- Test conditions:

Test Campaign	Heat Flux W/cm²	Pressure atm	Shear (Pa)
IHF 3-in Nozzle	5500	5.5	0

- Nitrile Phenolic seams performed successfully as expected
- Insulating layer was tested by itself and performed very well



10mil seam during arcjet testing and post-test image of model

6. ETU Testing: Completed

- ETU tests conducted at NASA Langley Research Center
- 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)

Carrier Structure

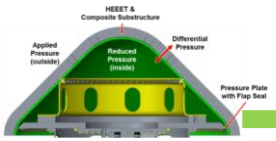
LaRC Autoclave

ETU Carrier Structure Proof Test Pre-Integration

Integrate TPS on Carrier Structure

NDE (CT)

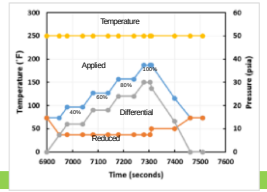
Static Mechanical Test

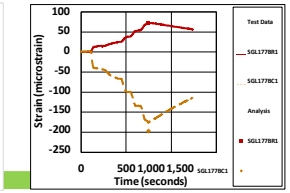


Static Pressure Load Diagram

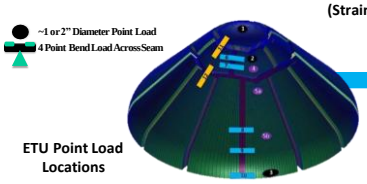
OML Instrumentation (Strain Gages + TCs)

Combined Load Nominal Profile

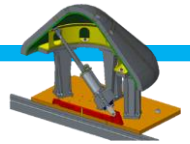




Good agreement between composite laminate strain measurements vs pre-test predictions with no attempt to improve how the system is modeled



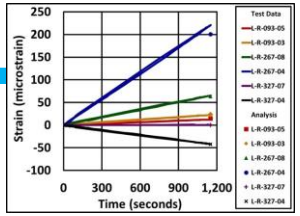
ETU Point Load Locations



Point Loading Configuration

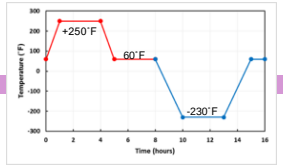
Point Load Test 1

Point Load Test @ LaRC



Good Correlation Between Test Data and Pre-Test Prediction of Laminate Strains

LaRC 6x6-Foot Thermal Vacuum Chamber

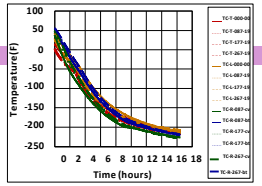


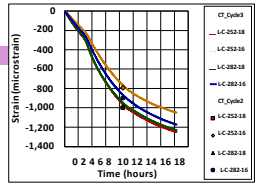
Thermal Cycle Nominal Profile

Thermal-Vacuum

Point Load Test 2

NDE (CT)





Comparison of laminate strains between Cycles #2 and #3, very repeatable

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7: Summary / Remaining Tasks

- Data analysis for all recently completed testing is underway – preliminary data and inspection show no material failures
- Upcoming work:
  - 4pt Bend Testing Rd 2 at NASA Langley (November 2018)
  - 4pt Bend Testing Rd 2 at LHMEL (October 2018)
  - AEDC high shear (Round 2) arcjet testing (June 2019)
  - Final documentation in Design Data Book (March 2019)