Enabling Future Venus *in situ* Missions: Heat-shield for Extreme Entry Environment Technology (HEEET) Progress towards TRL 6

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November 8, 2018

16th Meeting of the Venus Exploration and Analysis Group (VEXAG)
November 6–8, 2019
Applied Physics Laboratory, Johns Hopkins University
Laurel, Maryland

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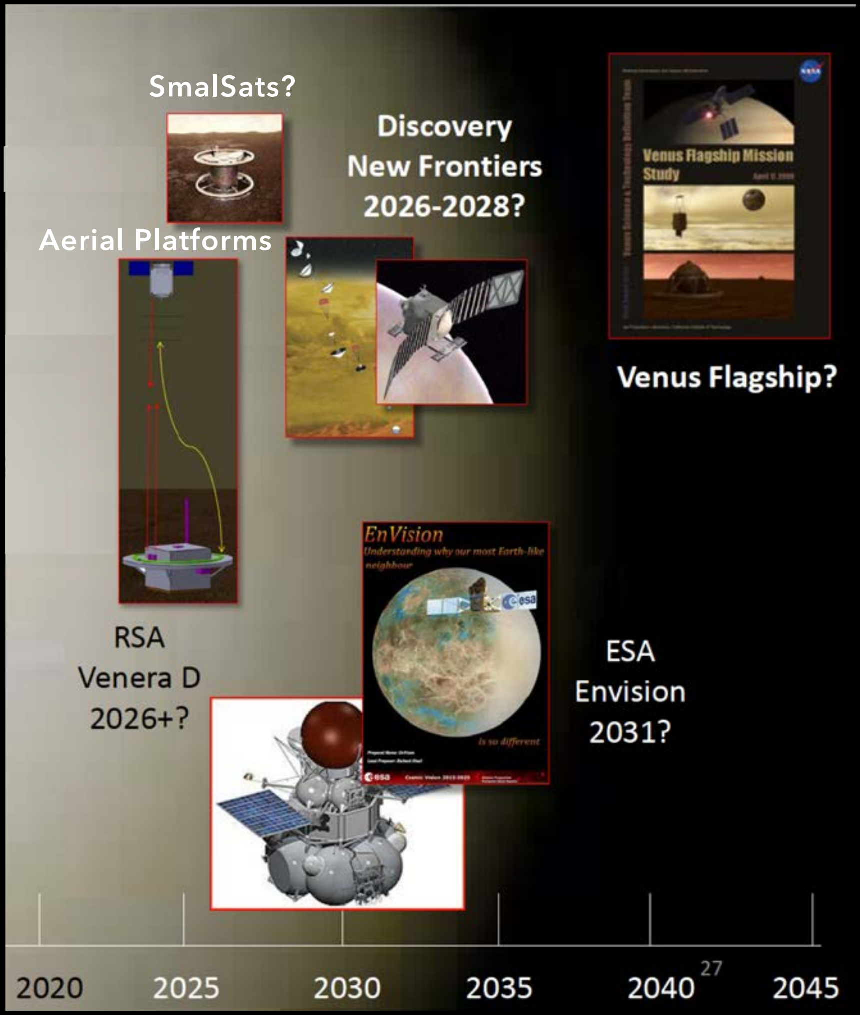
STMD/GCDP and SMD sustained support made the HEEET development possible and the team is grateful.

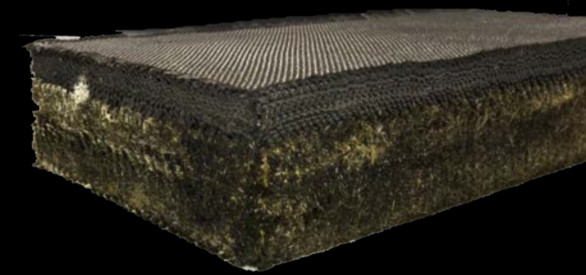
Ready for Venus *in situ* Missions? YES!

- 40 year Gap and U.S. exploration of Venus - highlighted in the presentation "Case for Venus" by Martha Gilmore and Robert Grimm – March, 2018.
- Entry with rigid aeroshell is very well established :
  - Small Spacecrafts, Aerial Platforms, Probes and Small and Large Landers
- Ablative TPS to withstand the extreme entry at Venus has been one of the challenges
- HEEET development is nearing completion and ready at TRL 6
- Ready to enable Venus missions



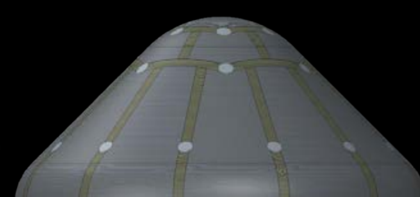
HEEET – Background

- Leverages advanced 3-D weaving and resin infusion.
- A dual layer system - robust and mass efficient across a range of extreme entry environments
- TRL 6 by March of 2019
- The development to-date includes:
  - Establishing requirements and developing concept
  - Testing – Aerothermal and Thermo-structural
  - Specifications from raw materials to weaving, tile fabrication (forming/resin infusion) and integration
  - Technology transfer to industry (BRM and FMI)
  - Heat-shield (1m dia.) design, build and testing
  - Documentation.



Apply Acreage Tiles

Route Seam Channels



Install Radial and Circumferential Seams and Closeout Plugs

Full Scale MDU/ETU

Accomplishments - FY'18

Full Scale Integrated System Testing (1m Engineering Test Unit (ETU)– Saturn Design)

Carrier Structure

LaRC Autoclave

ETU Carrier Structure Proof Test Pre-Integration

Integrate TPS on Carrier Structure

NDE (CT)

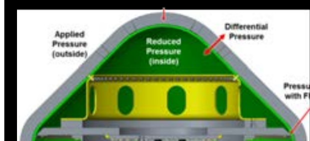
Static Mechanical Test

Point Load Test 1

Thermal-Vacuum

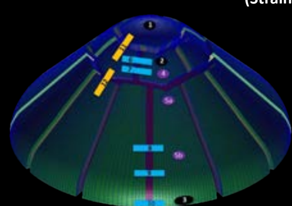
Point Load Test 2

NDE (CT)



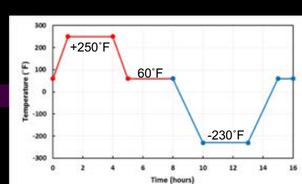
Static Pressure Load Diagram

OML Instrumentation (Strain Gages + TCs)



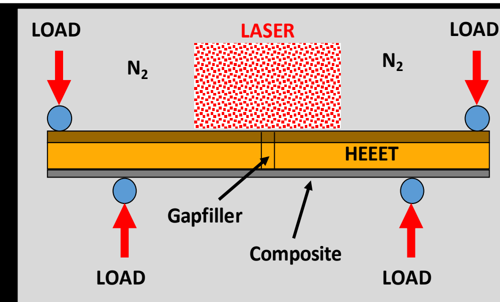
Loading Configuration

6x6-Foot Thermal Vacuum Chamber @ LaRC

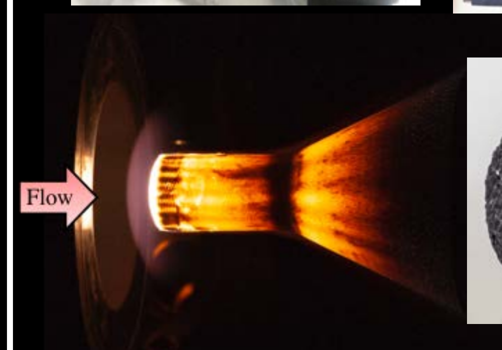


Thermal Cycle Nominal Profile

Component Level Testing Thermo-structural and Arcjet



Schematic of LHMEL Structural Panel Test



Excerpts from Independent Review Board Findings (Sept., 2018)

IRB is chaired by Prof. Braun and it includes experts from APL, JPL, JSC, KSC, LaRC and ARC

- IRB commends the HEEET Team for the quantity and quality of test data obtained in FY18; especially appreciated the project's approach to testing coupons with known defects. Did an excellent job in completing the structural and thermal vacuum tests on the ETU.
- Although not complete, the project is doing an excellent job of using FY18 test data to correlate and validation thermal/structural models. ***Preliminary correlations between modeling and test are excellent.*** From the data presented, the thermal and recession margins recommended appear to bound the test data obtained.
- The IRB agrees with the Project that Spring of 2019 is an appropriate time for its TRL assessment.
- Finally, the Project should work with NASA to develop a plan to ensure some low-level continuity of personnel to transfer this technology into a future spaceflight mission.

Looking ahead

- ETU Testing: Data reduction, post-test analysis and documentation (on going and will be completed by December, 2018)
- Shock Testing: Data reduction, post-test analysis and documentation (completed)
- FY18 Arcjet testing – AEDC , IHF 3” and IHF 6” - data reduction, post-test analysis and documentation (on going and to be completed by December, 2018)
- Thermo-structural Testing (4-pt Bend Test at LaRC and LHMEL)
  - In progress
  - Data reduction, post-test analysis and documentation (January, 2019)
- **AEDC Rd 2 Testing**
  - July 2019 – earliest test opportunity available.
- **Design Data Book** (to be completed by February, 2019)
  - AEDC Rd2 analysis and documentation will be completed once Test is done and added to the DDB at a later time

Design Data Book

Executive Summary

- Need for TPS for Extreme Environments
- Woven TPS concept
- Requirements for HEEET Development Project
- Scope of Development Effort
- Summary of Other Volumes
  - HEEET System Manufacturing Guide
  - Design Development
  - Aerothermal Testing
  - Structural and Thermostructural Testing
- Status and Recommendations

System Manufacturing Guide

- System Architecture
- System Implementation Requirements
- Manufacturing and Integration Overview
- Individual Processes
  - Verification of Inputs
  - Process
  - Verification of Product
- Appendix: Process Specs

Design Development

- Failure Modes and Margin Policy
- Selection of Weave
- Selection of Infusion
- Forming
- Panel to Panel Attachment
- Substrate Attachment
- Machining
- Selection of Adhesives
- Gap-filler
- Selection of Adhesive Thickness
- Assembly
- Repair
- Acceptance Policy
  - Process Controls
  - Inspection
  - Acceptance Test
- Aerothermal Response Model Development
- Structural Model Development
- Material Properties

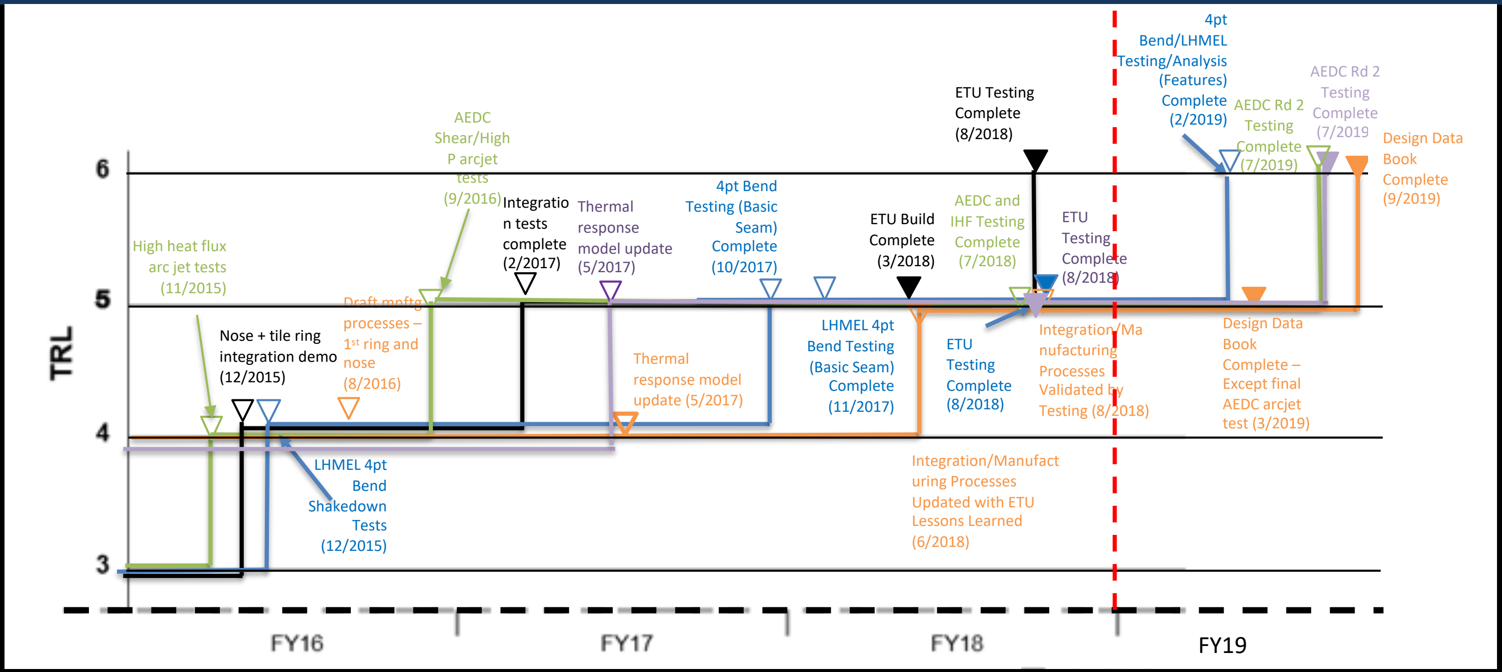
Aerothermal Characterization

- Overview
- Properties Testing
- Failure Modes
  - Acreage
  - Gap-filler
  - Adhesive
  - System Architecture Features
- Aerothermal Response Modeling
  - Acreage
  - Gap-filler
- Findings
- Appendices: Individual Test Series Reports

Structural Characterization

- Overview
- Properties Testing
- Failure Modes
  - Acreage
  - Gap-filler
  - Adhesive
  - System Architecture Features
- Structural Response Modeling
  - Acreage
  - Gap-filler
- Findings
- Appendices: Individual Test Series Reports

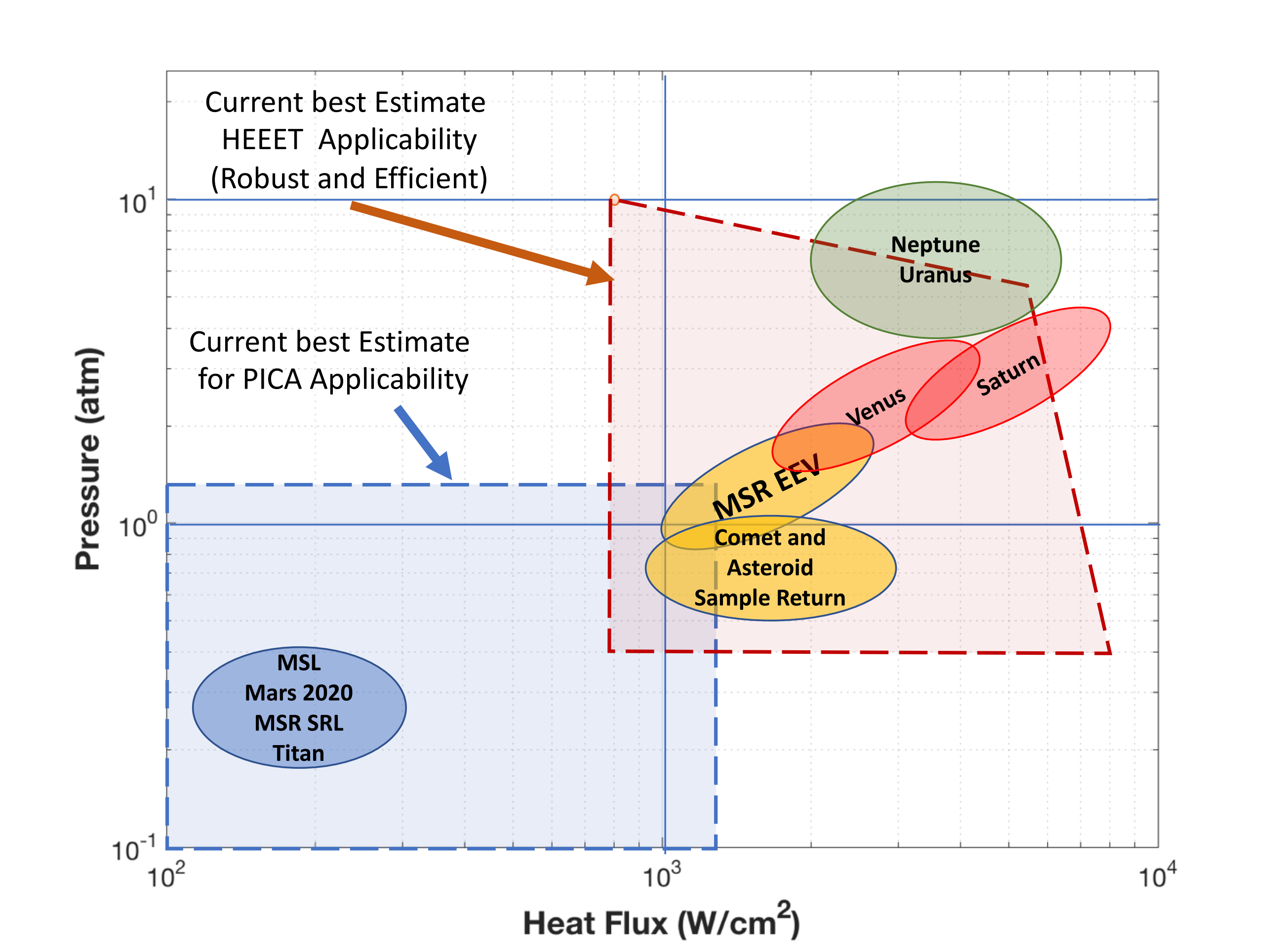
HEEET TRL Status



- Aerial Mass for Venus, Saturn and Sample Return Missions
- Acreage and Seam Thermal Performance
- Component and Integrated System Structural Performance
- Manufacturing and Integration
- Technology Transfer
- Design Data Book

Independent Review Board will be performing the TRL assessment in March, 2019

HEEET Enables Venus and Other Planetary Missions



Note: The applicability boundary especially for HEEET is based on limited arc-jet tests. The HEEET acreage material has not failed in any of the tests and so there is some confidence. The heat-shield design (with seam) does carry higher risk at higher conditions due to a) ground test facility test limitations and b) extrapolation.

Concern: Sustaining the Capability

- HEEET development targeted NF-4 missions
  - HEEET team supported four of the NF-4 proposals
  - None were selected.
- If Mars Sample Return Earth Entry Vehicle uses HEEET
  - Capability will be sustained for 5+ years
- If not, HEEET will have to wait for a mission
  - Discovery, NF-5 or Flagship missions ~ (2030 – 2040)
- If HEEET needs to be shelved for 5 or more years
  - Industry may not be able to maintain the capability
  - NASA developed HEEET and intellectual owner – particularly for integration which has yet to be technology transferred to industry
- NASA expertise, if maintained, can help transfer and certify new vendors
- **Sustaining HEEET may become critical for future Venus missions**
  - **Risk needs to be addressed through assessment, mitigation planning and implementation.**

Backup / Additional

Level 1 Project Goals	
Heatshield for Extreme Entry Environments Technology (HEEET)	
Goal #1	Develop and demonstrate thermal performance of a three-dimensional woven, dual-layer thermal protection for robotic science missions to destinations such as Saturn, Venus and higher speed sample return missions.
Goal #2	Develop and demonstrate robust, scalable and mass efficient integrated heat-shield system for mission infusion under Discovery and New Frontiers mission opportunities.
Goal #3	Advance manufacturing readiness level through technology transfer to facilitate mission infusion
Goal #4	Develop and deliver engineering design tools and documentation to support mission infusion