



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

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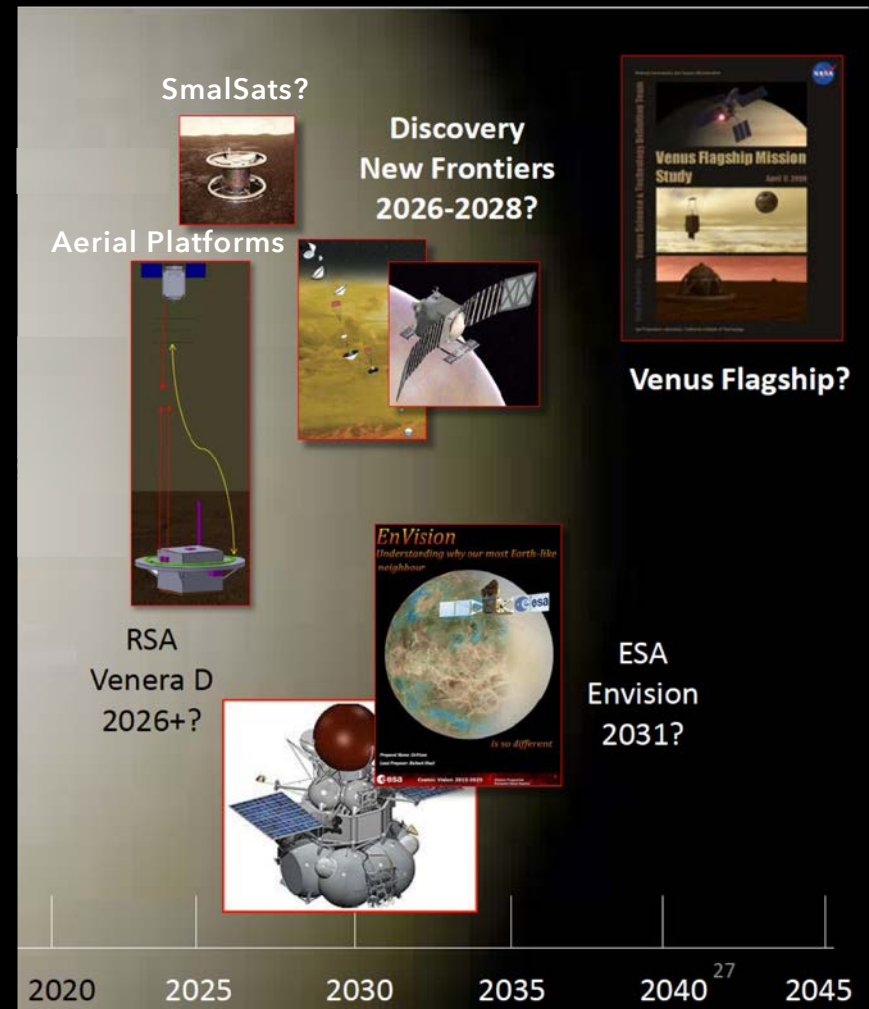
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STMD/GCDP and SMD sustained support made the HEEET development possible and the team is grateful.

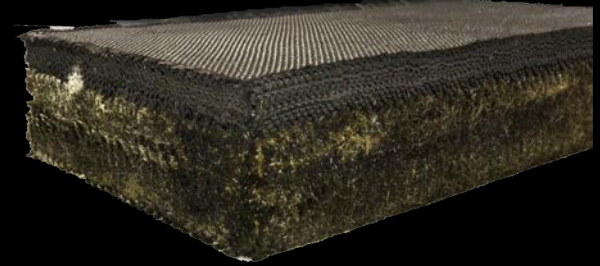
Ready for Venus *in situ* Missions? YES!

- 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

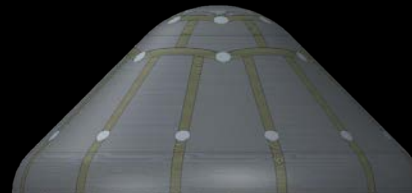
- Leverages advanced 3-D weaving and resin infusion.
- A dual layer system - robust and mass efficient across a range of extreme entry environments
- TRL 6 by March of 2019
- The development to-date includes:
 - Establishing requirements and developing concept
 - Testing – Aerothermal and Thermo-structural
 - 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 Acreege Tiles



Route Seam Channels



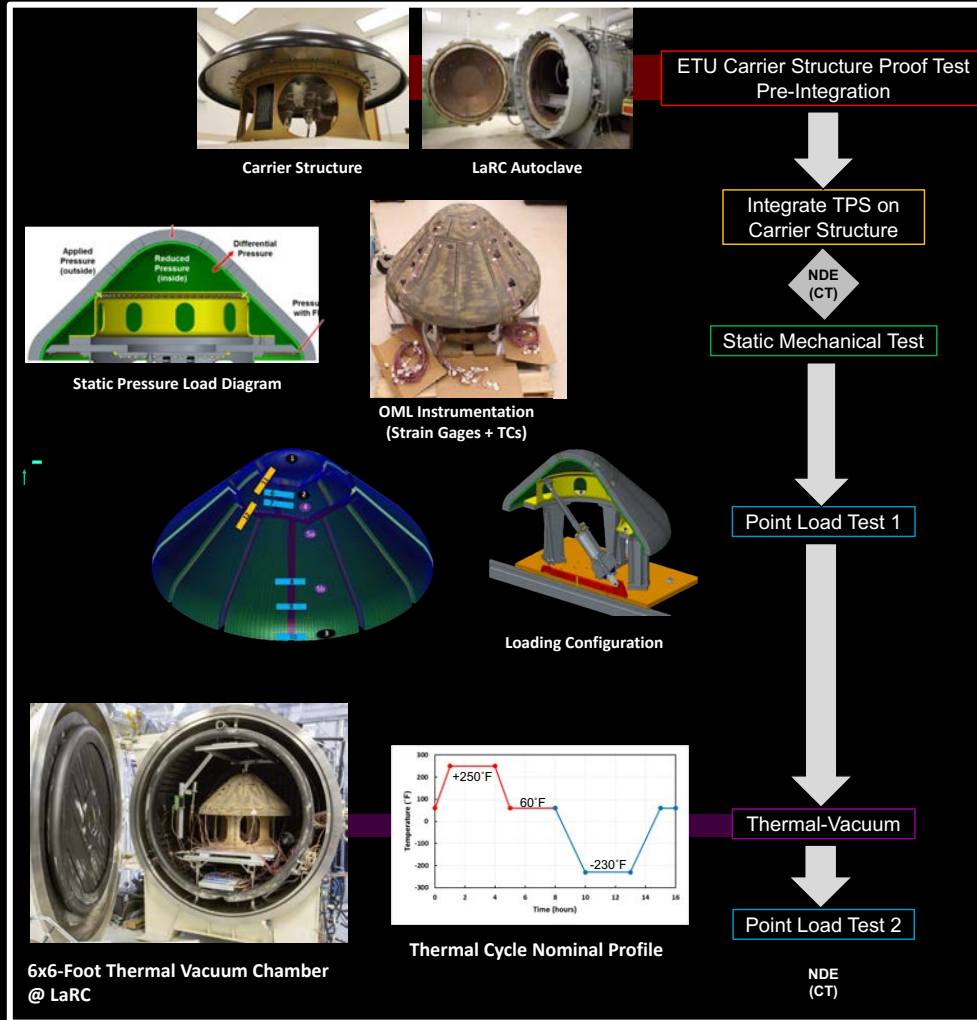
Install Radial and Circumferential Seams and Closeout Plugs



Full Scale MDU/ETU

Accomplishments - FY'18

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



Component Level Testing Thermo-structural and Arcjet



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**

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**

System Manufacturing Guide

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

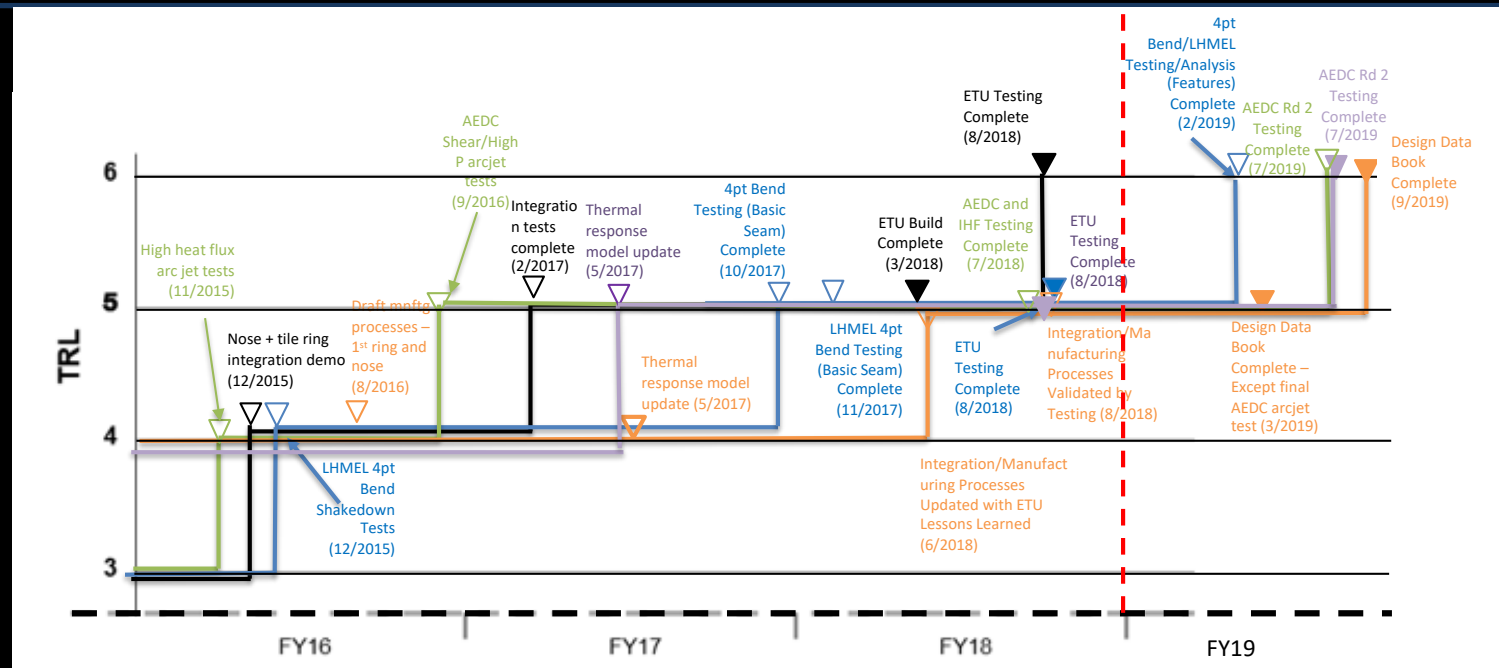
Structural Characterization

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

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**

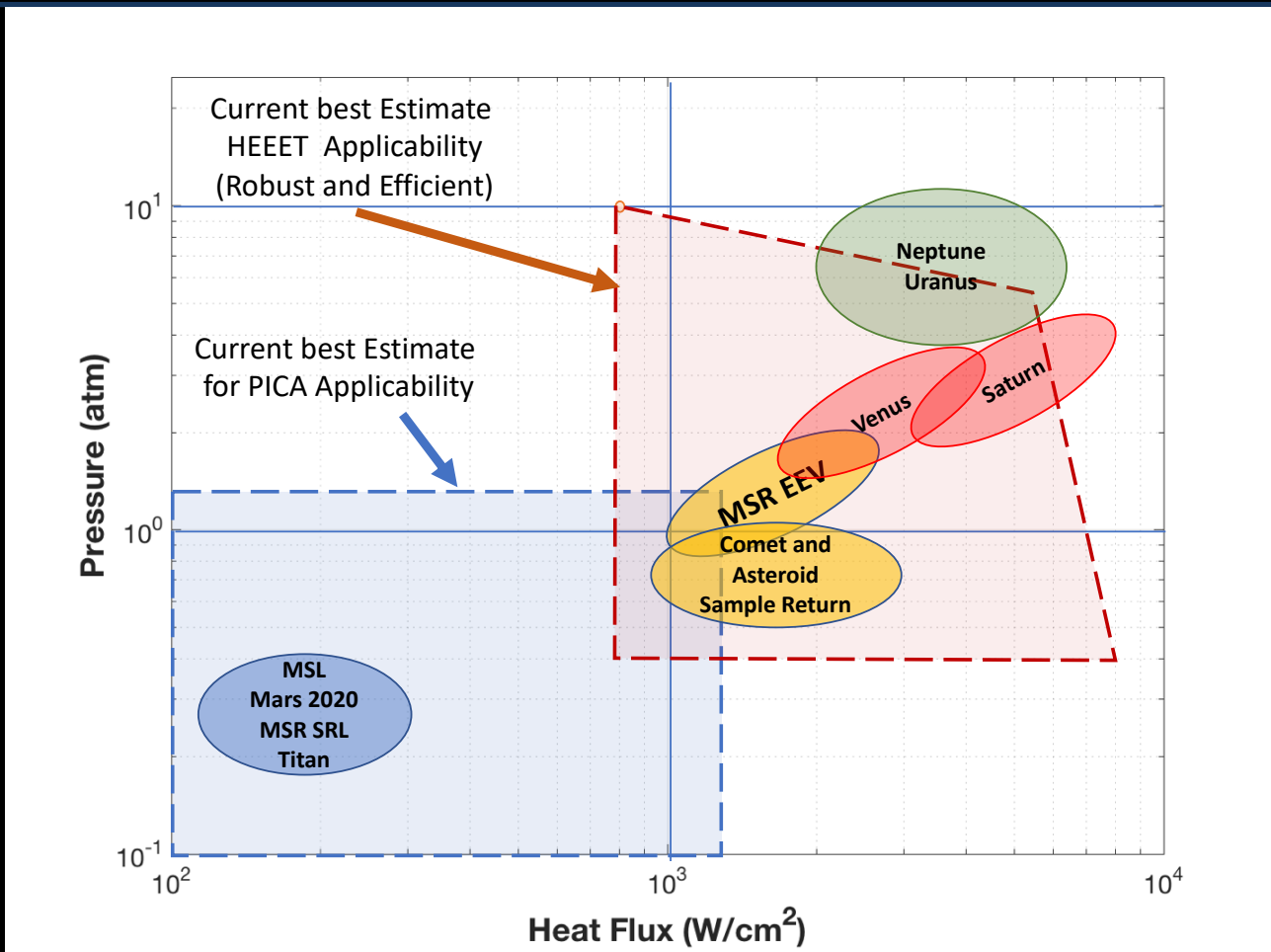
HEEET TRL Status



- 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 HEET is based on limited arc-jet tests. The HEET 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