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Applied Physics Laboratory, Johns Hopkins University
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HEEET Team

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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!

- Entry with rigid aeroshell is very well established:
  - Aerial Platforms, Probes and Small and Large Landers
  - Enabler of aerocapture for small and large spacecrafts
- 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

Figure from the “Case for Venus,” M. Gilmore and R. Grimm
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
  - Aerothermal and structural margin approaches for system design
  - 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.
Accomplishments - FY’18

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

- ETU Carrier Structure Proof Test Pre-Integration
- Integrate TPS on Carrier Structure
- Static Mechanical Test
- Point Load Test 1
- Thermal-Vacuum
- Point Load Test 2
- NDE (CT)

Component Level Testing
Thermo-structural and Arcjet

- OML Instrumentation (Strain Gages + TCs)
- Loading Configuration
- 6x6-Foot Thermal Vacuum Chamber @ LaRC
- Thermal Cycle Nominal Profile
- Schematic of LHMEL Structural Panel Test

LaRC Autoclave
- Static Pressure Load Diagram
- Carrier Structure
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 (ongoing 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 (ongoing 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**

- Areal 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
• Risk for any TPS intended for most extreme environments cannot be fully retired through ground test.
• The applicability boundary especially for HEEET is based on limited arc-jet tests.
• HEEET has not failed in any of the tests.
Concern: Sustaining the Capability

- HEEET development targeted NF-4 missions
  - HEEET team supported four of the NF-4 proposals in step 1 and none were selected.
  - HEEET was not identified as a factor for non-selection of any proposal.

- 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 |