Heatshield for Extreme Entry Environment Technology (HEEET)

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Technology Forum, VEXAG-11

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Missions enabling entry technologies
- Deployable (Low-ballistic coefficient entry system - ADEPT)
- Ablative TPS for Rigid aeroshell (high-ballistic coefficient system)
  - TPS capable of (heat-flux > 1500 w/cm²; pressure > 1.0 atm)

Two Choices for ablative TPS for rigid aeroshell:
- Reviving heritage carbon phenolic, or
- Developing advanced TPS

Combining the advance weaving techniques and resin infusion, able to create a range of 3-D Woven TPS
- Presented it at VEXAG (2012)

Advanced ablative TPS for extreme entry environment
- HEEET, a project to mature the technology to meet NF-4, is currently funded by STM
Outline:

- HEEET project formulation phase (FY’12)
- 3 Year Technology Maturation Project Plan

Background:

- HEEET - 3-D Woven TPS Family
  
  Woven TPS: An approach to the design and manufacturing of ablative TPS by the combination of weaving precise placement of fibers in an optimized 3D woven manner and then resin transfer molding when needed

- In FY’12, established the viability of the 3-D Woven TPS.
  
  Explored the “10,000” manufacturing ways of formulating a TPS
  
  Ablative TPS options, dry-woven as well as resin infused systems, ranged in density from (0.3 g/cc – 1.4 g/cc) in overall density

- Highlighted the Woven TPS potential for meeting the mission needs of Venus, Saturn and higher-speed Sample Return Missions (Vexag 2012)

VEXAG-OPAG recommendation to SMD-PSD and the resulting advocacy and support by SMD-PSD was critical in securing 3-year project funded by STMD/Game Changing Development Program
A Brief History of a Game Changing Technology:
Woven TPS Technology Maturation and Mission Insertion

- **April 2011**: Woven TPS GCT BAA
- **Jan. 2012**: 3-D Woven Multifunctional Ablative TPS (3D-MAT)
- **June, 2012**: Enabling Orion with Lunar Capable Compression Pad
- **Oct. 2013**: Heatshield for Extreme Entry Environment Technology (HEEET)
  - Tech. Maturation to enable Venus, Saturn and outer planets missions
- **2017**: Robust Heat-shield for Human Missions (Future Potential)
- **2020 - 2022**: Tech. Maturation to enable Venus, Saturn and outer planets missions

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HEEET Challenges: From Formulation to Tech Maturation

- HEEET is a core-technology with broad applicability - a game-changer
- Defining Capability Requirements:
  - Near-term technology maturation success with budget and schedule constraints
  - Mission insertion focus
  - Longer term sustainability
- Engaging the community from the get-go
  - What does TRL 5/6 mean?
  - Ensuring proposal teams have relevant information and insight to assess HEEET
- Other:
  - Cost vs Tech. Maturation Risk
    - Selecting a single option for NF-4 Mission
      - “Coupons” to “integrated system” (IRL)
      - Manufacturing (MRL)
      - Robustness, efficiency and tailorability

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FY’13 ACCOMPLISHMENTS
Dual layer architecture choices characterized

- System needs to be thermally efficient and yet be robust in a wide range of entry environment
  - (1 KW/cm² – 10 KW/cm²) (1 atm. – 10 atm)

A single system down-selected:

- Tailorable, robust and mass efficient for NF-4 missions
- Top layer is designed to be recession resistant (heat-flux, pressure)
- Insulating layer is designed to handle large heat-load

Data obtained to-date shows better mass efficiency and robustness compared to heritage Carbon Phenolic

- No failure of any kind observed from the arc jet testing

Project Plan:

- Defining capability requirements, developing verification approaches, ensuring timely deliverables to meet proposal development for mission all this with community input via
  - Derived community input and consensus via HEEET workshop

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5 TPS Level I requirements identified:

- **The TPS System shall function throughout all mission phases**
  - Ground, launch, transit and entry
- **The TPS System shall be operable.**
  - Dust generation, outgassing, shelf life, etc...
- **The TPS system shall be manufacturable.**
  - Thickness, conform to carrier structure, etc...
- **The TPS System shall interface with the entry vehicle.**
  - Backshell, penetrations, instrumentations, etc...
- **The TPS System shall be certifiable.**

31 TPS Level II requirements identified

- 17 of these are prioritized for focus within HEEET project
GAME CHANGING DEVELOPMENT PROGRAM

- Five Level 1 requirements and 31 level 2 requirements.
- In-scope Level 2 requirements analyzed from verification perspective
  - Led to details tasks, major milestones, deliverables, schedule and cost.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Level</th>
<th>Test Method</th>
<th>Goals</th>
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<tbody>
<tr>
<td>The TPS material shall have stable and predictable response at heat flux, pressure, shear and enthalpy combinations of the (mission specific) entry environment.</td>
<td>6</td>
<td>Arcjet Testing [IH 3-inch 2000-8000 W/cm², IHF 6-inch 250-1000 W/cm², LHMEL 1000-8000 W/cm², AEDC 4000Pa]</td>
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<td>The seams shall have stable and predictable response at heat flux, pressure, shear and enthalpy combinations of the (mission specific) entry environment.</td>
<td>6</td>
<td>Arcjet Testing [IH 3-inch 2000-8000 W/cm², IHF 6-inch 250-1000 W/cm², LHMEL 1000-8000 W/cm², AEDC 4000Pa]</td>
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<td>The Heat Shield system shall survive random/sinusoidal vibe at (Launch Vehicle (LV) specific) levels</td>
<td>5</td>
<td>Vibe Panel Test</td>
<td>Vibe Panel Test</td>
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<td>The Heat Shield system shall survive acoustic loads at (LV specific) levels</td>
<td>3</td>
<td>Acoustic Analysis</td>
<td>Acoustic Analysis</td>
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<td>The Heat Shield system shall maintain structural integrity after exposure to a (mission specific) dusty flow environment during entry</td>
<td>NO</td>
<td>Not an applicable requirement for anticipated missions utilizing HEEET.</td>
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Stagnation point analysis

Trajectories are terminated $M = 0.8$ (+10 seconds after typical Mach termination)

Max Heat Flux
- $(V=11.6 \text{ km/s}, H=22^\circ)$: 5 kW/cm²

Max Heat Load
- $(V=11.6 \text{ km/s}, H=8.5^\circ)$: 34 kJ/cm²

Entry Trajectory and Env provided by: D. Prabhu
A new 3” nozzle at Ames IHF Facility, designed, installed and became operational in Aug-Sep, 2013 (thanks to SMD-PSD support) provided Venus relevant test conditions for verifying the robustness of HEEET.
New IHF 3” Nozzle Testing

- ~4000 +/- 500 W/cm², 5.5 atm, 1” dia models
- All materials performed well (5 samples and a sample with seam)
- 3” nozzle is a new capability at NASA ARC

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**HEEET Dual Layer Materials**

- 10 different HEEET dual layer materials were tested

- Tested at DoD standard conditions used to evaluate traditional 2D CP materials at AEDC (turbulent with high shear)

- All of the coupons tested performed very well

- No material failure was observed

- Comparison of recession and bond-line temperature used in architecture down-select

**Preliminary Seam**

Very good performance for initial seam concept
A heat shield manufactured from HEEET will require seams.

In FY13 preliminary arcjet testing was conducted to evaluate seams concepts, adhesive, stitched, etc...

Test results are extremely promising and are providing guidance into the seam requirements.

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Venus (10.8 km/s) Areal Mass Comparison

- Areal mass of the 2-layer system is ~50% of the Carbon Phenolic for a broad range of entry trajectories
  - The two layer system studies showed the choice of architecture (weave and resin parameters) is not driven by mass efficiency.

- Performance combined with robustness makes HEEET an exceptional TPS
➢ System
  ➢ Molding flat panels
  ➢ Seams
  ➢ Resin Infusion at scale

➢ Integration
  ▪ aeroshell sub-structure and with close-out accommodations for backshell

➢ Flight System design tools development and verification
  ▪ Engineering Test Unit
    – ~1.5m Base Diameter, 45° Sphere Cone with characteristics applicable for larger size
      • Smaller than Venus lander missions such as VITaL
      • Design will be proven at a smaller scale that is applicable for larger scale
    – Integrated “tiled” design as would be required for Venus lander mission

Successful ETU design, build and testing = TRL 5/6 (for full scale Venus, Saturn and higher speed sample return missions)
## Baseline Project Plan: Schedule-Milestones

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<th>FY14</th>
<th>FY15</th>
<th>FY16</th>
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<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
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<td><strong>Go, No-Go Reviews</strong></td>
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<td>Mission Infusion</td>
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<td><strong>Heatshield Design</strong></td>
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<td><strong>Acerage WTPS</strong></td>
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<td><strong>WTPS Seam</strong></td>
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<td><strong>Engineering Test Unit (ETU)</strong></td>
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- **FY14**
  - Q1: Go/No-Go (KDP)
  - Q2: Mission Infusion Workshop
- **FY15**
  - Q1: Go/No-Go (KDP)
  - Q2: Mission Infusion Workshop
  - Q3: NF AO Infusion Workshop
- **FY16**
  - Q1: DAC-1 Design Review
  - Q2: DAC-2 Design Review
  - Q3: DAC-3 Design Review
  - Q4: Updated Thermal Response & Material Prop. Response Model Validation Testing

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FY’13 has been a great year
- Successful testing, analysis and planning along with community advocacy resulted in HEEET project becoming a funded, 3-year tech. mat. effort

HEEET is a game changer with applicability for a wide range of missions that SMD-PSD is interested in
- Critical for Venus near, mid and longer term exploration
- Mission enabler once successfully developed and demonstrated with a broader applicability (technology push !)

Current project plan is aggressive
- Numerous challenges

Continued community engagement is necessary for mission infusion:
- Dialogue between HEEET project and proposing organizations/proposal teams
- Dialogue between STMD and SMD-PSD
- NASA (STMD) developed technology infusion in a SMD competed mission.
We are grateful VEXAG and look forward to continued advocacy for HEEET.

Support and commitment of STMD, SMD-PSD and Game Changing Development Program Leadership, in FY’13, allowed us to mature our plans.

Bally Ribbon Mills, our partner in this effort, has shown extraordinary commitment and willingness to explore the myriad of possibilities and met our requirements in a timely and cost effective manner. We thank them for their commitment to be a great partner in our effort to enable future planetary exploration.