Heatshield for Extreme Entry Environment Technology (HEEET)

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Technology Forum, VEXAG-11

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VEXAG

Venus Exploration Analysis Group

Scientific Focus, Missions Modes and Technologies

Critical/Enabling	X
Optional / Enhancing	+

Scientific Domain	Mission Mode	Aerobrake	Aerocapture	Entry	Descent/ Deployment	Descent & Landing
Atmospheric Composition	Probe/lander with height profiles down to the surface			X		X
	Sustained aerial platform (e.g. balloon)			X	X	
	Orbiter or multiple flybys with atmospheric remote sensing	+	+			
Surface Composition and Processes	Orbiter with active/passive remote sensing	+	+			
	Short-duration lander to an accessible location			X		X
	Short-duration lander to a more challenging location			X		X
	Mobile platform on the surface or in the lower atmosphere			X	X	X
Atmospheric Structure and Circulation	Sustained (floating/flying) platform(s)			X	X	
	Entry/descent probes and/or dropsondes			X		X
	Multiple landers or probes that survive to the surface			X		X
	Orbiter with passive and/or active remote sensing	+	+			
Interior Structure and Dynamics	Orbiter with active/passive remote sensing; minimize s/c disturbances and include USO for gravity experiment	+	+			
	Geophysical lander with a life time of ~1 Venusian year			X		X
	Lander network with a lifetime > 1 Venusian year			X		X

- **Ablative TPS is critical to Entry and Aerocapture Mission Modes**
    - **Enabling for most and enhancing for the rest**

Enabling Venus Exploration in the Coming Decades

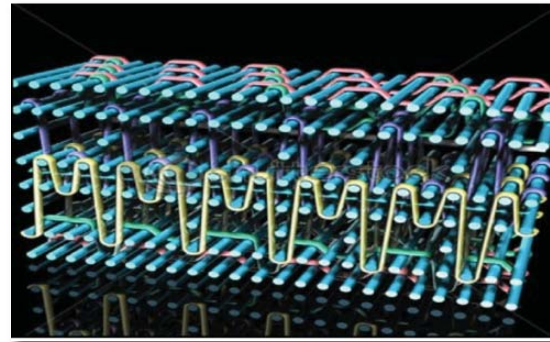
- Venus Exploration and Venus Technology Roadmaps
  - VEXAG (2012) Finding: " Continued development of entry technologies is critical to ensuring availability for New Frontiers-4 and Discovery 13 Venus mission proposals."
    - Recommendations (to SMD-PSD and STMD) were to ensure
- Missions and enabling entry technologies[1,2,3,4]
  - Deployable (Low-ballistic coefficient entry system - ADEPT)
  - Ablative TPS for Rigid aeroshell(high-ballistic coefficient entry 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 vs developing advanced TPS
- Advanced ablative TPS: HEEET project currently funded by STMD
  - Based on 3-D Woven TPS (presented at the VEXAG 2012)

1. **Decadal survey (*Visions and Voyages for Planetary Science in the Decade*** *2013-2022*, National Research Council, National Academies Press, Washington, DC, 2011)
2. **Venus Exploration Goals and Objectives** by VEXAG (2011)
3. "**Venus Technology Roadmap,**" **Report of the VEXAG Focus Group on Technology and Laboratory Instrumentation** (2013) (Draft)
4. **"Roadmap for Venus Exploration (Draft)"** by VEXAG

HEEEET: Outline and Background

Outline:

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



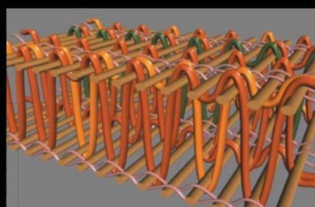
Background:

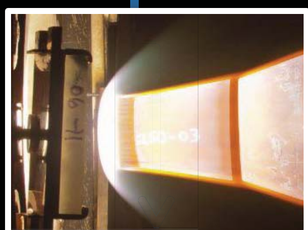
- HEEET - 3-D Woven TPS Family
  - *Woven TPS: An approach to the design and manufacturing of ablative TPS by the combination of weaving precise placement of fibers in an optimized 3D woven manner and then resin transfer molding when needed*
- In FY'12, established the viability of the 3-D Woven TPS.
  - 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





Woven TPS GCT BAA

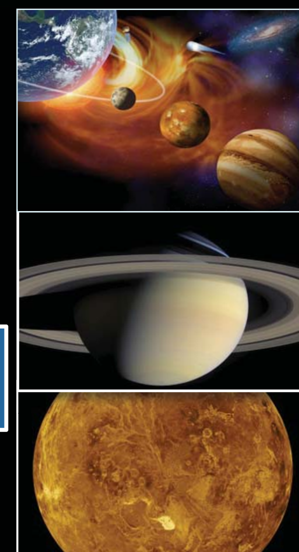
3-D Woven Multifunctional Ablative TPS (3D-MAT)

Enabling Orion with Lunar Capable Compression Pad

2017

Heatshield for Extreme Entry Environment Technology (HEEET)

Tech. Maturation to enable Venus, Saturn and outer planets missions



2020 - 2022

Robust Heat-shield for Human Missions (Future Potential)

April 2011

Jan. 2012

June, 2012

Oct, 2013

TBD

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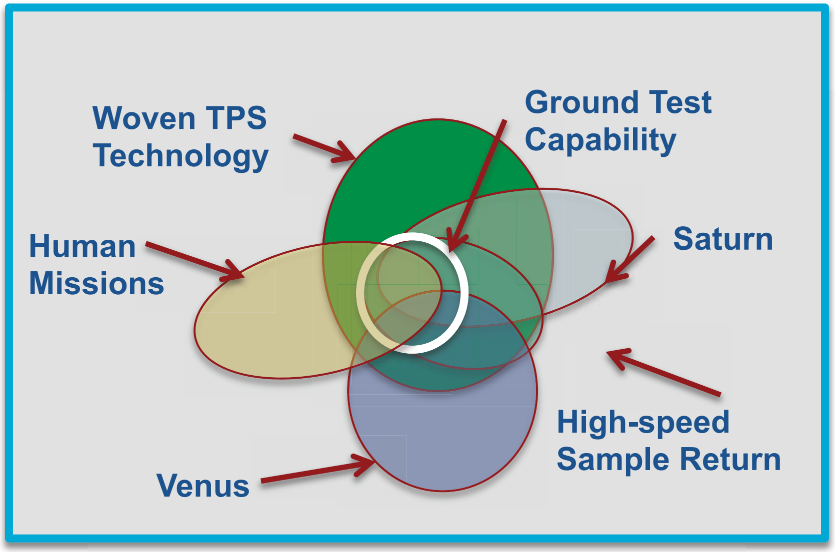
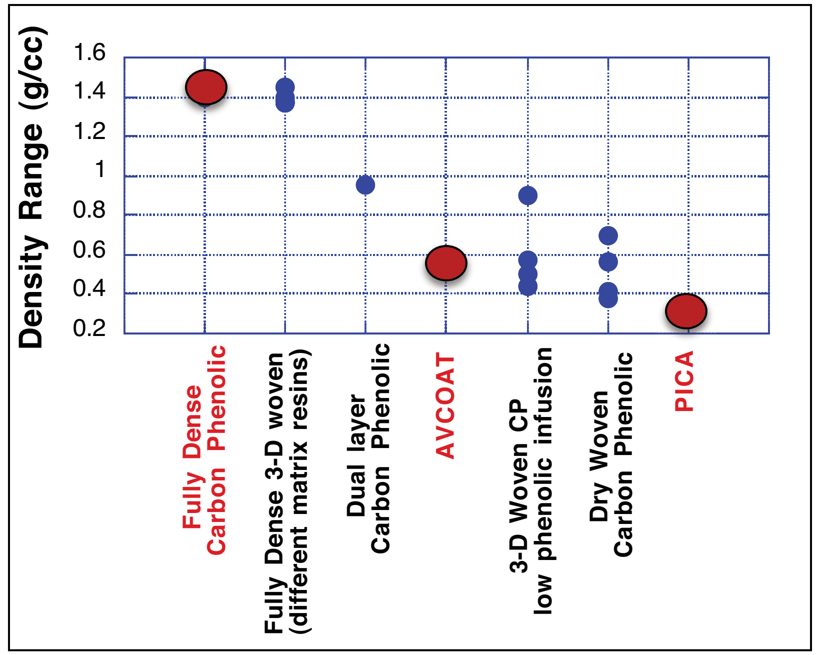
HEEET Challenges: From Formulation to Tech Maturation

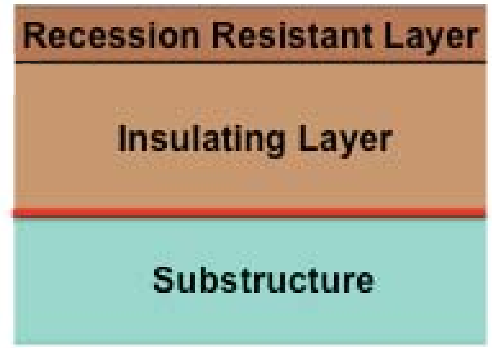
- HEEET is a a core-technology with broad applicability - a game-changer
- Defining Capability Requirements:
  - Near-term technology maturation success with budget and schedule constraints
  - Mission insertion focus
  - Longer term sustainability
- Engaging the community from the get-go
  - What does 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



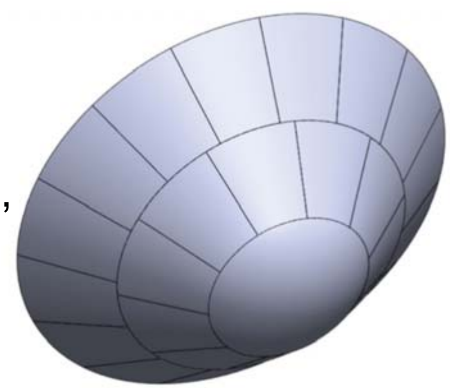


FY'13 ACCOMPLISHMENTS

FY'13 Accomplishments - Highlight



- Dual layer architecture choices characterized
  - System needs to be thermally efficient and yet be robust in a wi 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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Requirements

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

Technology Maturation Capability Requirements

- 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.

The TPS System shall function throughout all mission phases.	1	The TPS material shall have stable and predictable response at heat flux, pressure, shear and enthalpy combinations of the (mission specific) entry environment.	The TPS needs to survive entry with no degradation in performance due to unexpected catastropic failure modes.	Material response model correlation with data from family of arc-jet tests	YES	6		Arcjet Testing [IHF 3-inch 2000-8000 W/cm2, IHF 6-inch 250-1000 W/cm2, LHMEL 1000-8000 W/cm2, AEDC 4000Pa Shear] Material Property Testing
	2	The seams shall have stable and predictable response at heat flux, pressure, shear and enthalpy combinations of the (mission specific) entry environment.	The TPS needs to survive entry with no degradation in performance due to unexpected catastropic failure modes.	Material response model correlation with data from family of arc-jet tests	YES	6		Arcjet Testing [IHF 3-inch 2000-8000 W/cm2, IHF 6-inch 250-1000 W/cm2, LHMEL 1000-8000 W/cm2, AEDC 4000Pa Shear] Material Property Testing
	3	The Heat Shield system shall survive random/sinusoidal vibe at (Launch Vehicle (LV) specific) levels	The TPS needs to survive all load events with no degradation in performance throughout all mission phases	Modal survey test of the ETU for model verification. Coupon level testing to support strength/strain requirements	YES	5		Vibe Panel Test
	4	The Heat Shield system shall survive acoustic loads at (LV specific) levels	The TPS needs to survive all load events with no degradation in performance throughout all mission phases	Modal survey test of the ETU for model verification. Coupon level testing to support strength/strain requirements	YES	3		Acoustic Analysis
	5	The Heat Shield system shall survive cold soak to (mission specific) deg C	The TPS needs to survive all load events with no degradation in performance throughout all mission phases	Panel thermal cycle, thermal vac, specific to the tested sub-structure and tested attachment scheme and correlate to FEM. Coupon level testing to support strength/strain requirements at temperature.	YES	6		ETU Thermal Cycle, 4 point bend specimens, CTE Panel
	6	The Heat Shield system shall survive hot soak to (mission	The TPS needs to survive all load events with no degradation in	Panel thermal cycle, thermal vac, specific to the tested sub-structure and tested attachment scheme and correlate to FEM. Coupon level testing to	YES	6		ETU Thermal Cycle, 4 point bend specimens, CTE Panel

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

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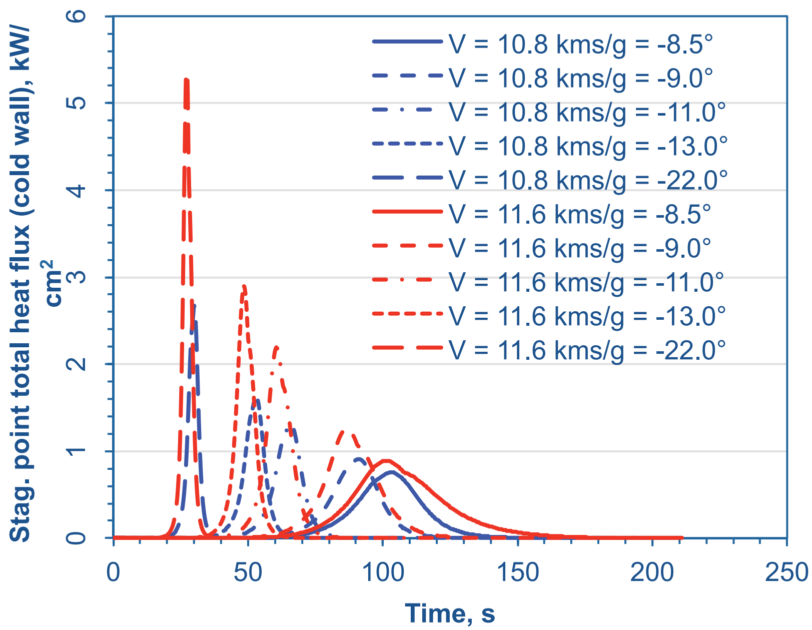
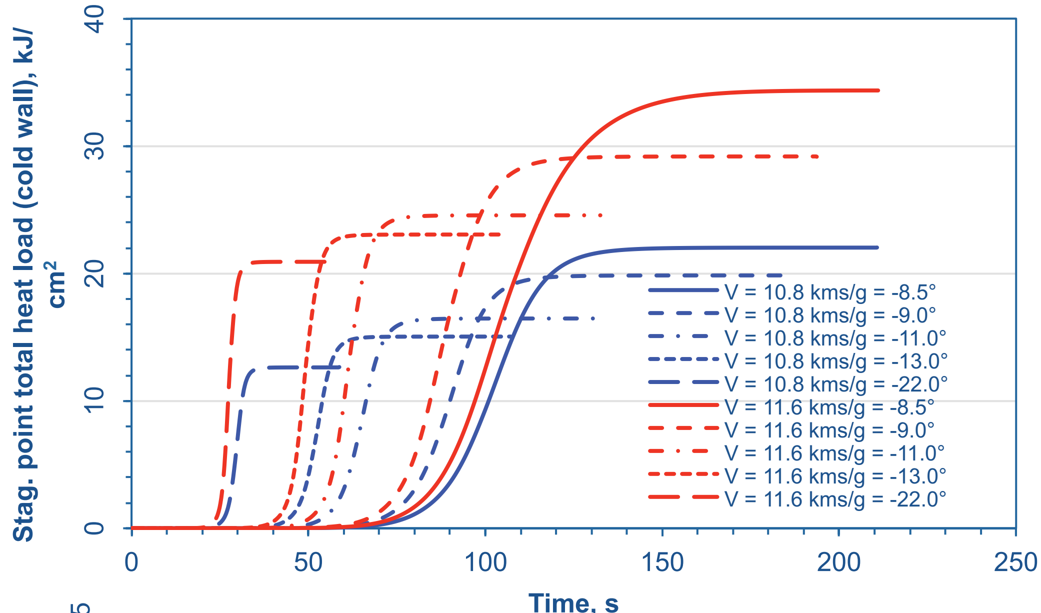
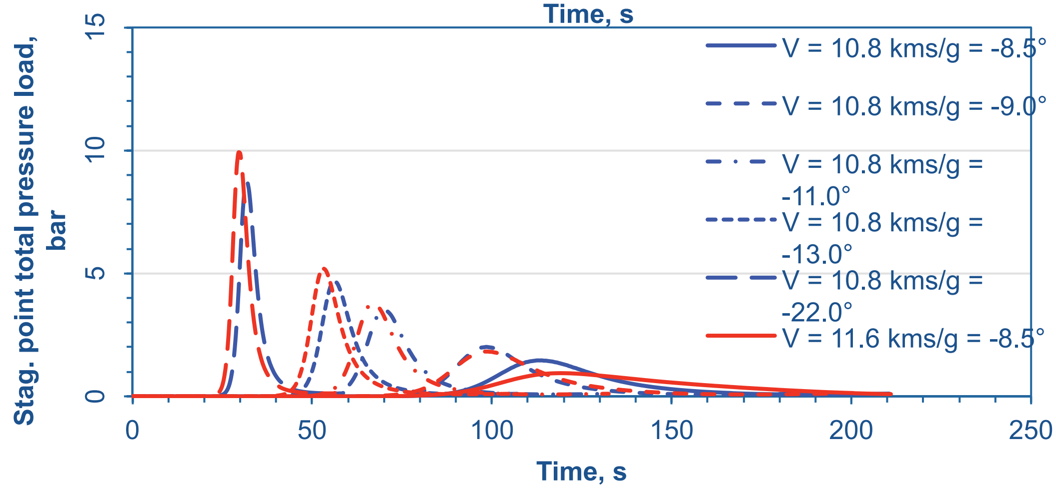
Venus Trajectories (provided by EVT)





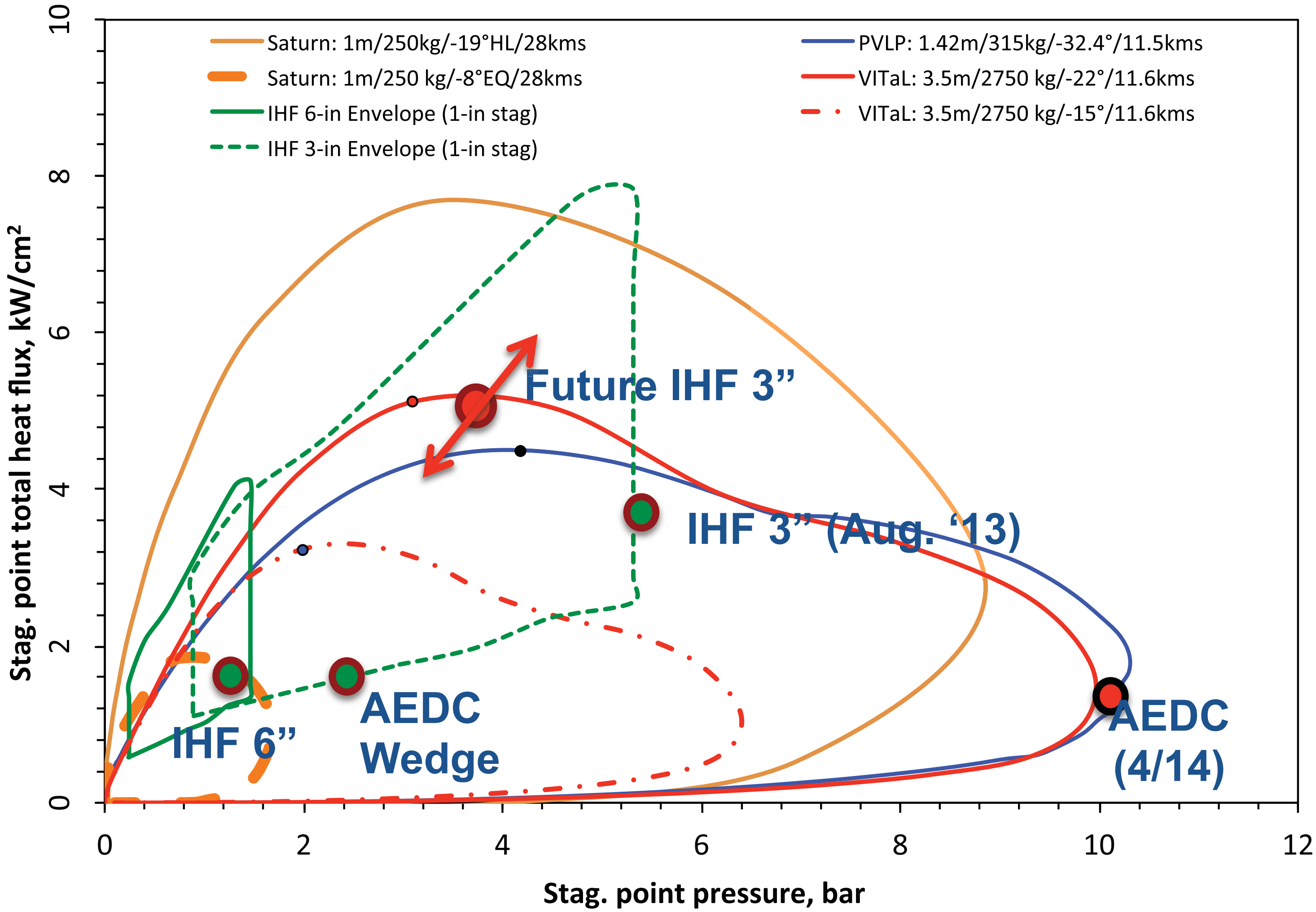
- Stagnation point analysis
- Trajectories are terminated M = 0.8 (+10 seconds after typical Mach termination)
- Max Heat Flux
  - (V=11.6 km/s, H=22°): 5 kW/cm²
- Max Heat Load
  - (V=11.6 km/s, H=8.5°): 34 kJ/cm²



Entry Trajectory and Env provided by.: D. Prabhu

Testing Envelopes vs. Mission Trade Space

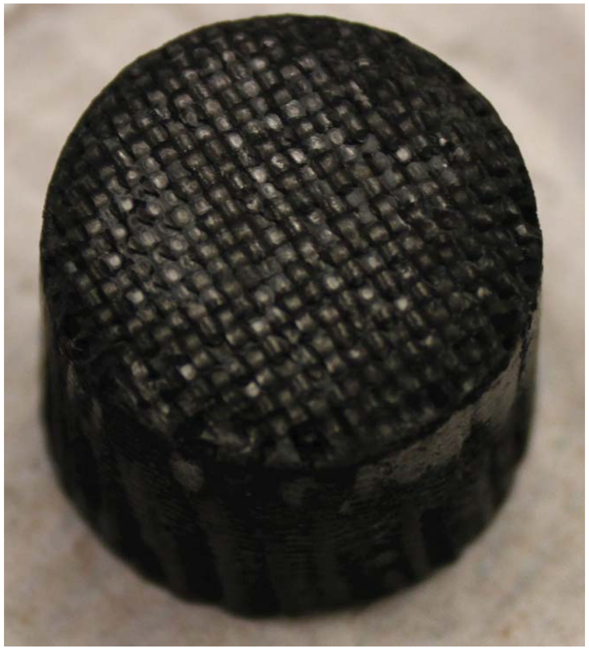
GAME CHANGING DEVELOPMENT PROGRAM



- 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

Pre-Test



Post Test

- ~4000 +/-500 W/cm^2, 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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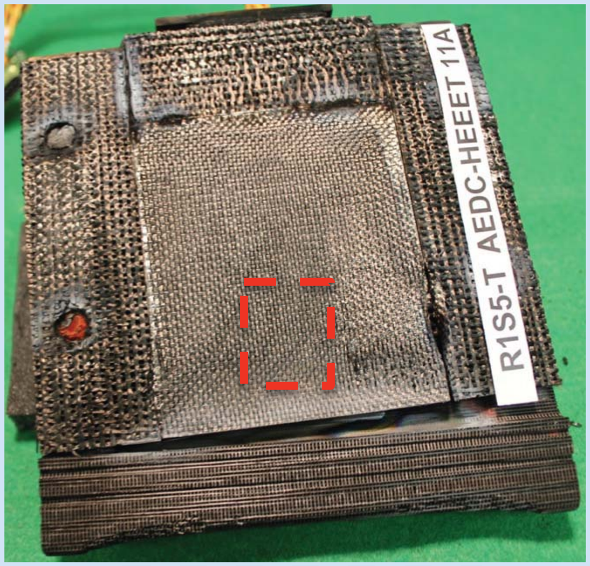
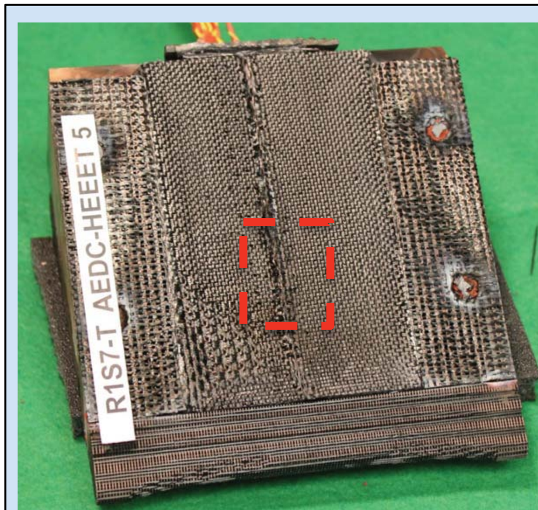
AEDC Arc Jet Testing

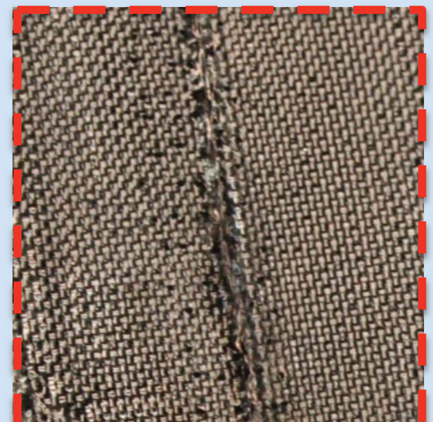
HEEET Dual Layer Materials



- 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

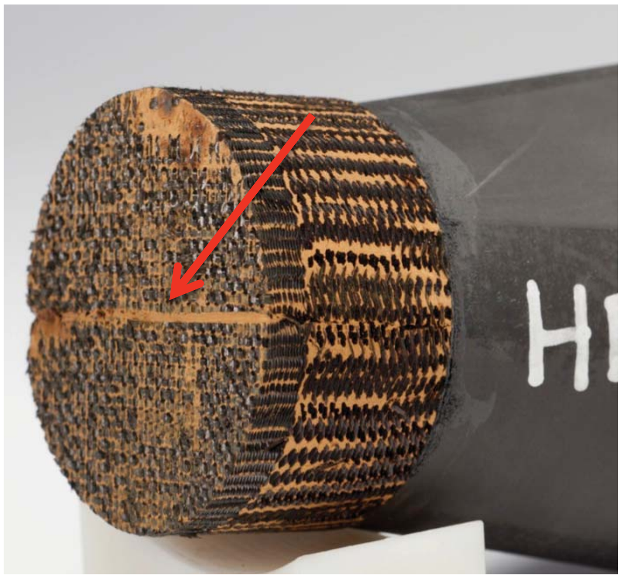
Preliminary Seam



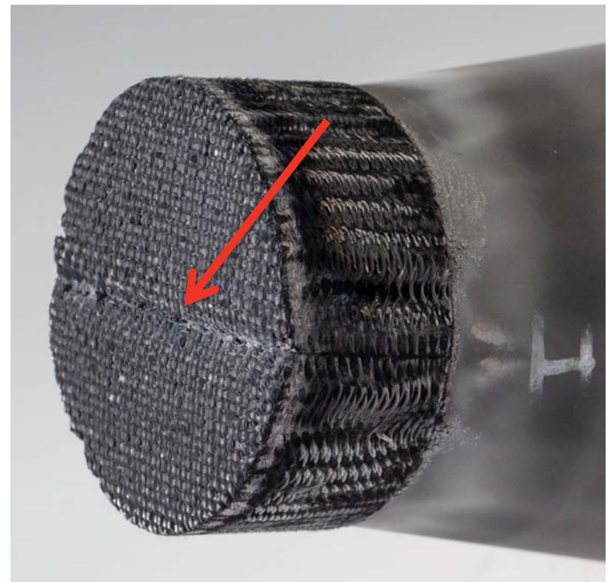


Very good performance for initial seam concept

HEEET Seam Arc Jet Testing (1600 W/cm^2, 1.3 atm, 2” Flat Face)



Pre-Test



Post-Test

- 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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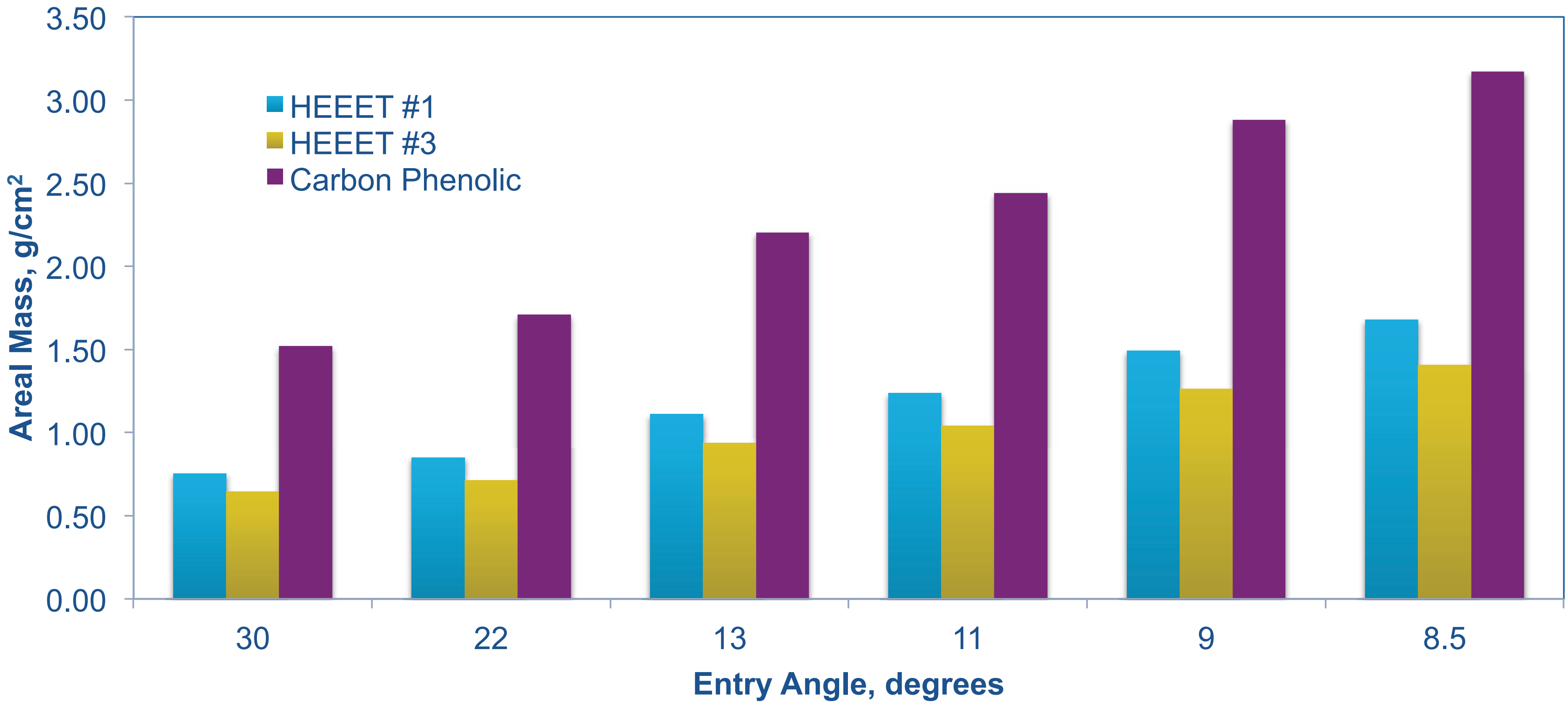
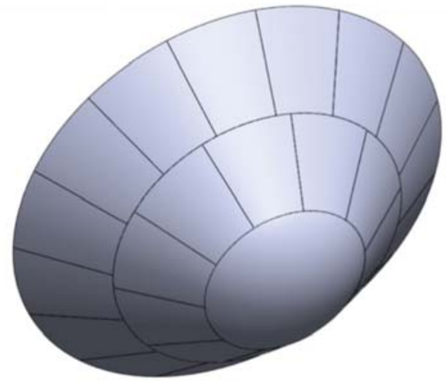
Venus (10.8 km/s) Areal Mass Comparison



- 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**

Tech. Maturation: From Coupons to Engineering Test Unit (ETU)



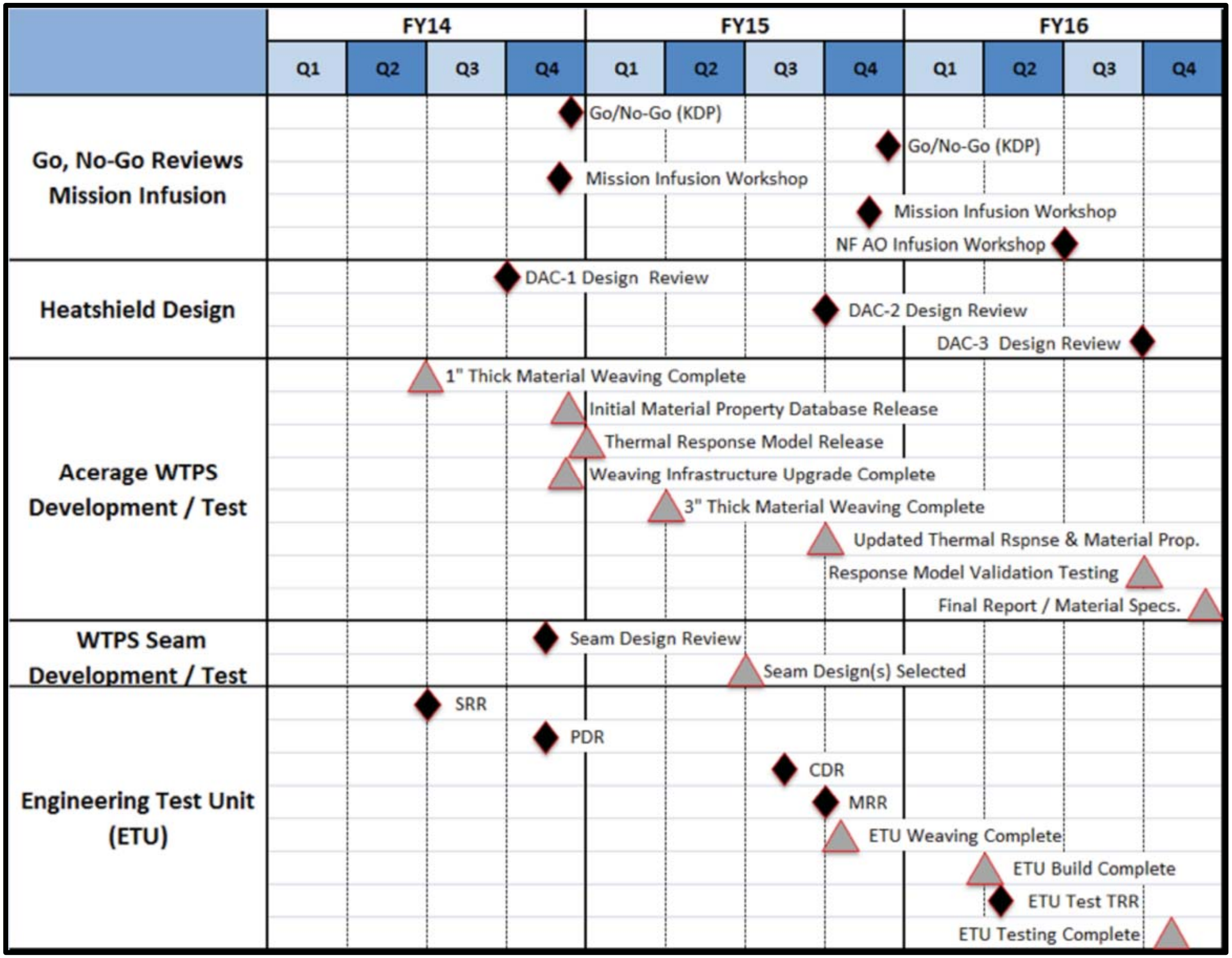
- System
  - Seams
  - Molding
  - Resin Infusion at scale
- Integration
  - aeroshell sub-structure and with close-out accommodations for backshell
- Flight System design tools development and verification
  - Engineering Test Unit

Size:

- ~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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Concluding Remarks

- 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 .

Acknowledgement

- We are grateful to the recommendations by VEXAG and look forward to continued advocacy for HEEET
- The support and commitment of STMD, SMD-PSD and Game Changing Development Program Leadership, in FY'13, allowed us to develop an approach to HEEET based on test data. We look to their continued support and commitment.
- Bally Ribbon Mills, our partner in this effort, has shown extraordinary commitment and willingness to explore the myriad of possibilities and meet our requirements in a timely and cost effective manner. We thank them for their commitment to be a part of exploration.