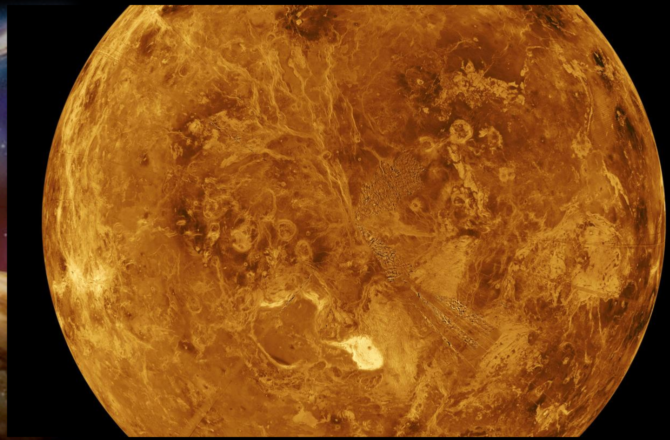
Woven TPS An Enabling Technology: An alternate to vanishing heritage TPS



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Introduction and Outline

Woven TPS :

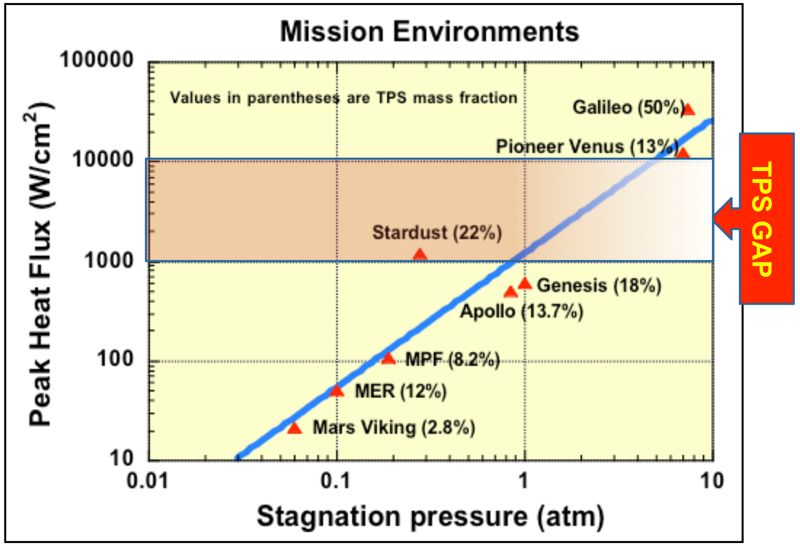
- Woven TPS is an emerging and exciting technology in development.
- Woven TPS is an enabler for Rigid Aero-shell, the workhorse Entry System.
- Woven TPS will result in a robust and certifiable TPS, leading to lower TPS risk, mission cost and higher payload mass fraction.
- Woven TPS technology maturation to TRL 6 target is 2016.

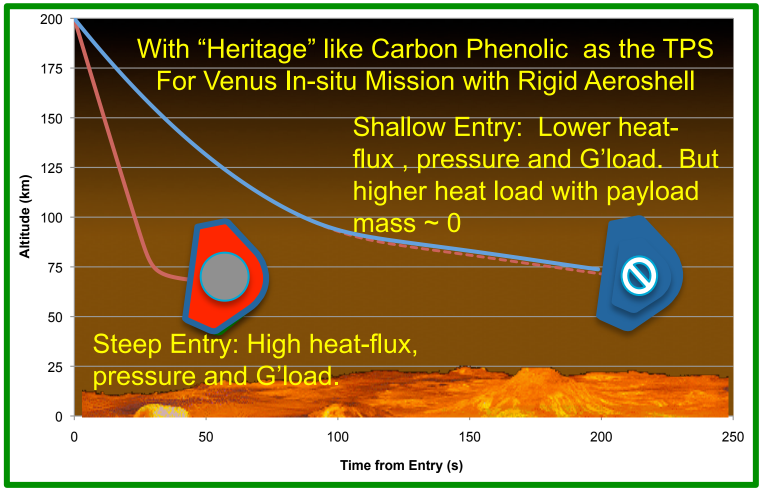
Outline of the talk:

- Ablative TPS past and present
- Venus: Extreme entry environment and ground test facility challenges for TPS development.
- Woven TPS project and progress to-date
- Concluding Remarks

SOA: Rigid Aeroshell with Carbon Phenolic Heatshield

- **Mission concepts have no other option but to baseline Carbon Phenolic (CP)**
  - CP is very capable and robust
  - CP enabled P-V & Galileo & is flight proven
- **Carbon Phenolic is mission constraining**
  - Mission design with CP and acceptable payload mass leads to:
    - Steeper trajectories result in,
    - Extreme heat-flux and pressure (Testing capability ?)
    - Extreme g'loads
- **Science and Mission Design seek to :**
  - Maximize science payload
  - Minimize mission risk
    - in certification of components and sub-system such as instruments or heat shield
  - Minimize development cost for the technology as well as missions cost that utilize the technology
- **Technology Sustainability:**
  - Alternate rayon based CP carries some technology development risk due to atrophy within the processing and manufacturing capabilities in the U.S.

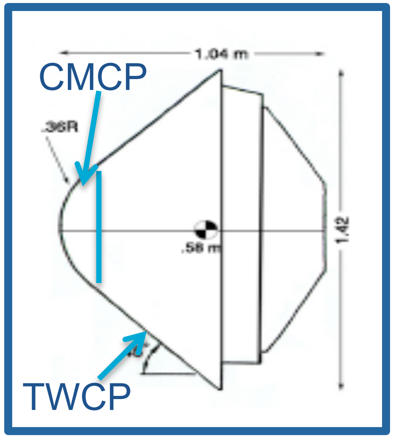




Quick Primer on Carbon Phenolic (CP)

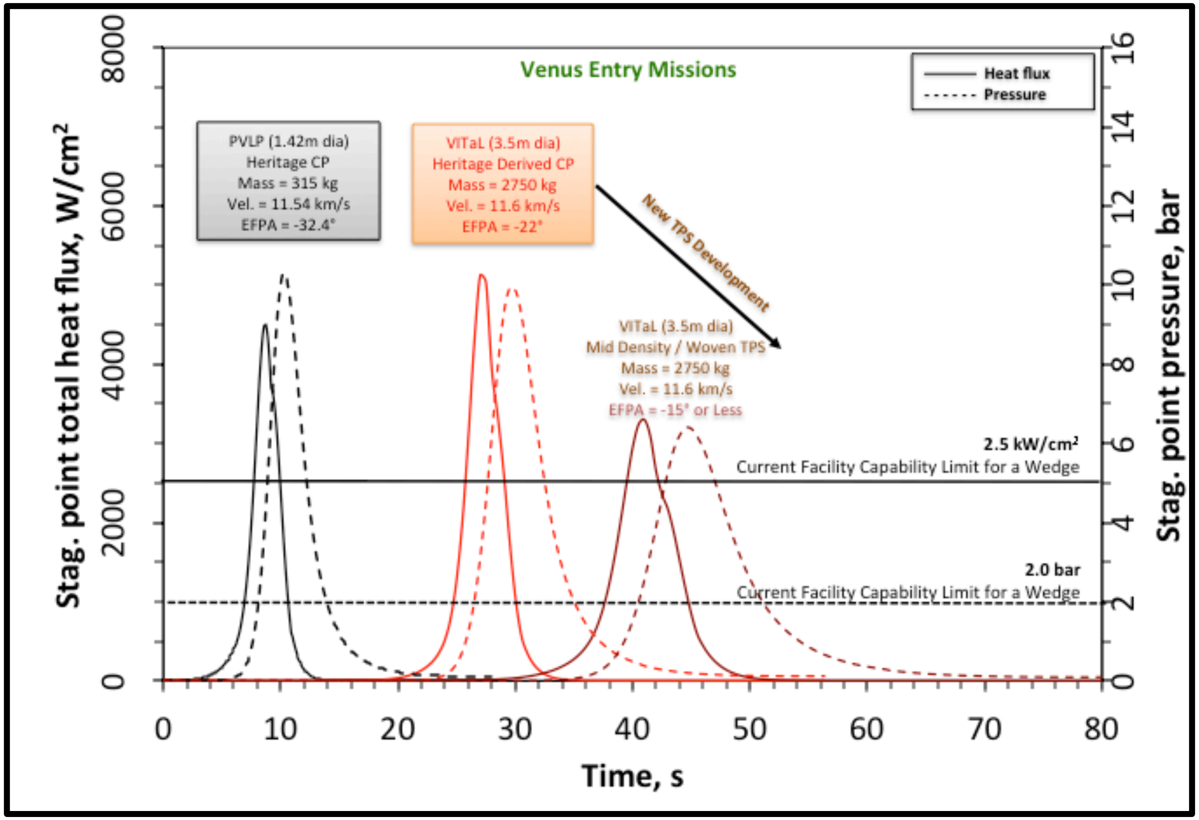
- **Carbon Phenolic (CP) heat-shield is made of two types**
  - Chop Molded and Tape Wrapped CP
  - CP comes in different grades such as reentry grade and nozzle grade and for brake pads, etc - not all of them will meet the extreme entry environments
- **Tape wrap technology is needed by application such as**
  - Rocket nozzles and DoD's slender entry body missiles
- **Chop Molded CP needed only for NASA entry missions**
  - Blunt nose region where tape wrap cannot be used
  - Not been manufactured for flight or used in over 4 decades
- **Both CMCP and TWCP use Rayon precursors**
- **NASA held two CP workshops (2010, 2012) to assess the SOA**
  - Heritage rayon based CP no longer viable for Venus (or Saturn)
  - Longer term sustainability of any CP is a ?
  - The industry is shrinking; especially for CMCP.

P-V Enabled by CP



NASA is addressing this challenge through Innovative TPS development Funded by Game Changing Development Program of STP and SMD

Entry Environment for Venus, Current Test Facility Capabilities (limitations) and TPS Development



CP is enabling for steeper entry flight path angle (EFPA) trajectories

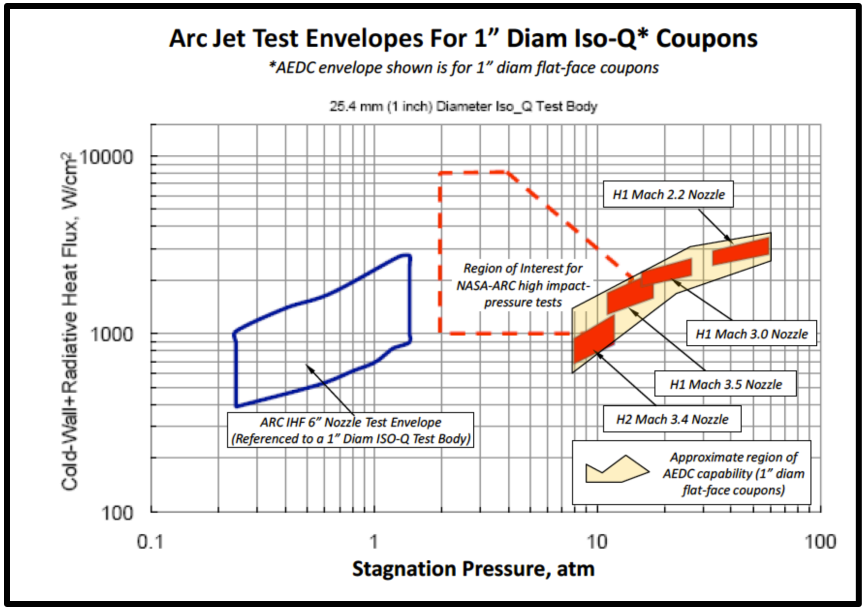
- **Vanishing Payload mass fraction for lower EFPA with CP**

Proposal/Mission risk as a result of facility limitation can be reduced or eliminated with efficient TPS that will

- **Lower the EFPA to fit within or close to ground testable entry conditions**

Material Development Challenges: Arc Jet Facilities Capability Limitations

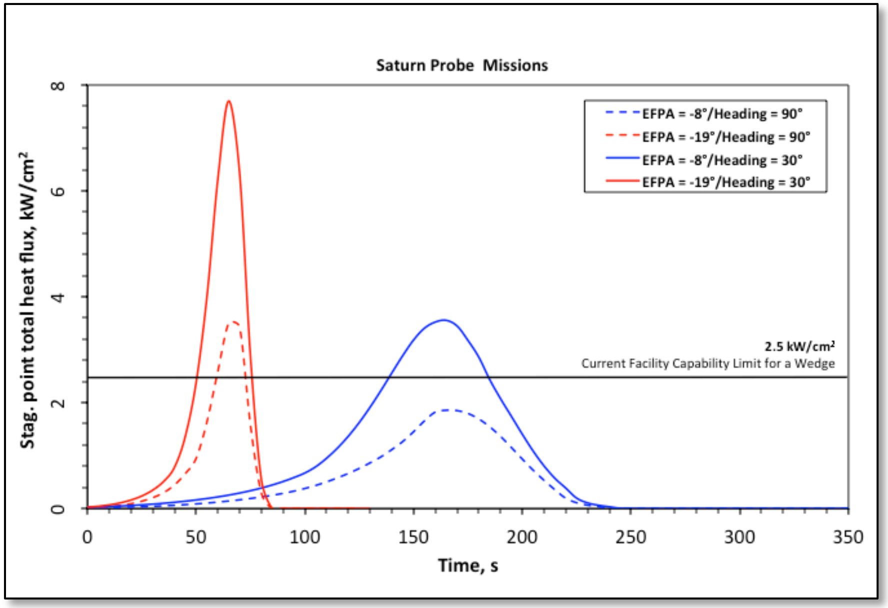
- Capabilities used during Galileo and P-V development no longer exist.
- Test conditions achievable in existing capabilities result in either under or over testing
- NASA ARC funded by SMD
  - 3" nozzle to somewhat mitigate this situation
- Model size dicated by facility nozzle size becomes too small relative to unit cell size, e.g. CMCP

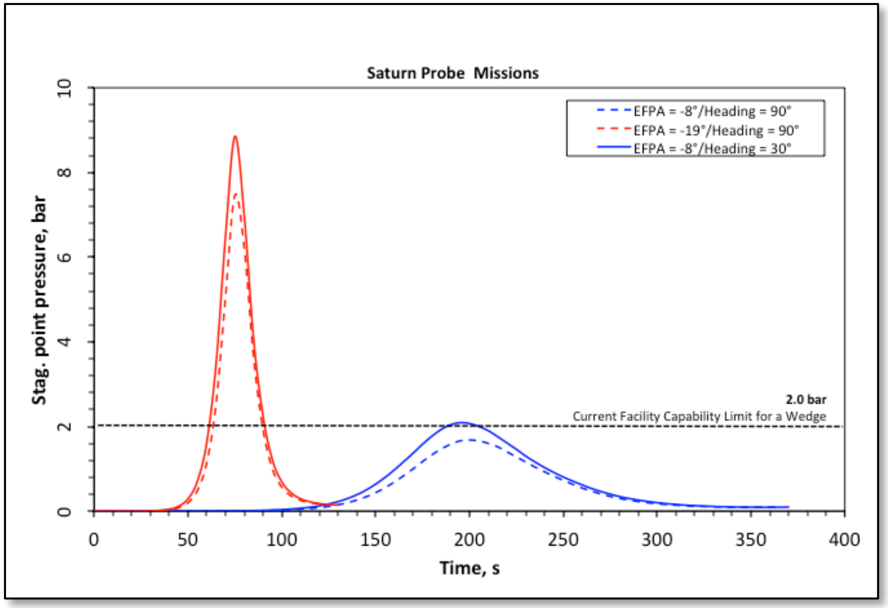


Acknowledgement: Mark Smith, AEDC

- Alternate CP or alternate TPS development testing and eventual certification Is not simple given the current ground test facility capabilities and entry mission conditions

Saturn Probe Missions



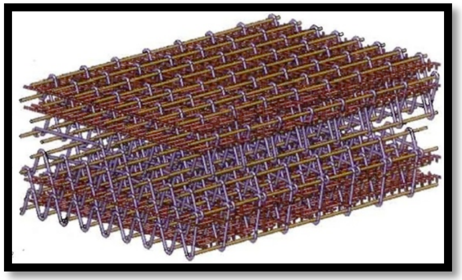


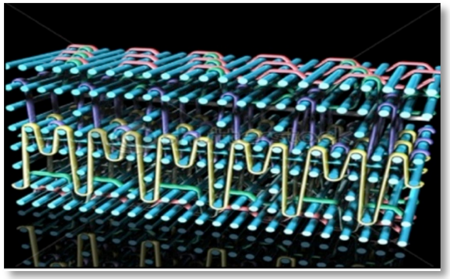
- **Saturn Probe missions entry environment is similar to Venus**
- **Saturn and Venus mission can be enabled by a near term, focused ablative TPS development**
- **Woven TPS is such as development**
  - **A single technology maturation effort to enable the PSDS recommended in-situ science missions with atmospheric entry**

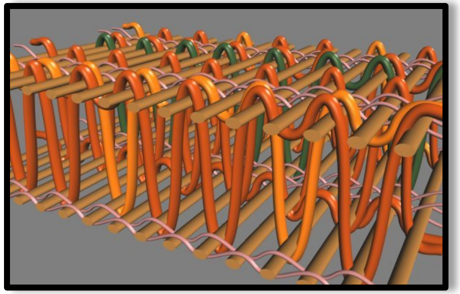
What is Woven TPS?

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

- Ability to design TPS for a specific mission
- Tailor material composition by weaving together different types of fibers and by exact placement using computer controlled, automated, 3-D weaving technology
- One-step process for making a mid density dry woven TPS
- Ability to infiltrate woven preforms with polymeric resins for highest density TPS to meet more demanding thermal requirements





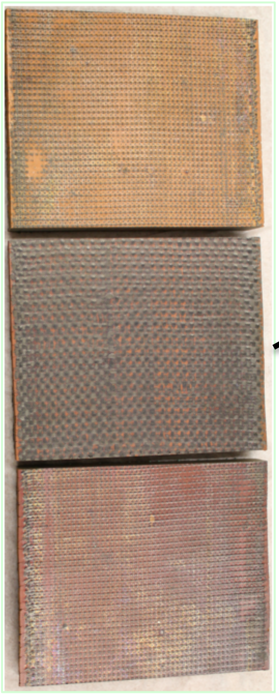


Woven TPS Project Goals:

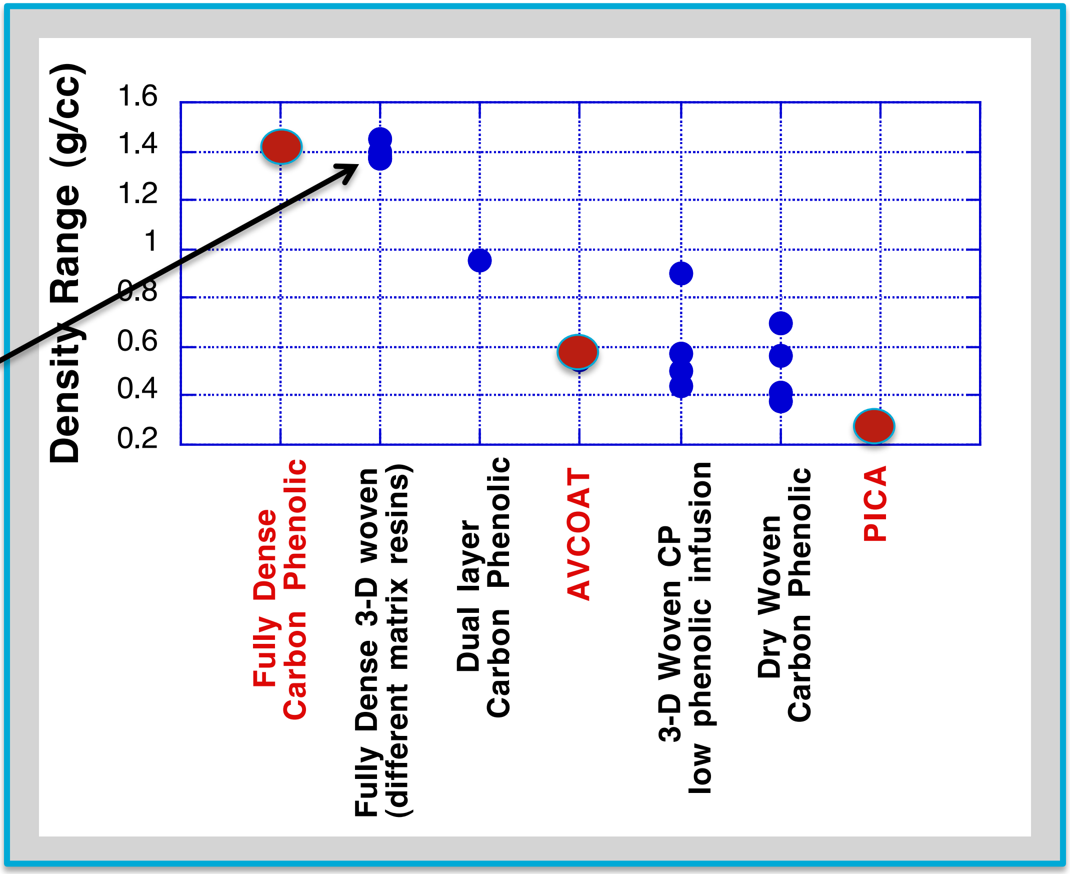
- Develop and prove feasibility of woven TPS manufacturing technique
- Demonstrate via testing low, mid and high-density WTPS in order to fill the mid-density gap as well as finding a superior replacement for the heritage carbon phenolic

WTPS Accomplishments

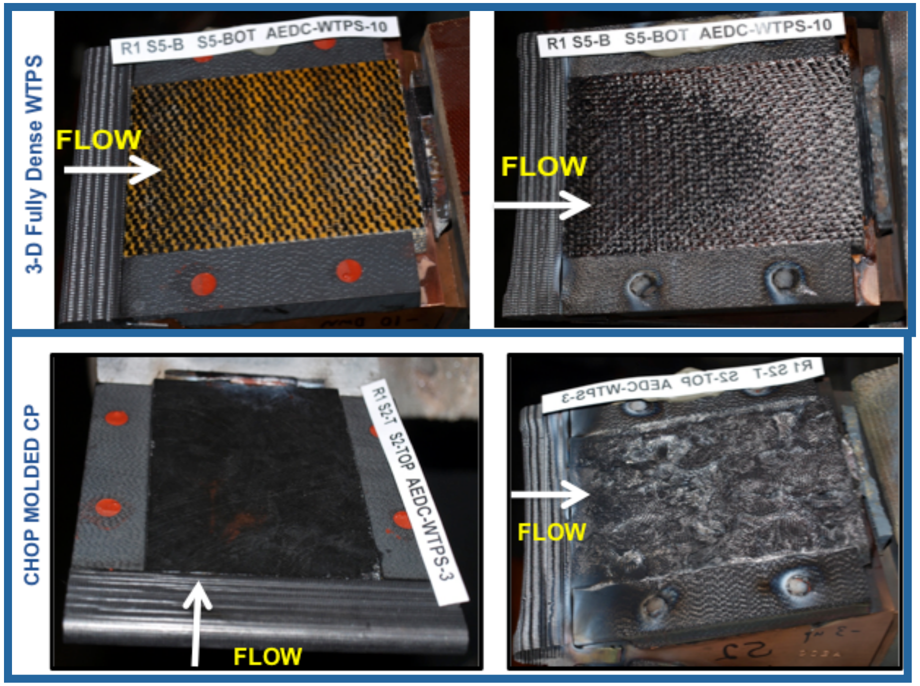
- **Demonstrated the feasibility of manufacturing low, mid and high-density WTPS in order to fill the mid-density gap as well as a potential replacement for the highest density carbon phenolic**



Fully Dense 3-D Woven (different resins)



Successfully Arc Jet Tested Woven TPS samples IHF and AEDC Arc Jet Facilities



17 different Woven TPS, low-to-High density variants, along with chop molded and tape wrapped carbon phenolic tested at the Ames IHF arc jet test facility.

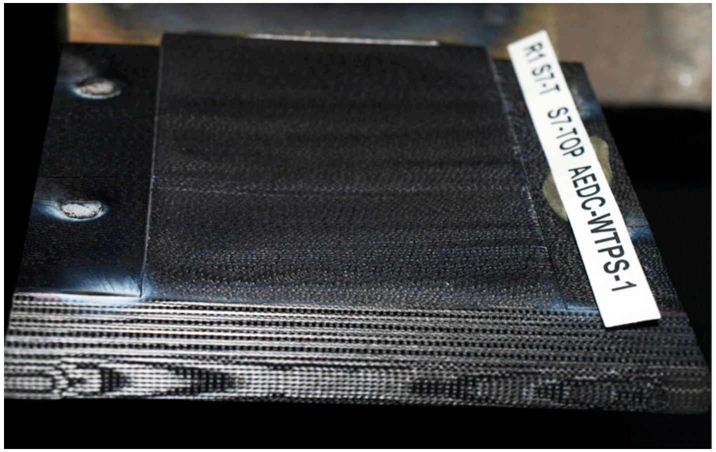
12 different Woven TPS, Mid-to-High density variants, along with chop molded and tape wrapped carbon phenolic tested at the AEDC arc jet test facility

3-D WTPS materials recess more uniformly and have better recession performance compared to traditional chop molded carbon phenolic

Highlights from AEDC testing: High heatflux, shear and pressure conditions

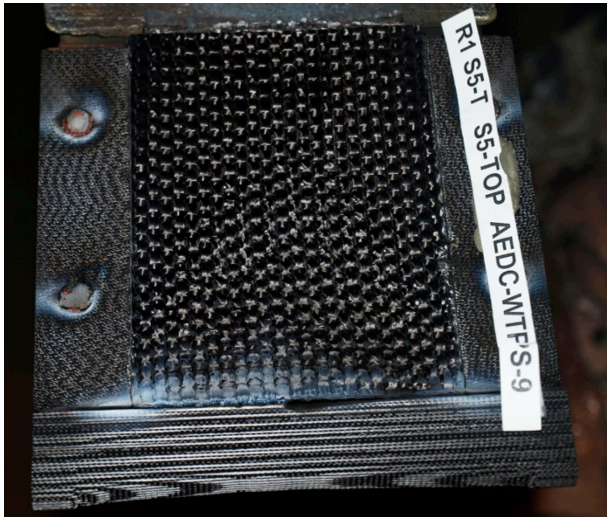
Traditional Carbon Phenolic

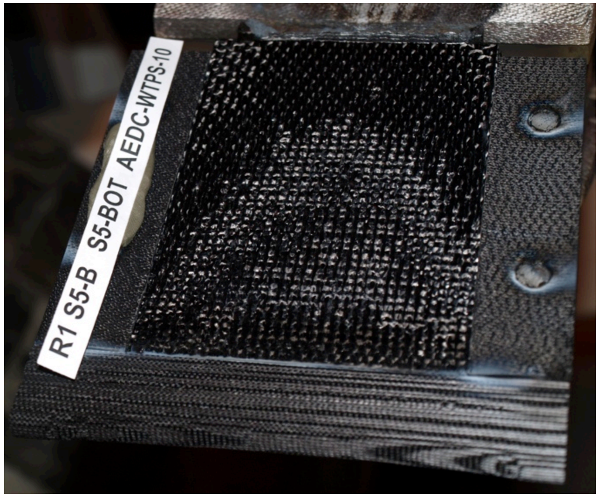
Shingled or (Tape Wrapped)

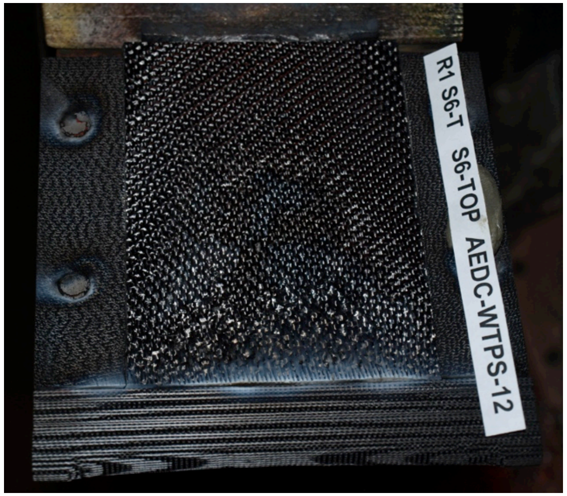


Chop Molded

3-D Woven TPS

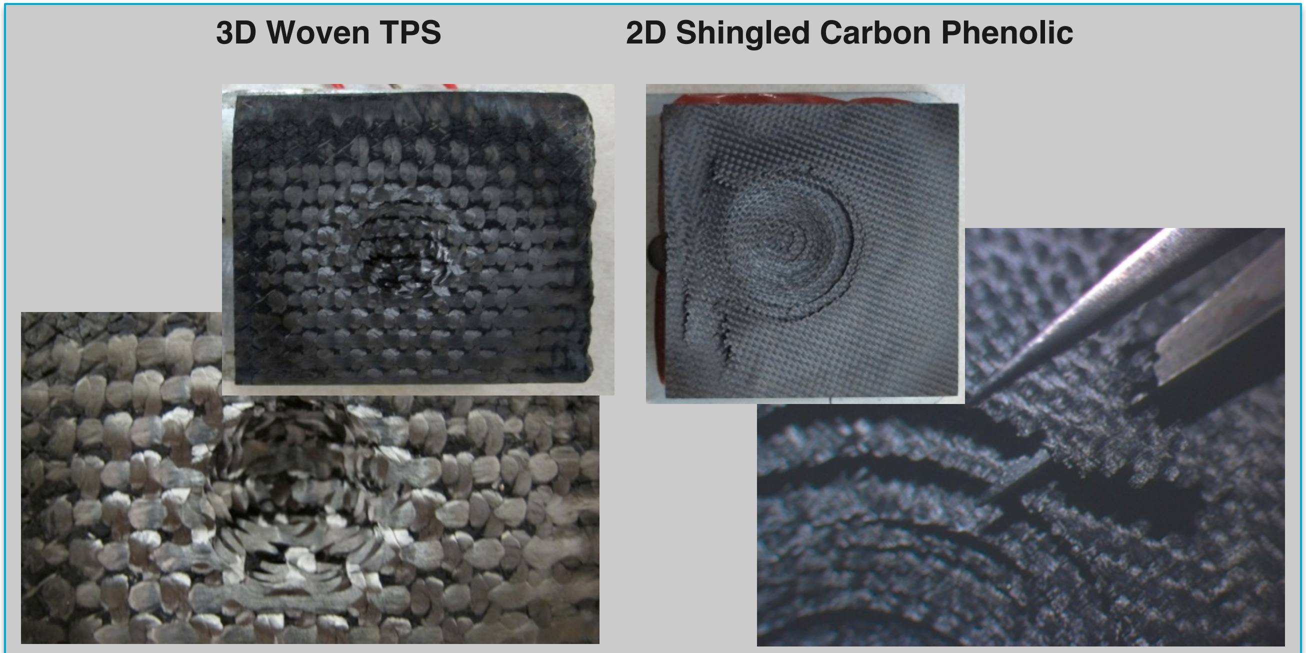




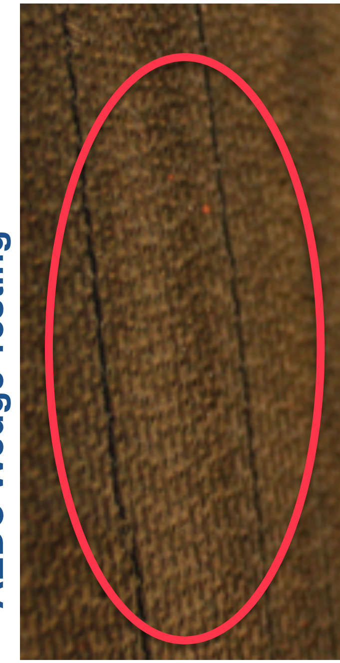


Explored Failure Modes: Woven TPS vs 2-D Carbon Phenolic

ARC Testing in mARC



AEDC Wedge Testing



- **2-D Shingled CP exhibits typical failure mode (ply separation) in a simple demonstration test performed at Ames. Similar behavior observed in the AEDC wedge testing - Woven TPS were well behaved**
- **The recession is larger in 2-D CP as compared to 3- Woven TPS**
- **Woven TPS, is not prone such failure mode, as it is robust by design due to 3-D nature of woven preforms.**

AEDC Testing: Recession Performance

Show the AEDC-MOVIE HERE

Summary: Progress to-date and Promise

- **Successfully met our goal of manufacturing and demonstrating Woven TPS for extreme entry environment missions in a very short period**
  - Able to manufacture low, mid and high density materials using weaving and resin infusion technology
- **Compared to the two types of CP (CMCP and TWCP), a single Woven TPS material/architecture is robust and can meet the mission needs of Venus, Saturn, etc.**
- **Woven TPS family of materials demonstrate**
  - Robustness
    - Mid-to-high density materials are very robust from the limited testing we did
  - Amenable to tailoring the properties to meet mission needs
  - A game-changer compared to all other ablative TPS and CP for NASA missions
  - Rapid development with a sustainable, US based industrial base achievable.
- **We can start to consider lower entry flight path angle Venus in-situ missions**
  - Lower risk, lower cost, lower mass mission design
  - If replacement for HCP is desired, Woven TPS can tailored to meet the need

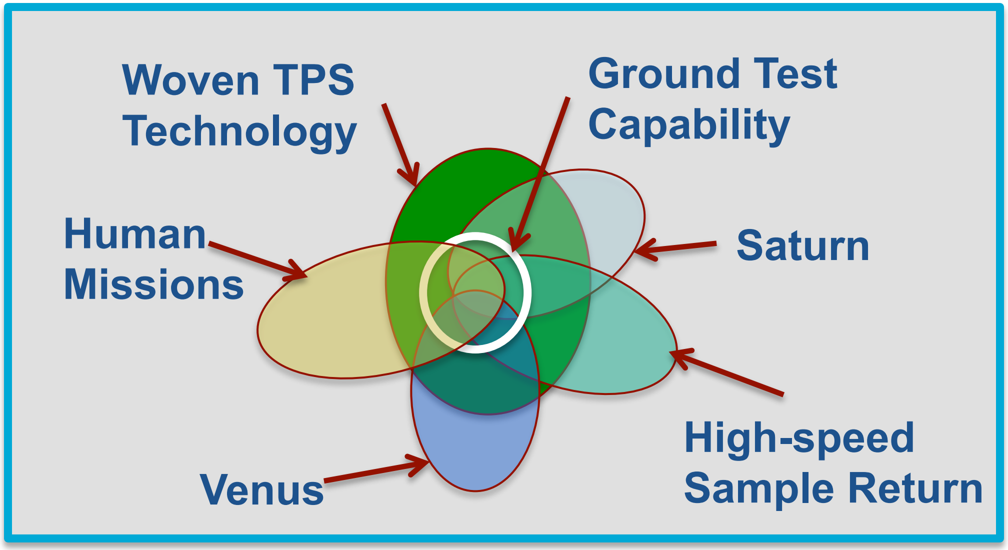
Our Challenge as Technology Developers this year

Determining the Capability Requirements for near term Technology Maturation:

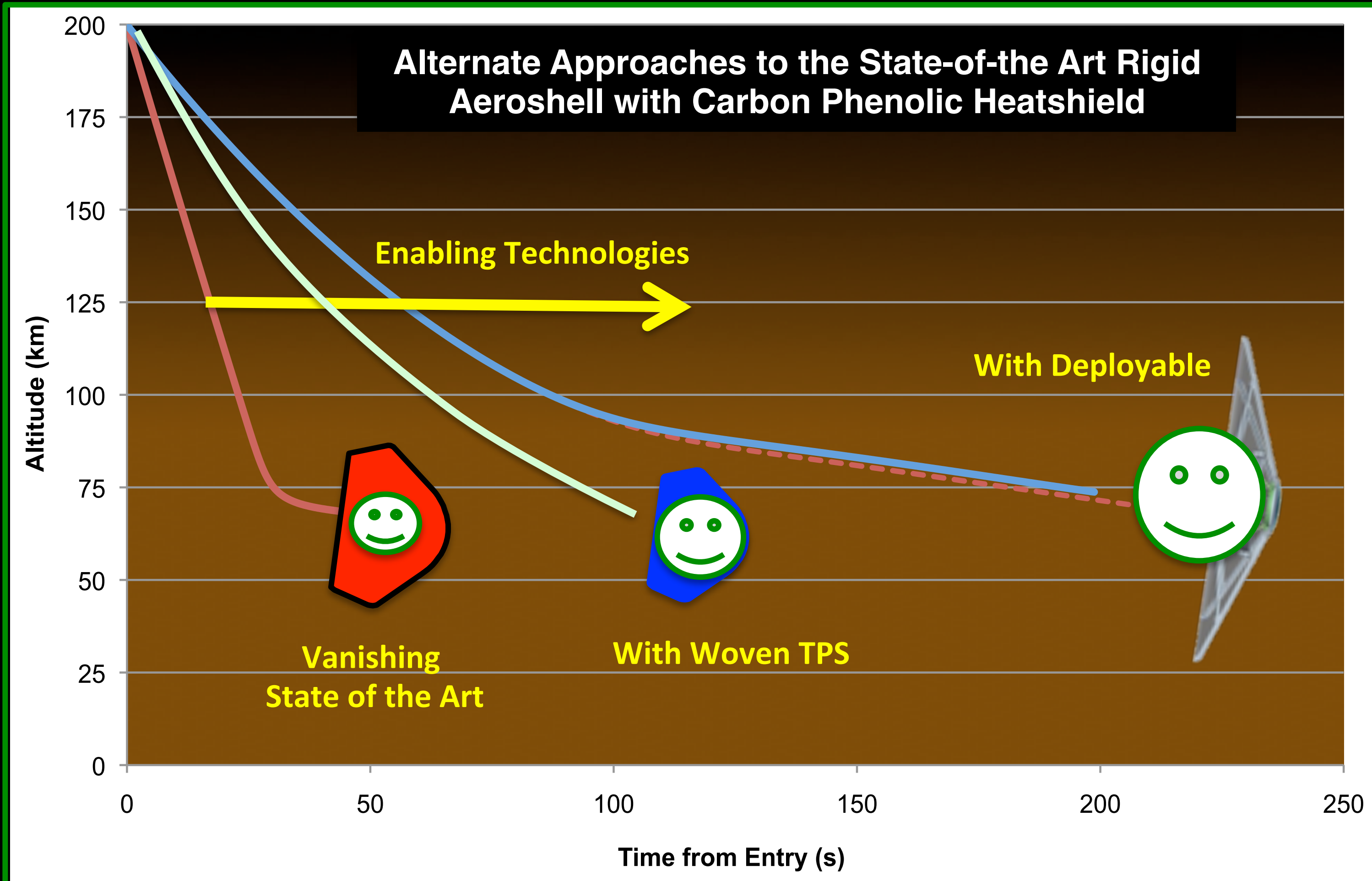
- **Common capability to focus on that will have the most benefit**
- **Cost-effective and timely project plan**
- **Near-term emphasis with a long term outlook**

We need stakeholder support and interaction

- Active interaction with mission designers to enable near term missions



Emerging Entry Technologies Enabling Exploration



Many ways to Enable Future Missions:

Deployable and Woven TPS are Recognized as Game-changing and Cross Cutting.

Summary and Concluding Remarks

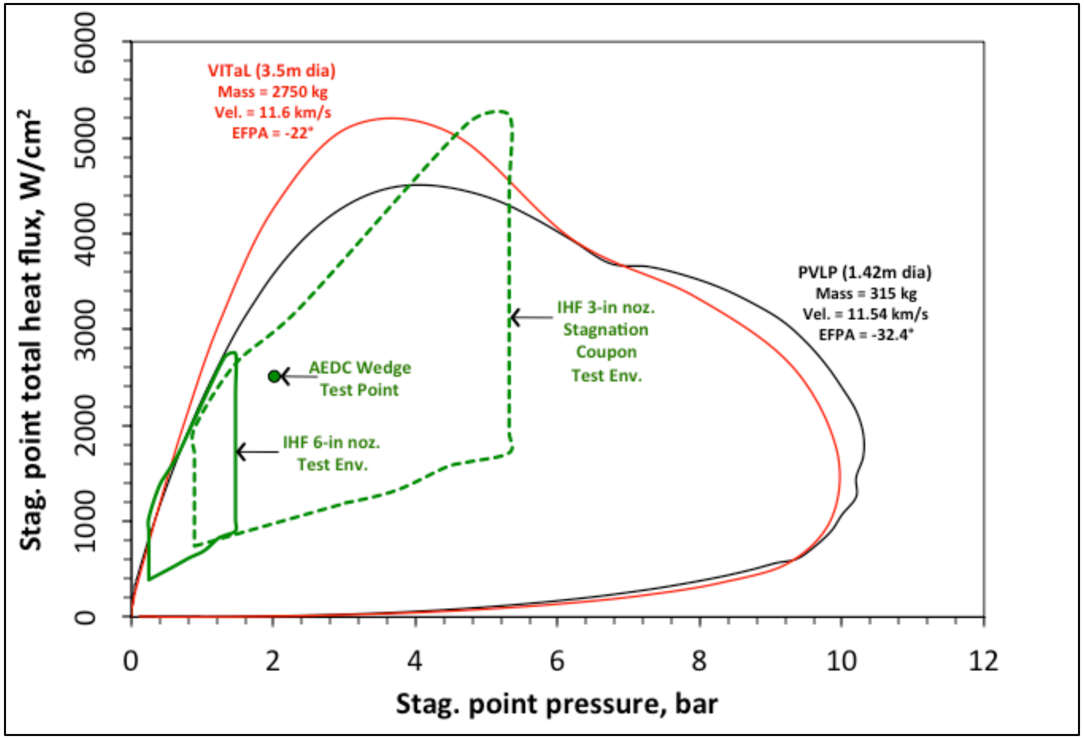
- **Carbon Phenolic faces two significant challenges:**
  - Steep entry trajectories resulting in payload mass penalty and the risk associated with the extreme entry environment
  - Certification and qualification challenges for any heritage derived CP
- **Woven TPS technology shows great promise and is a game changer**
  - Replaces the need for 2 types of Carbon Phenolic
  - Enabler for Venus missions (Probes, Landers, Balloons)
- **On-going technology maturation to TRL 5/6 by 2016 is viable and needs**
  - Engagement with Venus (& other PSDS recommended) mission design community
    - will benefit both the tech maturation and the proposal development teams
  - We are working with SMD and STP leadership to figure out pathway to interact with proposal teams without compromising the competitive nature of the pending proposal process for NF and Discovery

Acknowledgements

- **Without the dedication and support of people, across the country, this exciting development and the accomplishments would not be possible.**
- **Our sincere appreciation to:**
  - Grant Rossman (Georgia Institute of Technology), Hank Moody (Consultant), Mark Smith (AEDC), Mike Fowler (NASA JSC), Anthony Calomino(NASA LaRC_ and Steven Del Papa (NASA JSC)
  - ARC, JSC and AEDC arc jet crew
  - Our Vendors, especially Bally Ribbon Mills
- **GCDP/STP and SMD program executives, for their commitment and support, that led to the rapid maturity of the Woven TPS.**

Backup

Entry Environment and Ground Test Facility Limitation for Material Development and Flight Design Qualification



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