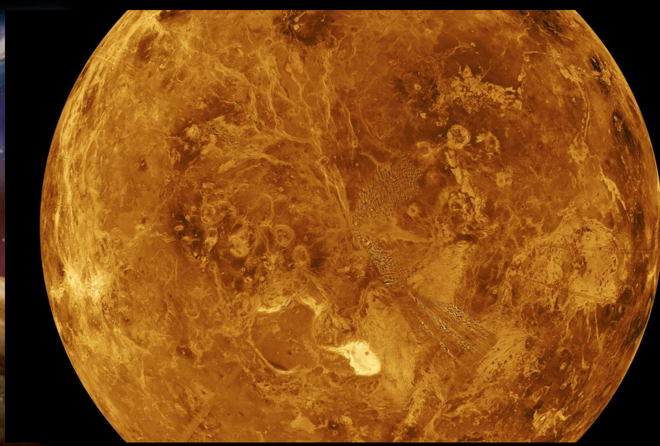
Woven Thermal Protection System (WTPS)

a Novel Approach to Meet NASA's Most Demanding Reentry Missions



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***IPPW 10**, June 17-21, 2013, San Jose, CA*

Introduction and Outline

Woven TPS Snapshot

- Highly promising, emerging technology
- Robust and certifiable TPS, leading to lower TPS risk, mission cost and higher payload mass fraction.
- Technology maturation target: TRL 5-6 by 2016

Outline

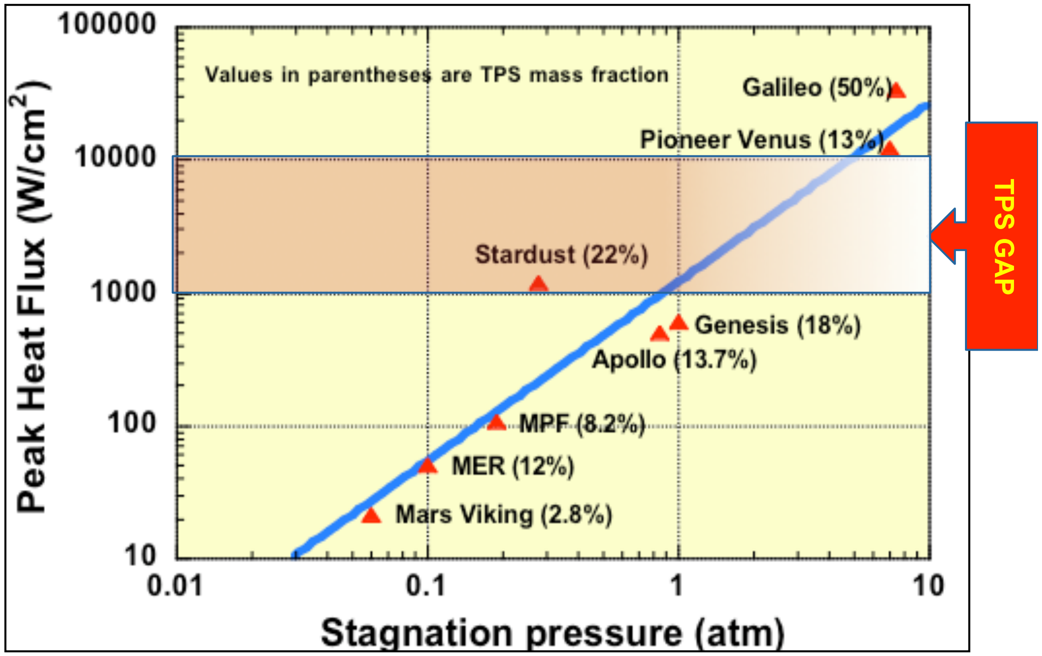
- **Ablative TPS** past and present
- **Venus and Saturn**: Extreme entry environment and ground test facility challenges for TPS development.
- **Woven TPS project and progress to-date**
- **Concluding Remarks**

SOA Rigid Aeroshell + Carbon Phenolic Heatshield

- **Science and Mission Design goals**
  - Maximize science payload, science return
  - Minimize mission risk, cost
- **Mission concepts currently baseline "heritage like" Carbon Phenolic** (CP)
  - CP is very capable, robust, flight proven
  - CP enabled Pioneer-Venus & Galileo
- **Carbon Phenolic is mission enabling, but trajectory constraining**

  Missions with CP + acceptable payload mass leads to:
  - Steeper trajectories result in:
    - Extreme g loads
    - Extreme: Heat-flux, pressures
      - Testing challenges
- **Long-term CP sustainability concerns**
  - Heritage CP rayon no longer manufactured
  - Alternate rayons have long term sustainability challenges
  - US manufacturing capabilities are atrophying

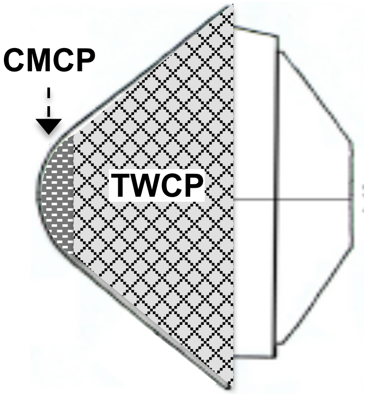
Historical TPS Mass Fraction
by Heat Flux and Pressure



Quick Primer on Carbon Phenolic (CP)

- **Carbon Phenolic** (CP) **heat-shield consists of 2 types of CP**
  - Chop Molded (CM) and Tape Wrapped (TW) CP
  - CP manufactured in different grades: reentry grade, nozzle grade,…
- **Tape wrapped CP used in rocket nozzles, DoD RVs**
- **Chop Molded CP used only for NASA entry missions**
  - Blunt nose region where tape wrap cannot be used
  - Not been manufactured for reentry in over 4 decades
- **Both CMCP and TWCP use Rayon precursors**
- **NASA held CP workshops in 2010 and 2012**
  - Heritage rayon (Avtex) based CP not viable for Venus or Saturn
  - Longer term sustainability of any CP/alternate rayon is a concern
  - With limited market, industry is shrinking, especially for CMCP

Pioneer-Venus enabled by CP

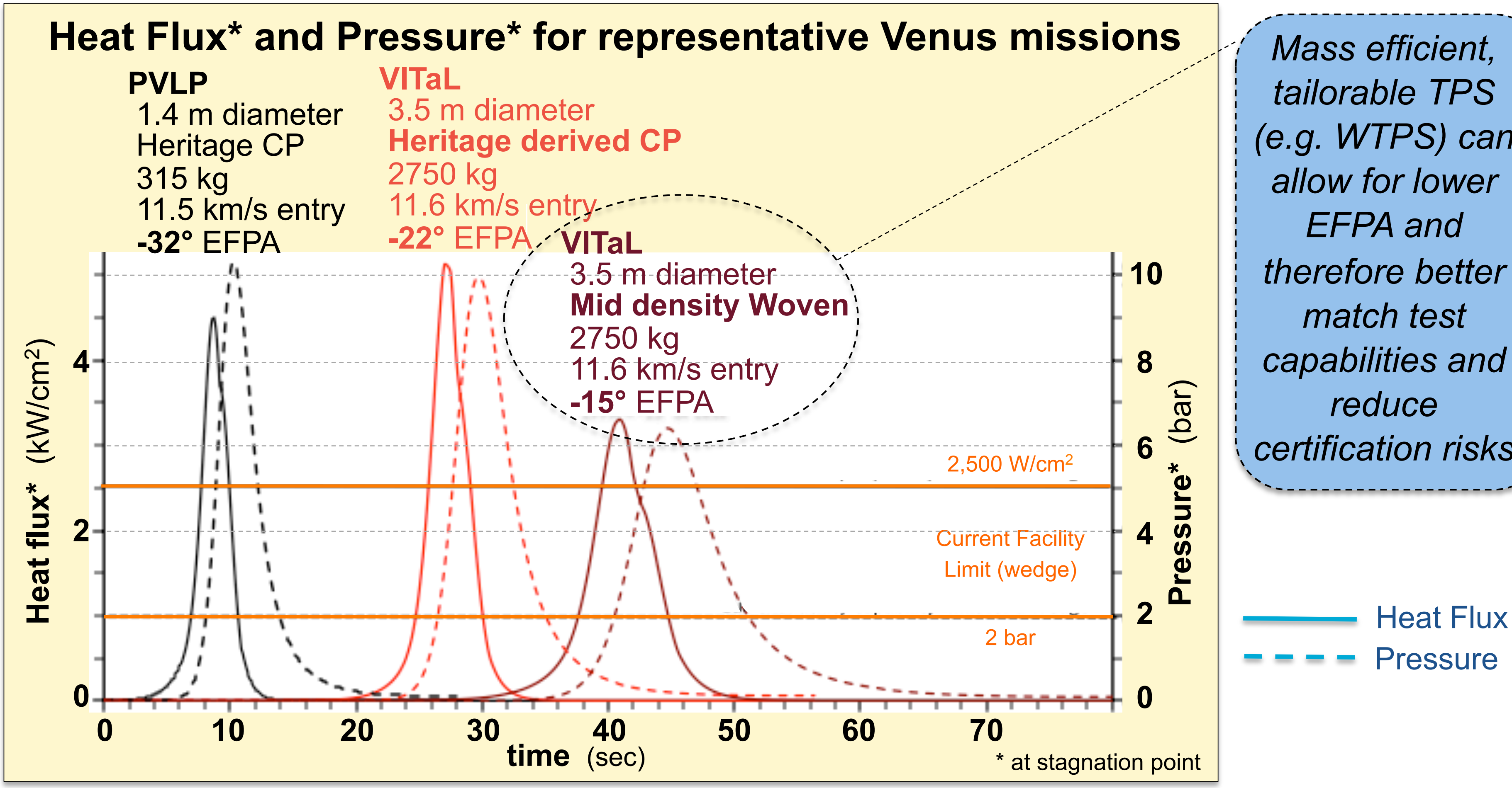


STMD and SMD are addressing this challenge through innovative TPS development

Venus Entry & Test Facility Issues

- **CP is more mass efficient at steeper entry flight path angles** (EFPA)
- **Severe entry conditions present a certification challenge due to facility limits**

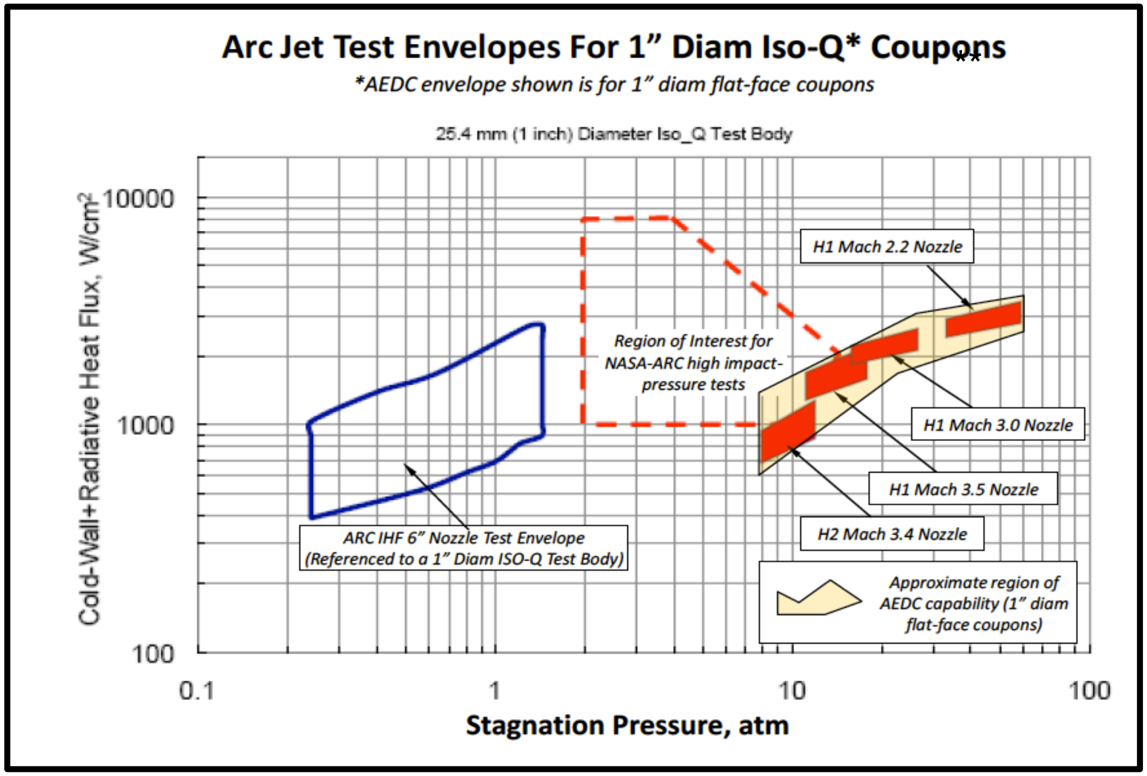
Heat Flux* and Pressure* for representative Venus missions



Mass efficient, tailorable TPS (e.g. WTPS) can allow for lower EFPA and therefore better match test capabilities and reduce certification risks

Material Development Challenges:
Current Arc Jet Facilities Capability Limitations

- Facility capabilities that supported Galileo, P-V development no longer exist
- Current facilities unable to achieve heat flux-pressure conditions of greatest interest
- NASA ARC IHF 3" nozzle funded by SMD will help
- To achieve very high heat fluxes requires small model size
- However, challenges arise testing small models



- For many NASA missions, testing/certification of alternate CP or other high performance TPS is a challenge given current test facility capabilities

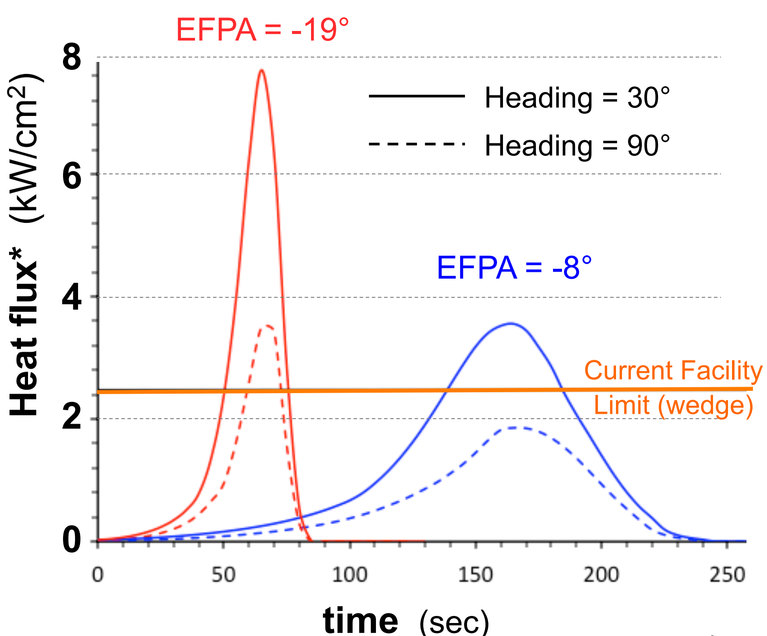
** from Mark Smith, AEDC

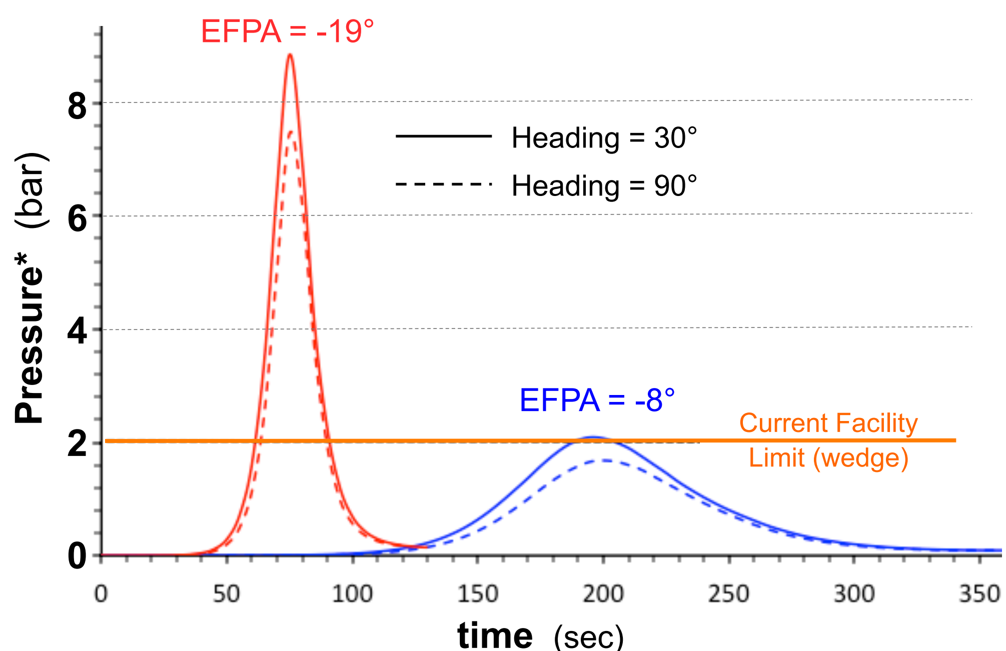
Saturn Probe Missions: Heat Flux

Many missions envisioned for Saturn & Venus entry have TPS requirements that fall into the TPS gap

Woven TPS offers the potential for a better performance-mass solution for heat shield design (fills the TPS gap) than CP

Heat flux* and pressure* time histories for a range of Saturn entries



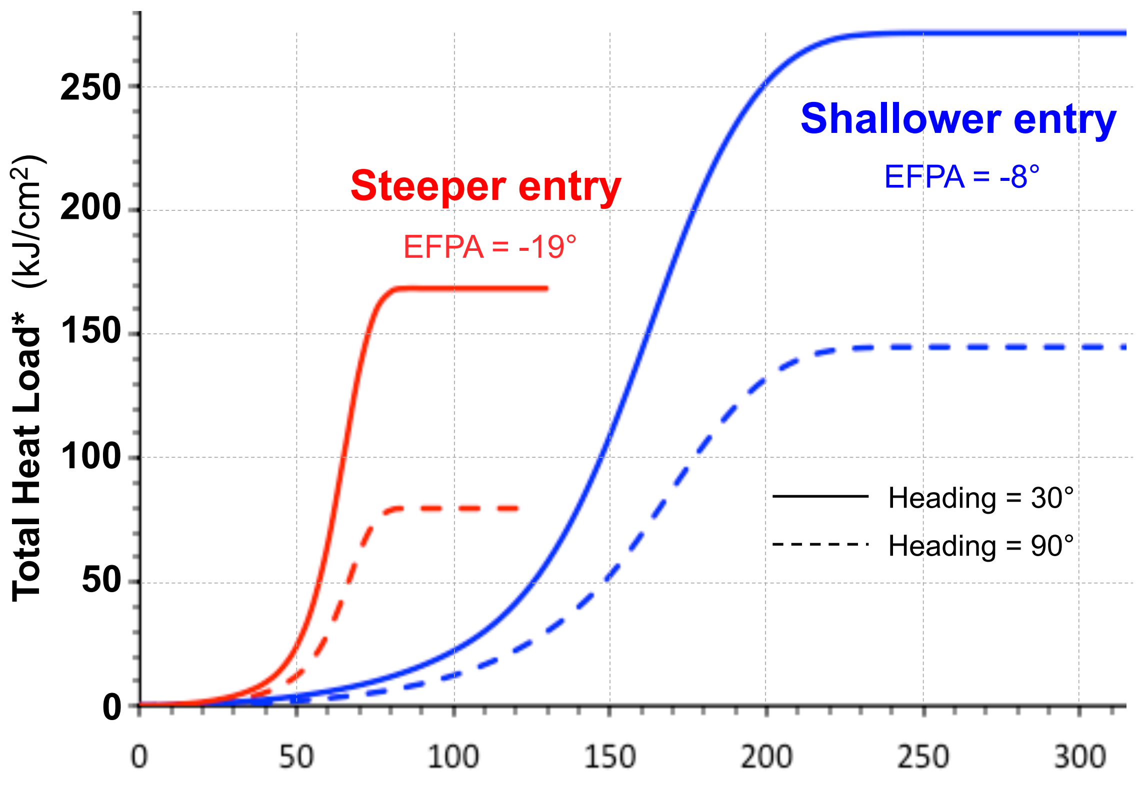


* at stagnation point

Saturn Probe Missions: Heat Load

New TPS development needs to target capabilities that are both robust across a wide range of environments (heat-flux, pressure, shear) and mass efficient for large heat-loads

Total heat load* for a range of Saturn entries



* at stagnation point

Steeper entry

Relatively lower heat load, due to shorter time of flight

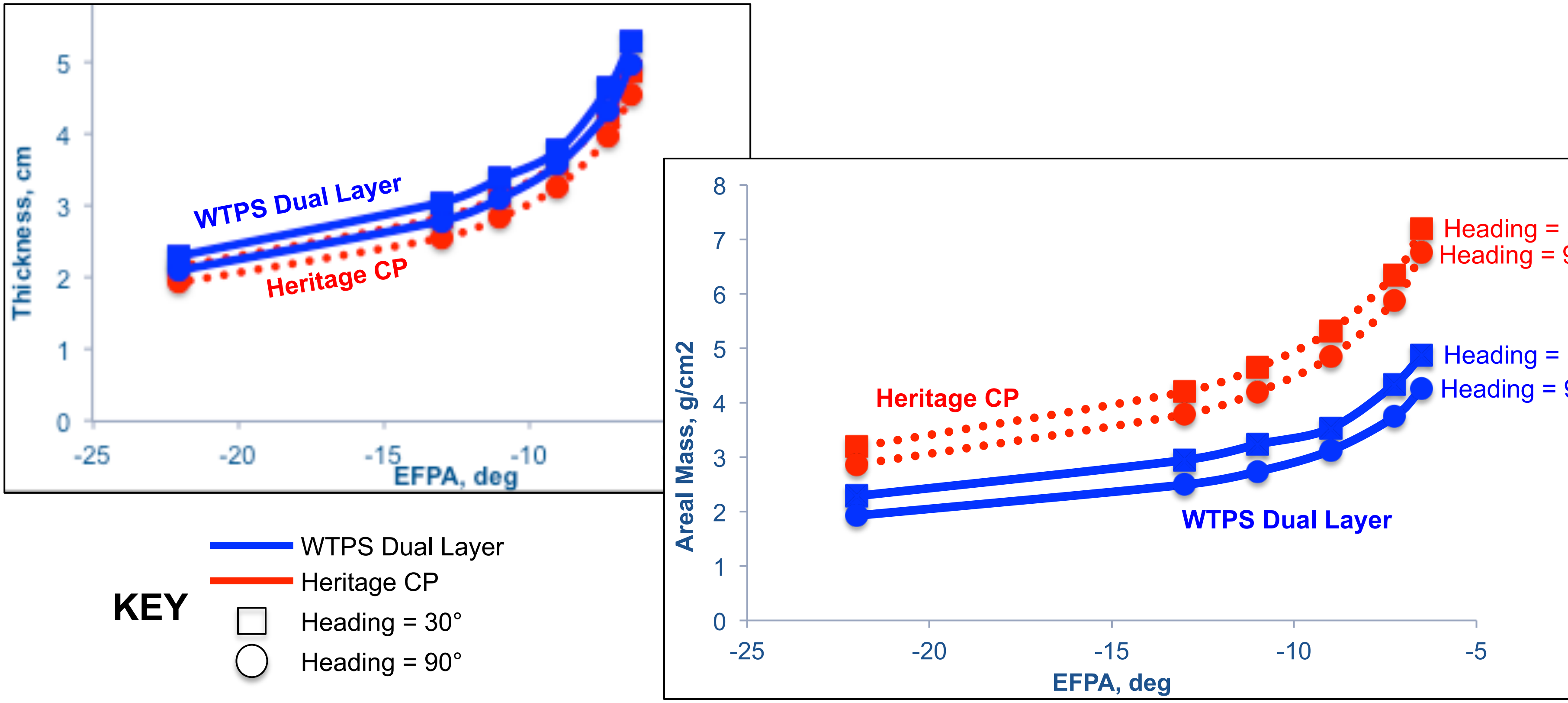
Higher heat flux, pressure and g load

Shallower entry

Preferable from TPS certification - better match with test facility capability and reduces mission risk

TPS mass fraction will be higher

WTPS Impact on Saturn Probe Mission Design



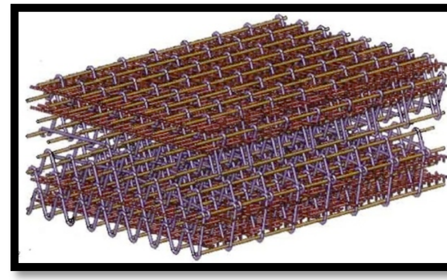
- **CP heatshield is ~40% of total vehicle mass @ -20° EFPA, 30° heading**

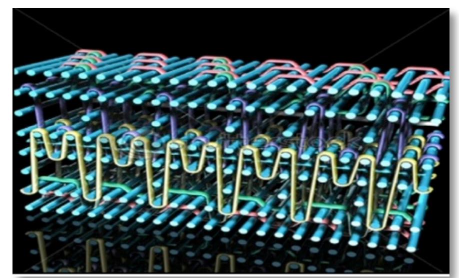
- **Minimal OML impact**: Zero-margin thickness estimate forCP and WTPS Dual Layer is nearly identical for a wide range of entry conditions
- **Significant Mission Flexibility:** TPS mass savings of { 30% - 40%) over a wide range of entry conditions provide a significant mission architecture flexibility: Mission design, with WTPS, can trade certification risk, mass and lower entry g load

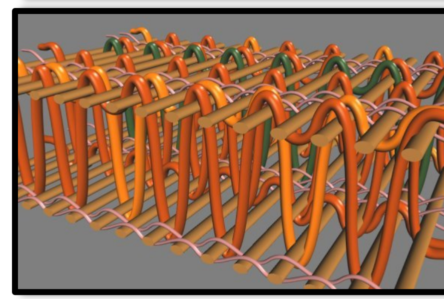
What is Woven TPS?

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 infusion when needed

- Ability to design TPS for a specific mission
- Tailor material composition by weaving together different types of fibers and control their 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:

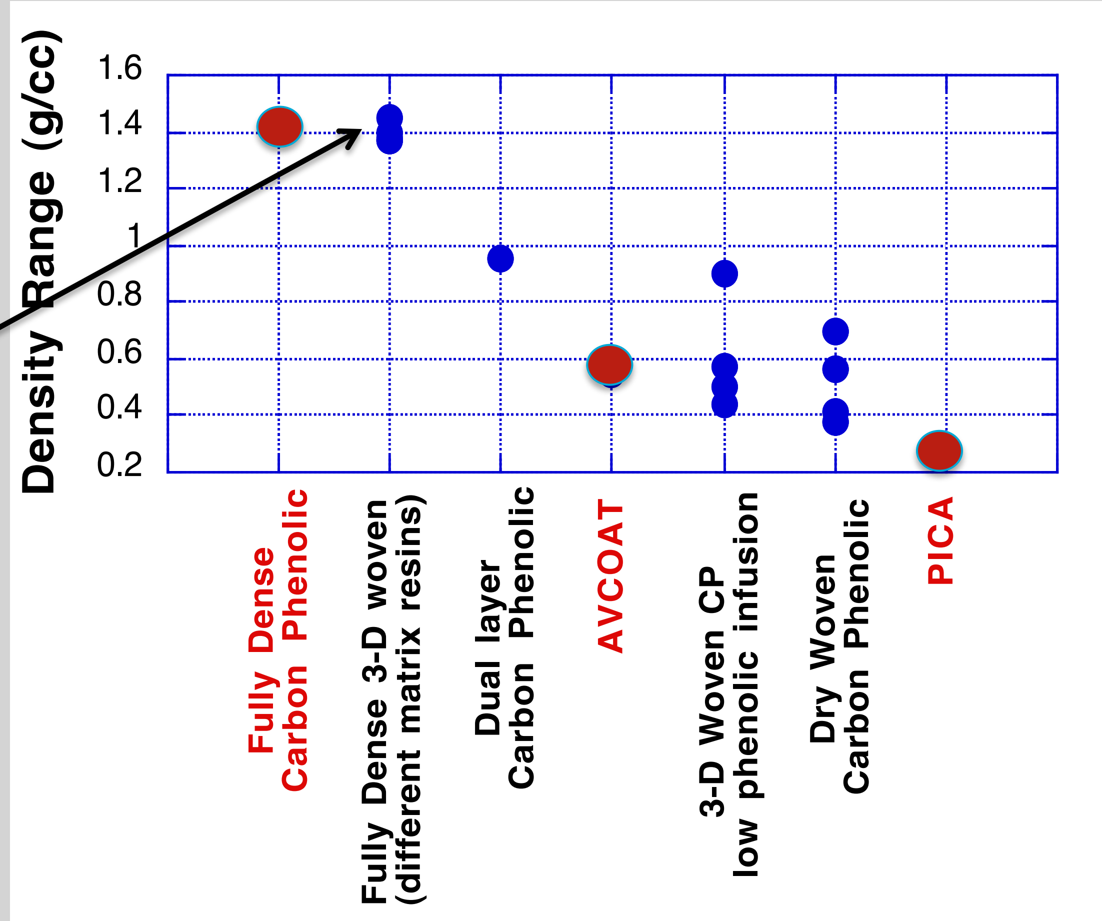
- Develop and prove feasibility of woven TPS manufacturing technique
- Demonstrate via testing low, mid and high-density WTPS in order to fill the mid-density gap as well as finding a superior replacement for the heritage carbon phenolic

WTPS Accomplishments

Demonstrated feasibility of manufacturing low, mid and high-density WTPS

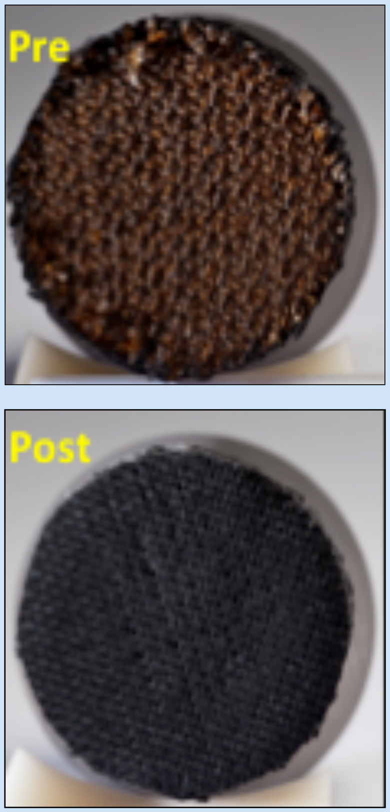
- **Efficient ablator candidate for mid-density TPS Gap**
- **Potential replacement for high density CP**

Fully Dense 3-D Woven (different resins)



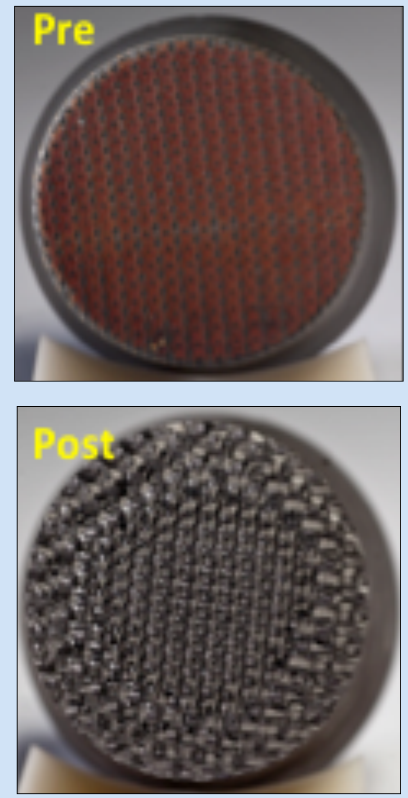
Woven TPS Testing in Ames Arc Jet

Ames IHF Arc Jet stagnation test results of Woven TPS



**Mid Density
Dry Woven CP Blend**

- 17 different Woven TPS types
- Chop molded and tape wrapped carbon phenolic tested
- Densities ranged from low (0.4 g/cc) to high (1.4 g/cc) variants

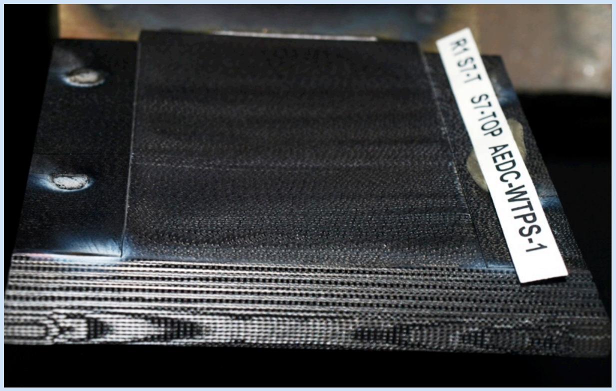


**Fully Dense 3-D
Woven CP Blend**

Results suggest high density 3-D WTPS has similar recession performance as CP

Woven TPS Testing in AEDC Arc Jet

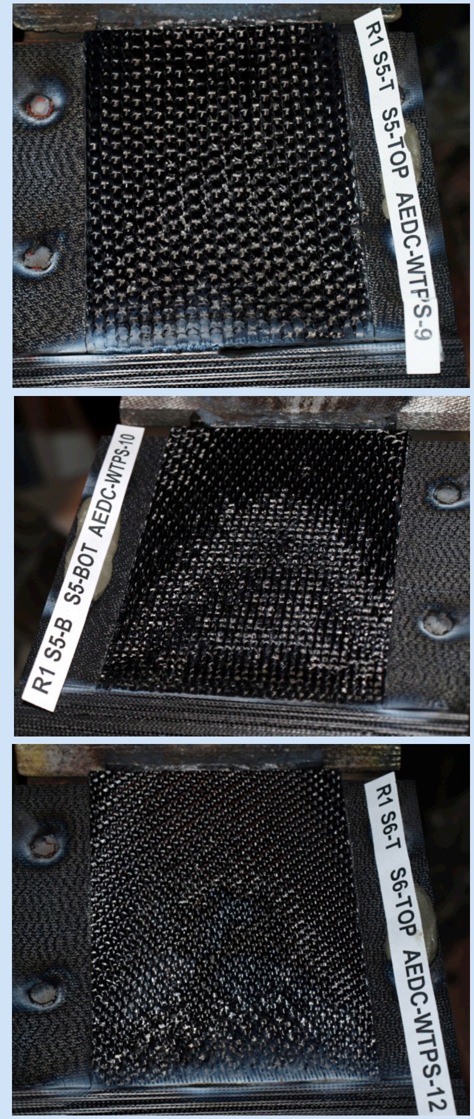
AEDC Arc Jet test results of CP & Woven TPS



Tape Wrapped Carbon Phenolic

Chop Molded Carbon Phenolic

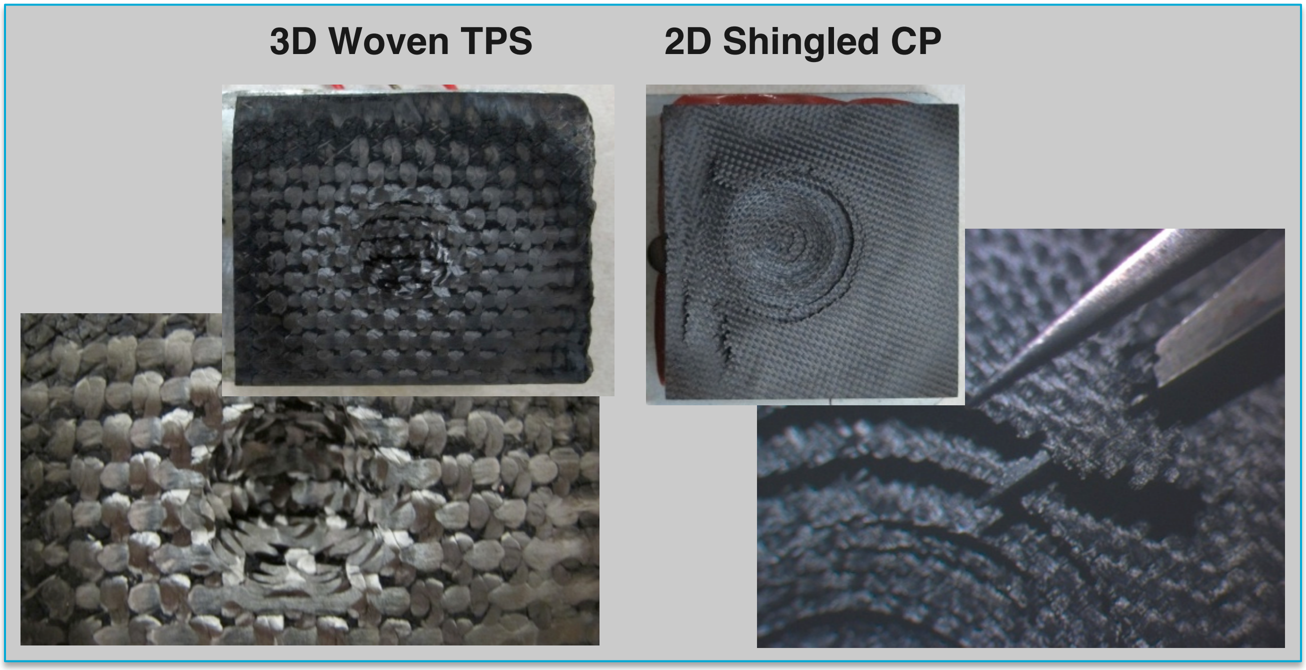
- 12 different Woven TPS types
- Chop molded and tape wrapped carbon phenolic tested
- Mid-to-High Density variants tested
- High heat flux, shear, and pressure



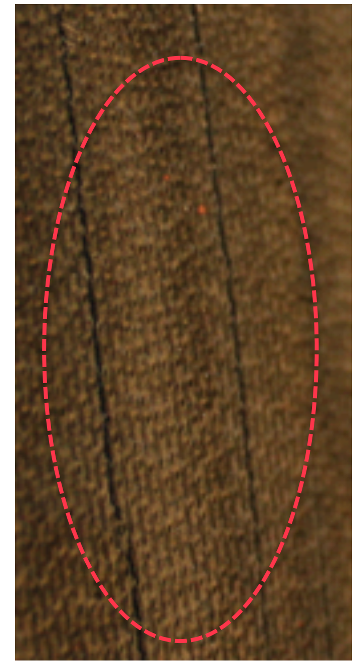
3-D Woven TPS

Explored Failure Modes: Woven TPS vs 2D Carbon Phenolic

Testing in Ames mini-Arc Jet (mARC)



AEDC Wedge Test



- **2D Shingled CP exhibits - ply separation**
- **Similar behavior observed in the 2D CP at AEDC during wedge testing**
- **Affected area is larger in 2D CP as compared to 3D Woven TPS**
- **Woven TPS is less prone to ply separation, given the 3D nature of the woven preform**

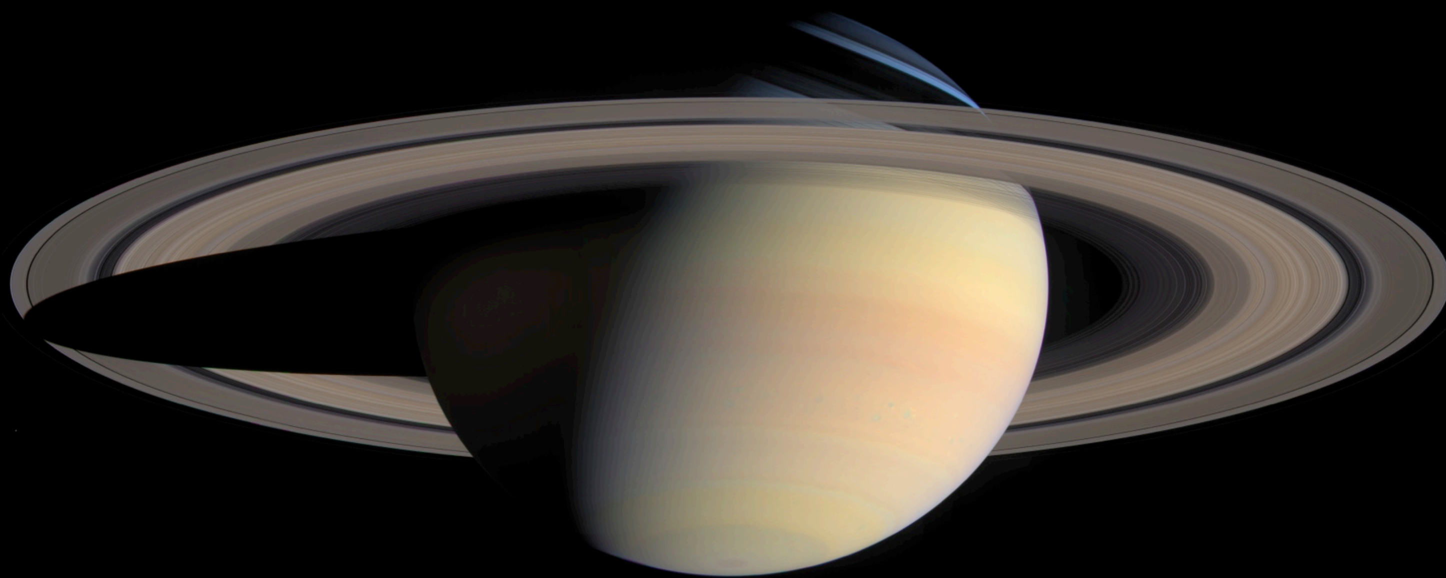
Summary & Conclusions

- Successfully manufactured low, mid and high density Woven TPS materials using advanced 3D weaving and resin infusion technology
- Successfully demonstrated feasibility of Woven TPS for extreme entry environment missions (IHF and AEDC arcjet testing)
- Initial arc jet results indicate Woven TPS material / architecture has comparable performance to Carbon Phenolic
- WTPS 3D is inherently more robust to ply separation than heritage like CP
- Woven TPS's tailorability has the potential to mass efficiently meet a broad range of mission needs

Next Steps

STMD has recently awarded a 3 year WTPS development effort called Heat Shield for Extreme Entry Environment (HEEET)

- **Objective: mature HEEET to TRL 5-6 by 2016 to support proposers to the next New Frontiers** (NF) **Announcement of Opportunity** (AO)



- **Successful mission infusion requires HEEET project to engage with mission proposing organizations and integrators or a regular basis**
- **WTPS Industry Day to be held at ARC in late July**

Acknowledgements

- **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 crews
  - Our Vendors, especially Bally Ribbon Mills

- **GCDP/STMD and SMD program executives, for their commitment and support, that led to the rapid maturity of the Woven TPS.**