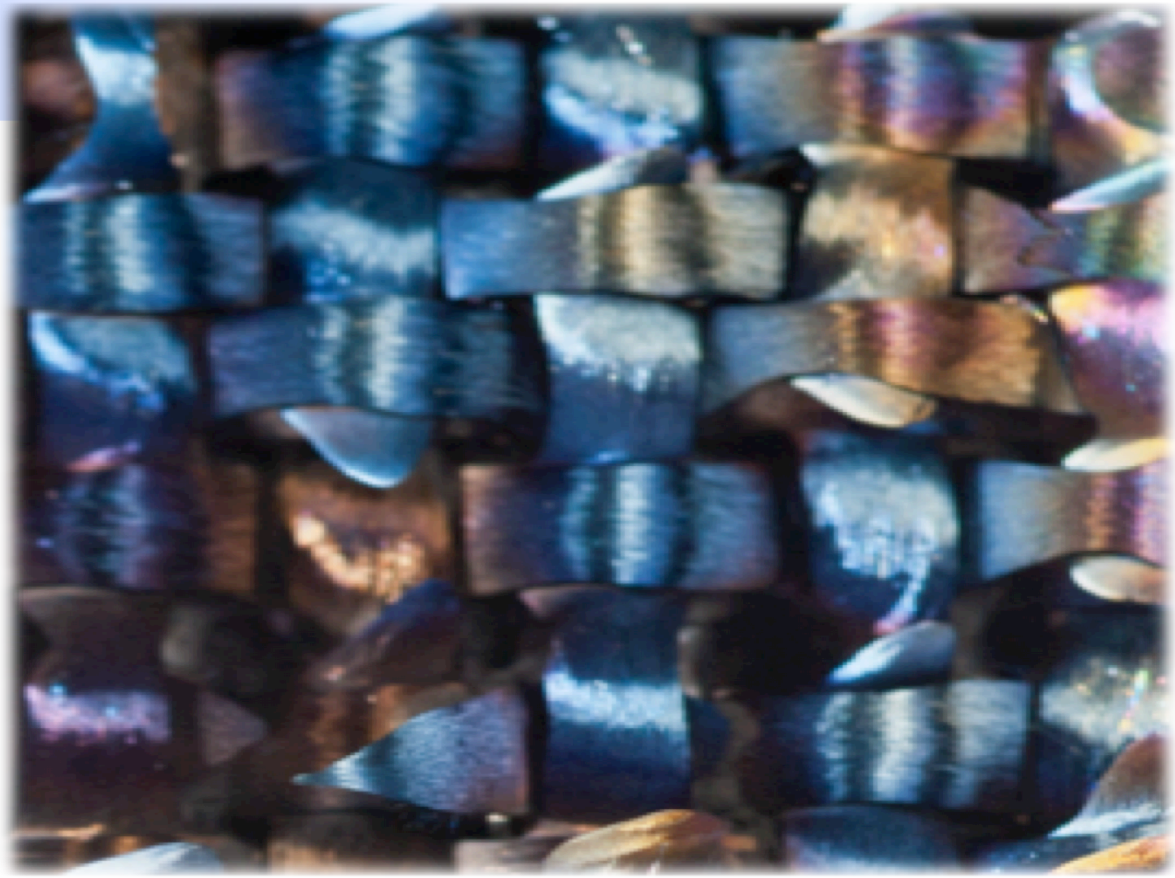
Woven TPS – A New Approach to TPS Design and Manufacturing

Jay Feldman and Mairead Stackpoole.
ERC Inc., NASA Ames Research Center, Moffett Field, CA 94035

Ethiraj Venkatapathy
NASA Ames Research Center, Moffett Field, CA 94035

NASA's Office of the Chief Technologist (OCT) Game Changing Division recently funded an effort to advance a Woven TPS (WTPS) concept. WTPS is a new approach to producing TPS materials that uses precisely engineered 3D weaving techniques to customize material characteristics needed to meet specific missions requirements for protecting space vehicles from the intense heating generated during atmospheric entry. Using WTPS, sustainable, scalable, mission-optimized TPS solutions can be achieved with relatively *low life cycle costs* compared with the high costs and long development schedules currently associated with material development and certification. WTPS leverages the mature state-of-the-art weaving technology that has evolved from the textile industry to design TPS materials with tailorable performance by varying material composition and properties via the controlled placement of fibers within a woven structure. The resulting material can be designed to perform optimally for a wide range of entry conditions encompassing NASA's current and future mission needs. WTPS enables these optimized TPS designs to be translated precisely into mission-specific, manufactured materials that can substantially increase the efficiency, utility, and robustness of heat shield materials compared to the current state-of-the-art material options. By delivering improved heat shield performance and affordability, this technology will impact all future exploration missions, from the robotic in-situ science missions to Mars, Venus and Saturn to the next generation of human missions. WTPS can change the way NASA develops, certifies, and integrates TPS into mission life cycles - i*nstead of being a mission constraint, TPS will become a mission enabler*. It is anticipated that WTPS will have direct impact on SMD, HEOMD and OCT and will be of interest for DoD and COTS applications. This presentation will overview the WTPS concept and present some results from initial testing completed.



Woven TPS – A New Approach to TPS Design and Manufacturing

Mairead Stackpoole[§], Jay Feldman*, Ethiraj Venkatapathy[§]

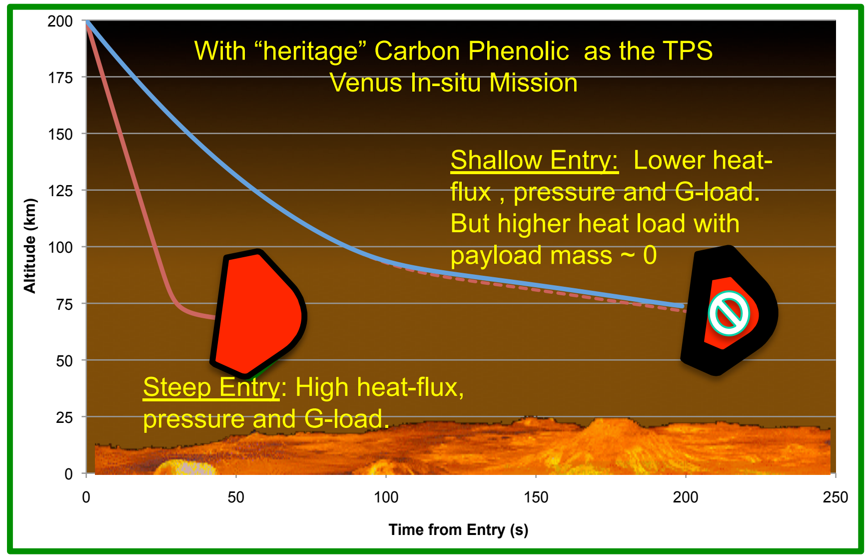
[§]NASA Ames Research Center, Moffett Field CA 94035, *ERC Inc., Moffett Field, CA 94035

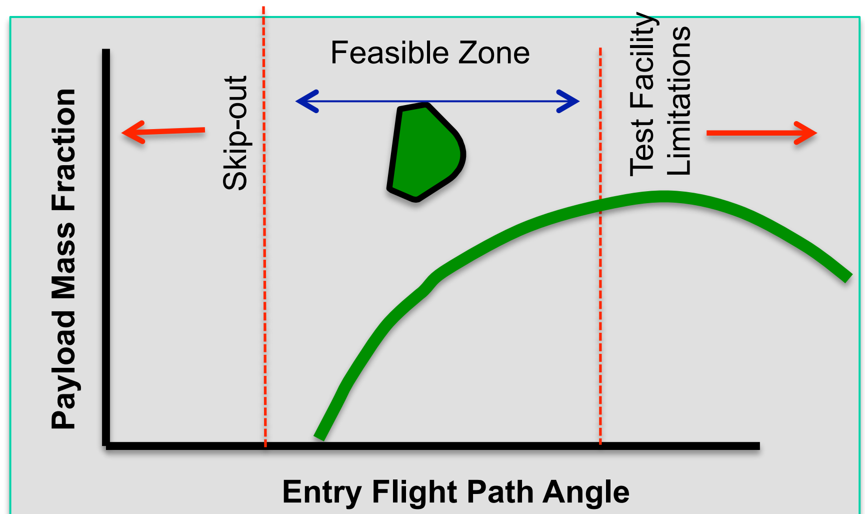
Outline

- Motivation
  - TPS Gap
  - TPS from a Mission Constraint to an Enabler
- Woven TPS
  - Background, Introduction and Benefits
- Current Plan and Progress
  - Key Technical Risks and Work in Progress to Retire Risks
- Summary and Ongoing Work

Challenges for Venus, Saturn, Neptune, Uranus, Jupiter and High Speed Sample Return Missions

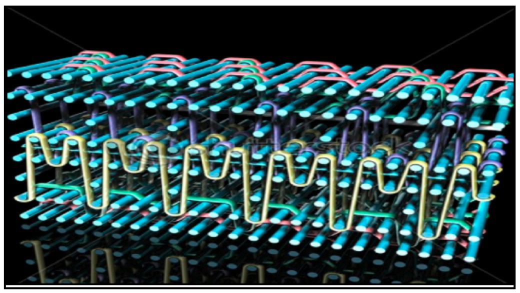
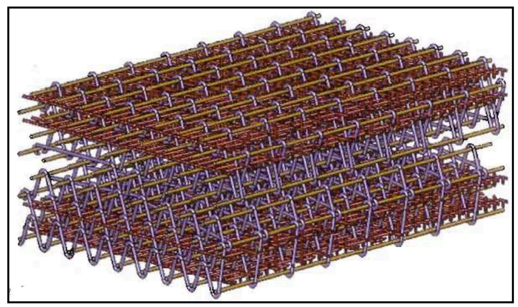
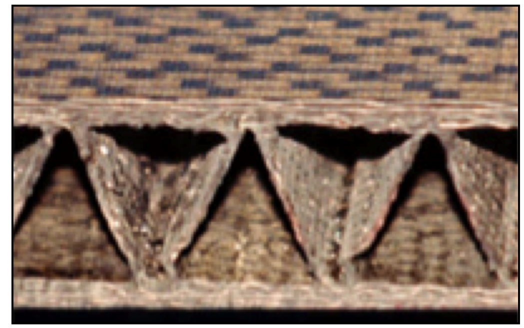
- **Mission concepts have had no other option but to baseline Carbon Phenolic (CP)**
  - CP is very capable and robust
  - CP enabled Pioneer Venus & Galileo missions & is flight proven
  - CP is currently the only option (no mid density TPS)
- **Carbon Phenolic is mission constraining**
  - Mission design with CP and acceptable payload mass leads to:
    - Steeper trajectories
    - High heat-flux & pressure
    - High G-loads
- **Science and Mission Designs seek to**:
  - Maximize science payload
  - Minimizing mission risk
    - in certification of components and sub-system such as instruments or heat shield





What is the 3D Woven TPS concept?

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 (e.g. carbon, ceramic, glass, polymeric)
- One-step process for making a mid-density dry woven TPS
- Ability to infiltrate woven structure with a polymeric resin to meet more demanding thermal requirements

Why is WTPS Revolutionary?

- **Woven TPS can rapidly fill an immediate efficient TPS need (the TPS Gap)**
  - Weaving TPS allows us to make not just a point design but we can make optimized mission specific TPS across a wide range of heat flux
- **Provides a sustainable more cost effective processing route**
  - Currently, NASA TPS materials have no other government or commercial applications and do not utilize manufacturing processes leveraging common commercial processes
- **Lessons learned applicable to a wide TPS design Space**
  - Woven TPS (system) allows us to learn and improve across the board
- **Potentially offers a new affordable approach to TPS certification that reduces long-term costs**
  - With current TPS, we cannot predict the thermal performance based on processing/ composition changes. Predicting performance a priori allows us to evaluate how constituents change the end product performance, especially for dry woven materials
- **Aim to change the approach to designing an efficient TPS for a given mission**
  - Conventional approach used to develop TPS is still trial and error and does not employ a predictive capability in the process. Ability to predict and hence design TPS allowing for rapid optimization for a particular mission scenario is very attractive.

WTPS Project Overview: Vision, Scope and Tasks

Advance 3D Woven TPS TRL from 2 to 3

Start date: 1/1/2012 End date: 2/28/2013

Vision: Close TPS gap & enable future missions with TPS that is not mission constraining but enabling

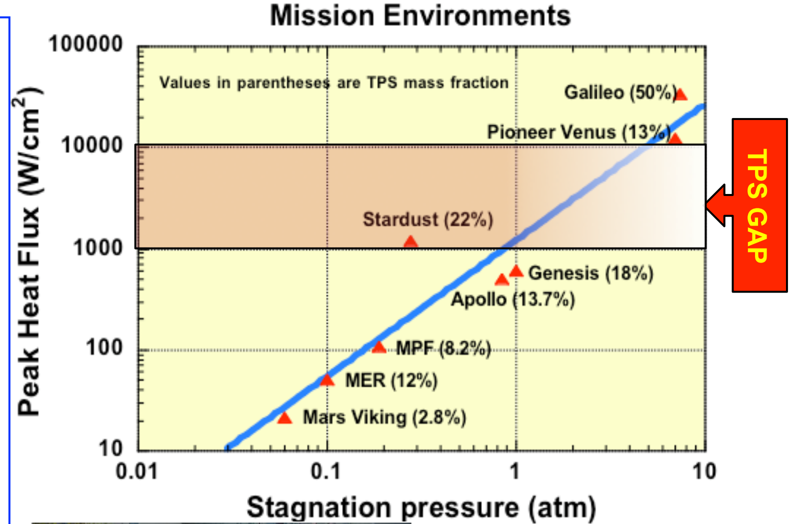
Background:

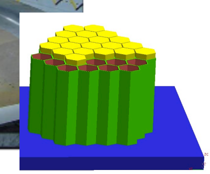
- Apr. 2011: Center innovation start-up funding for WTPS
- Sep. 2011: Woven TPS proposed to OCT GCD (BAA)
- Nov. 2011: proposal selected for funding start in Jan.'12

Project Goal: Explore feasibility and establish manufacturing of TPS using textile industry and resin infusion techniques.

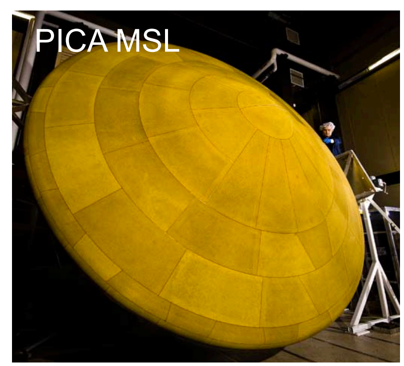
Project Tasks:

- **Manufacture a variety of WTPS materials**
  - Different yarn compositions, weave constructions, levels of resin infiltration, etc.
- **Obtain preliminary property database**
- **Perform arc jet tests on selected samples**
  - Explore and establish heat flux capability range
  - Compare thermal performance to heritage CP
- **Assess state-of-the art in analytical modeling tools and applicability for WTPS**
- **Prepare a TRL 3 to TRL 5/6 maturation plan**





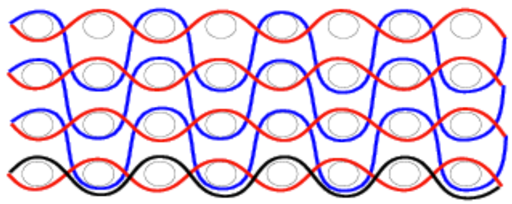
Sustainability



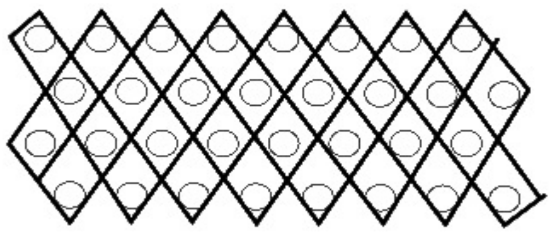
Life Cycle Costs

WTPS Architecture is Tailorable

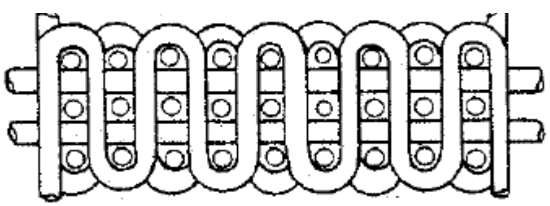
The Woven Substrate



Layer-to-Layer



Through the Thickness



3D orthogonal

The Yarn

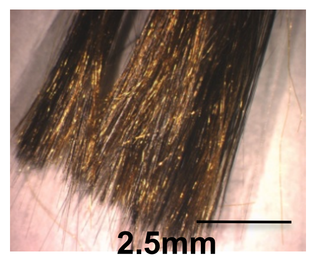
Denier

Carbon

Polymer

Oxide (silica)

Blended



The Matrix

<u>Full/Partial Infiltration</u>

Phenolic

Cyanate Ester

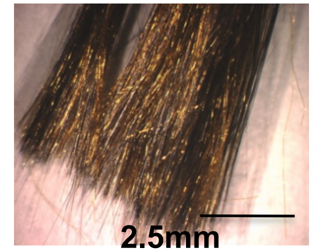
Polyimide

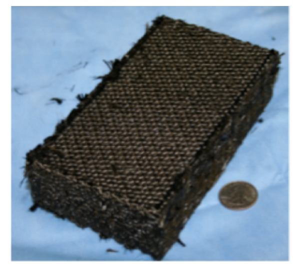
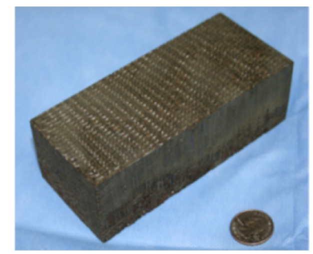
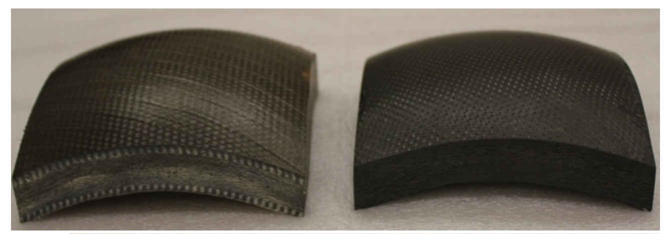
No matrix

WTPS can optimize **all aspects of architecture**

Successful Woven TPS Manufacturing and Testing

- Demonstrated the proof of concept of utilizing commercial weaving to manufacture TPS materials
- Bally Ribbon Mills fabricated multiple 3D woven preforms for testing
  - Weaving multiple fiber types together
  - Graded materials in terms of density and composition
- Resin infused 3D test articles fabricated using resin transfer molding (RTM)
  - Preliminary Mechanical/Thermal property samples
  - Samples to support arc jet testing
- Arcjet testing Dec 2011 & Jan 2012
  - December arc jet test at JSC – fully dense CP materials at conditions as high as possible
  - January arc jet test at ARC – dry woven concepts

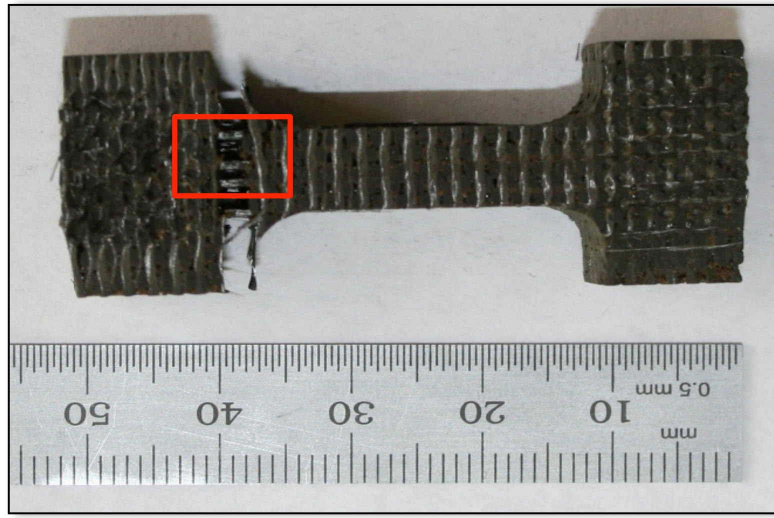


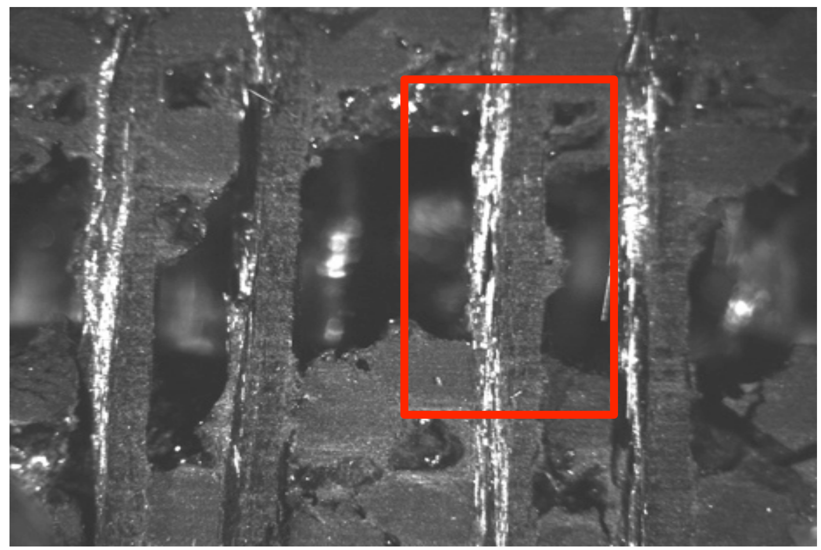





3-D Woven TPS Mechanical Property Comparison with 2-D CP

Material	Normalized TTT Tensile Strength	Normalized TTT Young's Modulus
2D Carbon Phenolic	1	1
3D Woven Carbon Phenolic (non-optimized)	3.7	0.7

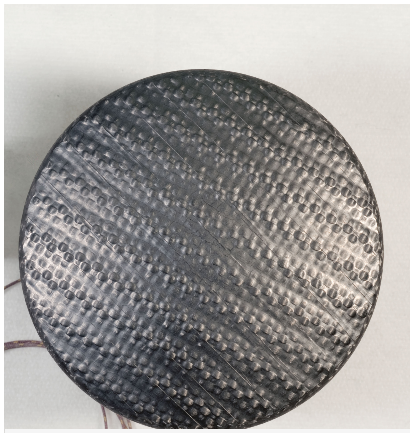
- > 300% improvement in strength in Z direction over traditional 2D carbon phenolic TPS materials (sample not taken to failure)
- Z fibers continue to bridge crack even after fracture
- Z fibers prevented catastrophic failure of samples

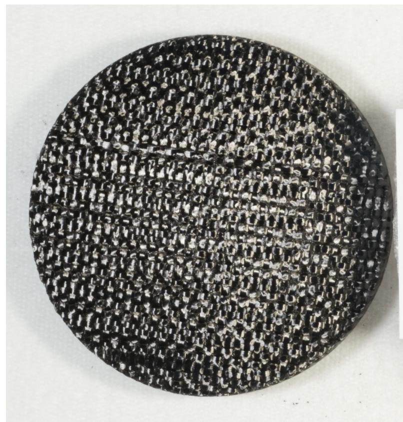




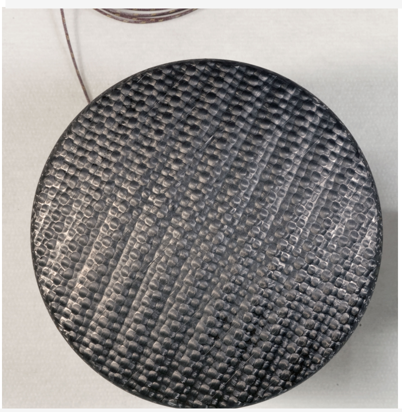
Fully Dense 3-D Woven CP – Recent Arc Jet Test

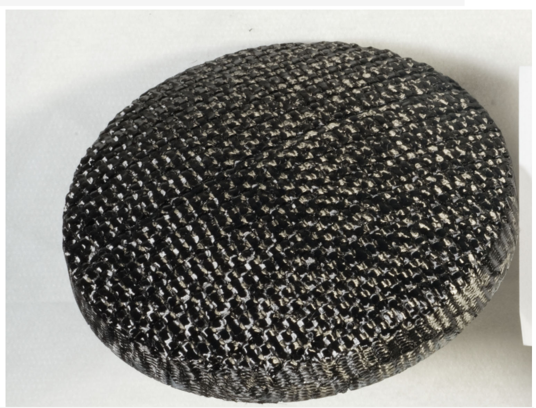
Pre test **Post Test**





WTPS Sample 3 (heritage resin)





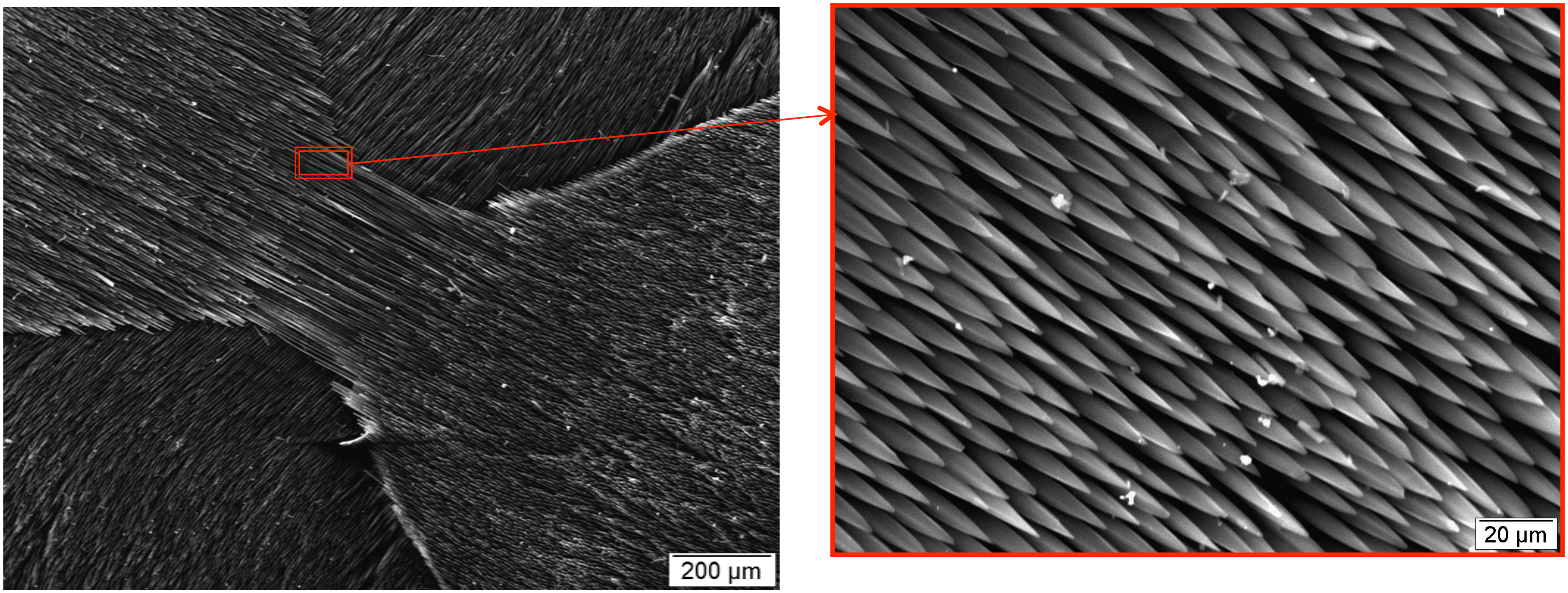
WTPS Sample 4 (Alternate resin)

- 2 Samples tested
  - Both were fully dense carbon phenolic materials
    - Heritage resin
    - Alternate resin
  - Both samples had a 3-D woven carbon substrate

- Cold Wall Heat Rate: 590 W/cm^2
- Stagnation pressure 625 psf (4-in iso-q slug cal measurements)
- Duration ~ 100 s
- Integrated heat-load ~59 kJ/cm^2 (Cold Wall measurement)

10

Fully Dense 3-D Woven CP – Recent Arc Jet Test Microscopy



Microscopy provides insight into the ablation/oxidation mechanism of woven yarns

Mid-Density & Dry Wovens – Recent Arc Jet Test

Pre test | **Post Test**


Carbon phenolic blend woven TPS graded density


Carbon phenolic blend woven TPS constant density

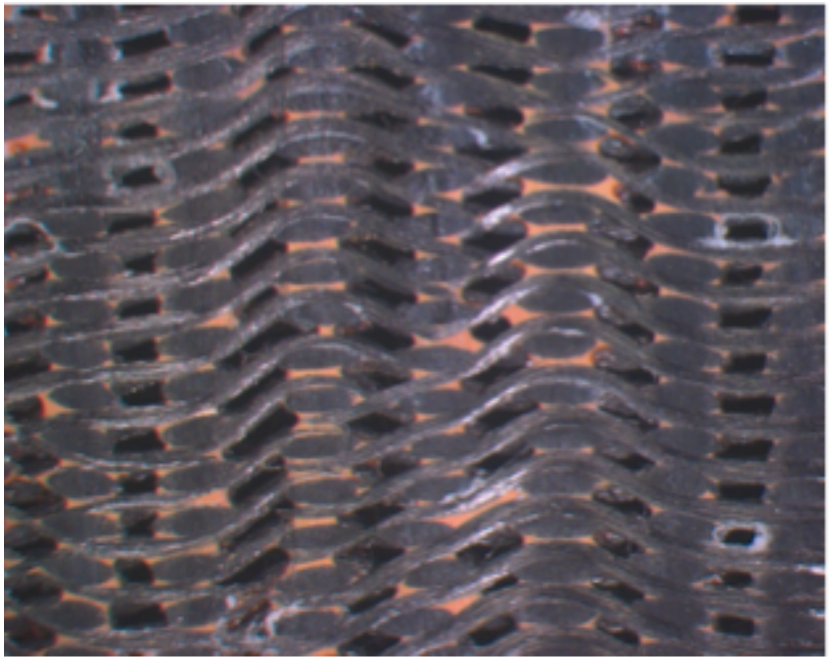
- 5 mid-density samples tested (3 were woven only – no resin)
  - Carbon phenolic blend woven TPS constant density
  - Carbon phenolic blend woven TPS graded density
  - Carbon phenolic blend woven TPS graded density and composition (Nextel at backface)

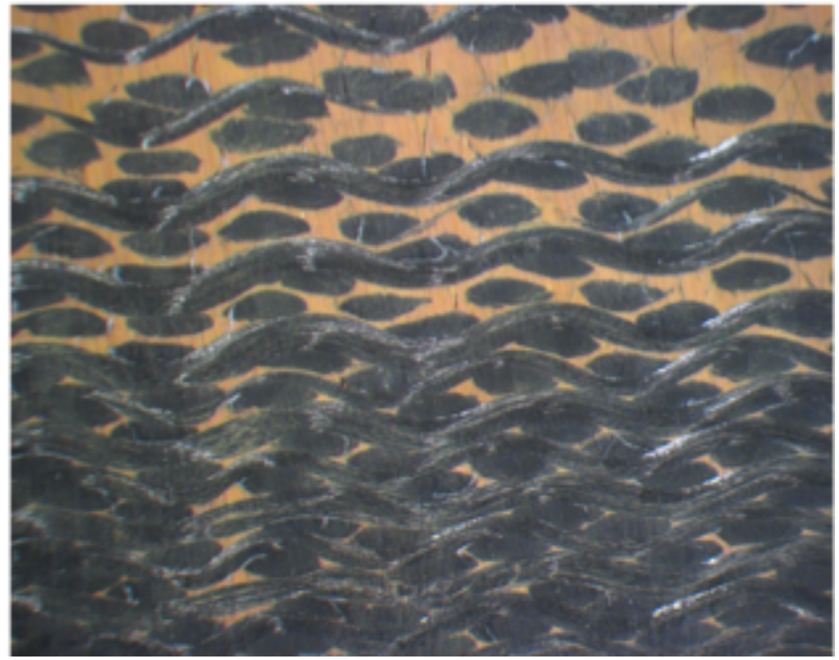
- Cold Wall Heat Rate: ~700 W/cm^2
- Pressure: 0.8 atm.
- Duration: ~ 40 Sec

Significance: Provides confidence in dry woven TPS (no resin infusion) as a viable mid-density TPS material

- no unexpected failure or spallation detected

Addressing RTM Scale Up Risk





- Initial scaled-up RTM sample had substantial porosity throughout the matrix
- Increasing pressure and adding more ports for resin infusion leads to improved processing with minimal porosity

What are the Technical Risks Identified?

- Fiber Choice - Rayon based yarn (like traditional CP) is unavailable
  - Mitigation: Utilize high purity PAN based C fibers initially with denier similar to heritage rayon based C fibers (1650 – 1800)
- Weave type - Insufficient time to evaluate different weave/fiber parameters
  - Mitigation: Limited insight into influence of weave type and performance of PAN based fibers from early testing
- Performance of unimpregnated woven fiber architecture: no experience in aerothermal testing of dry woven architectures
  - Mitigation: Materials will be manufactured both fully and partially infiltrated with phenolic resin
- Analysis risks – tool development for dry woven
  - Mitigation: engage analysis experts with experience in 3D composite tool development
- Incorporation of Phenolic Matrix via Resin Transfer Molding (RTM)
  - Mitigation: Evaluate alternate resin systems.

WTPS Summary

- Exciting new approach to TPS development
  - Focused effort, lean team and maximum utilization of funds
- Leverage sustainable industrial base
- High confidence that 3D Woven TPS will prove to be superior in performance and robustness, and help fill the TPS Gap
  - **Mid-density dry woven for intermediate conditions**
  - **Resin infused 3-D woven graded TPS for intermediate – high conditions**
- An alternate that is not just a replacement but an enabler is needed
  - Current missions have no choice but to live with the constraints of "heritage like" CP (efficiency, sustainability)
  - We believe WTPS can change the way we develop and design with TPS.
    - WTPS project is exploring the ***capability*** to optimize a material for a specific mission – a more efficient TPS is mission enabling