



Performance of Woven TPS Ablative Materials

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Outline

- Motivation
 - TPS from a Mission Constraint to a Mission Enabler
 - TPS Gap
- Woven TPS – The Concept
- Manufacturing and Testing
 - Thermal and Mechanical Performance
 - Arc-jet Testing
- Summary and Future Efforts



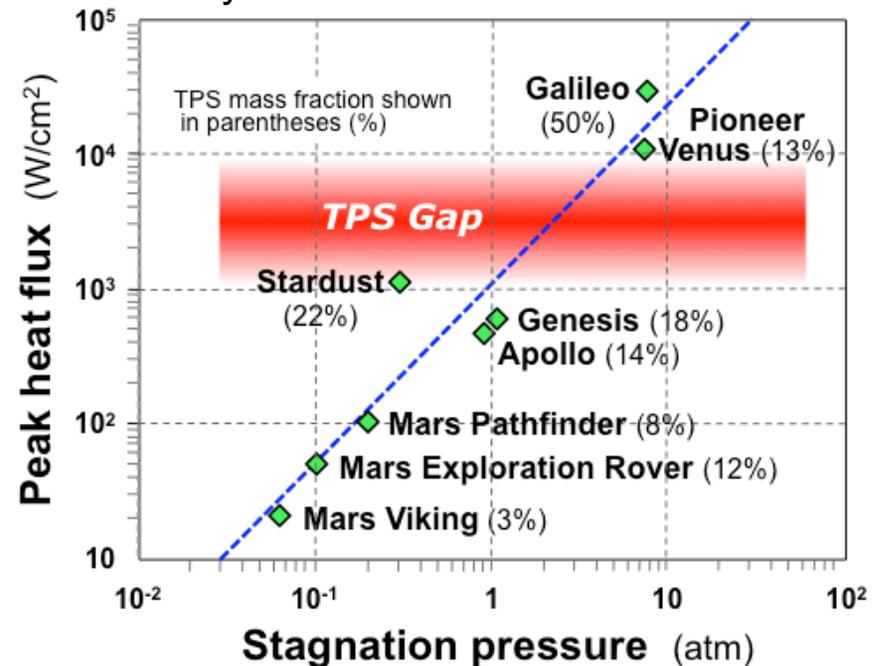
TPS Challenges for Venus, Saturn, Neptune, Uranus, Jupiter and High Speed Sample Return Missions

- **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 + normal payloads result in:

 - Steeper trajectories, extreme g loads
 - Heat-flux, pressures exceed test capability

Historical TPS Mass Fraction
by Heat Flux and Pressure



For typical Entry Systems Missions

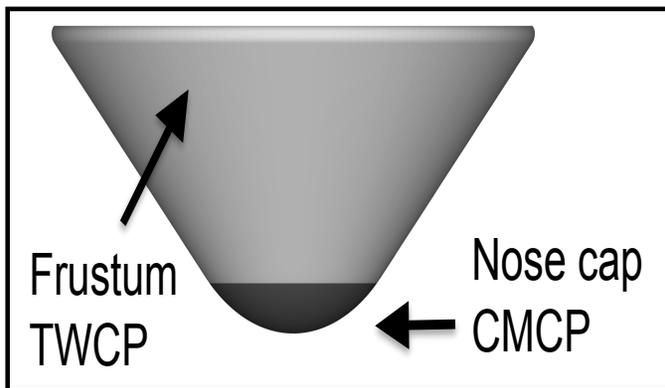
*at high heat fluxes CP is an efficient TPS.
Below ~ 1200 W/cm², PICA and other ablators
perform well.*

There is no efficient TPS option in the gap!



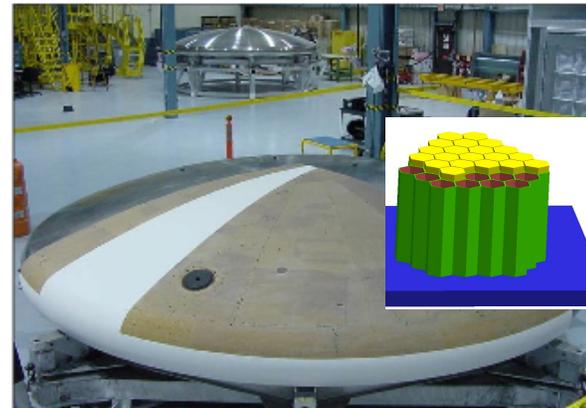
Challenges with State of the Art TPS

Tape-wrapped & chop-molded carbon phenolic

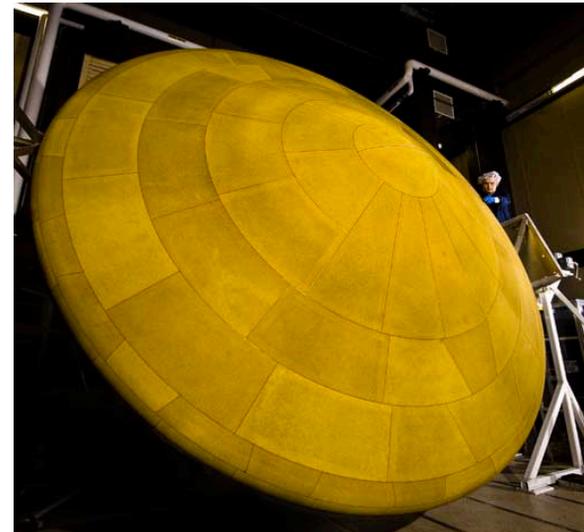


- Challenges for using traditional CP
 - Heritage CP used for entry no longer available (Avtex)
 - New CP material would need to be certified
 - Chop-molded CP has not be used for NASA application since 1980s

Sustainability and Life Cycle Costs



AVCOAT

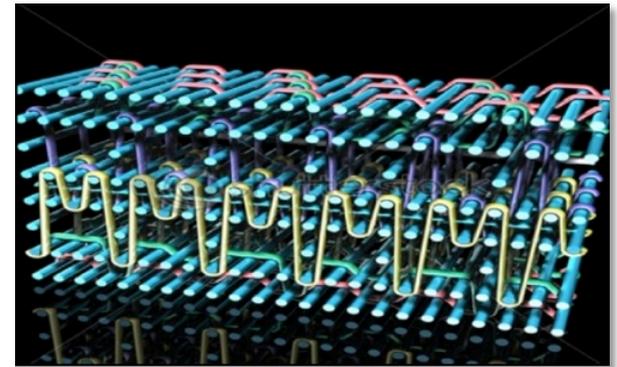


PICA MSL



Woven TPS Concept

- **Automated 3D weaving technology is very flexible and customizable:** there are *MANY* variables that can be changed within a single preform
 - Fiber composition (e.g. carbon, polymer, glass)
 - Fiber denier (fineness)
 - Weave density (fiber volume fraction)
 - Weave type (e.g. layer-to-layer, orthogonal)
- Resin infusion can also be tailored
 - No resin (dry weave)
 - Partial infusion &/or surface densification
 - Full densification
- Manufacturing flexibility allows for the optimization of a material for a given mission
- WTPS leverages a ***sustainable*** weaving technology (not NASA-unique)



Recession resistant layer

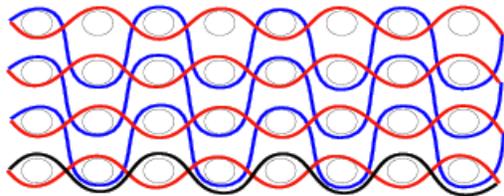
insulation layer 1

insulation layer 2

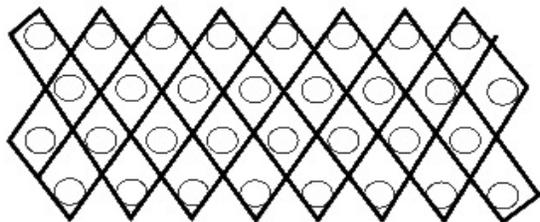


How Tailorable is the WTPS Architecture?

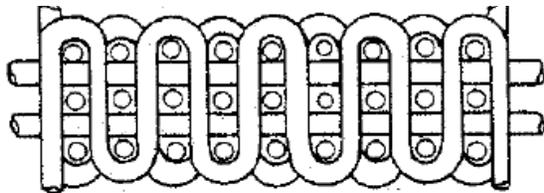
The Woven Substrate



Layer-to-Layer



Through the Thickness



3D orthogonal

The Yarn

Denier

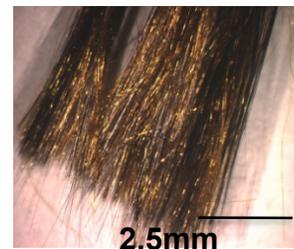
Continuous /Spun

Carbon

Polymer

Oxide (silica)

Blended



The Matrix

Full/Partial Infiltration

Phenolic

Cyanate Ester

Polyimide

New resins

No matrix

WTPS can optimize **all aspects of architecture**



Focus on WTPS Project Achievements

Advance 3D Woven TPS TRL from 2 to 3
Start date: 1/1/2012 End date: 2/28/2013

WTPS Project Overview: Vision, Scope and Tasks

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 (IR&D)
- 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. Demonstrate performance compared to heritage CP

Project Tasks:

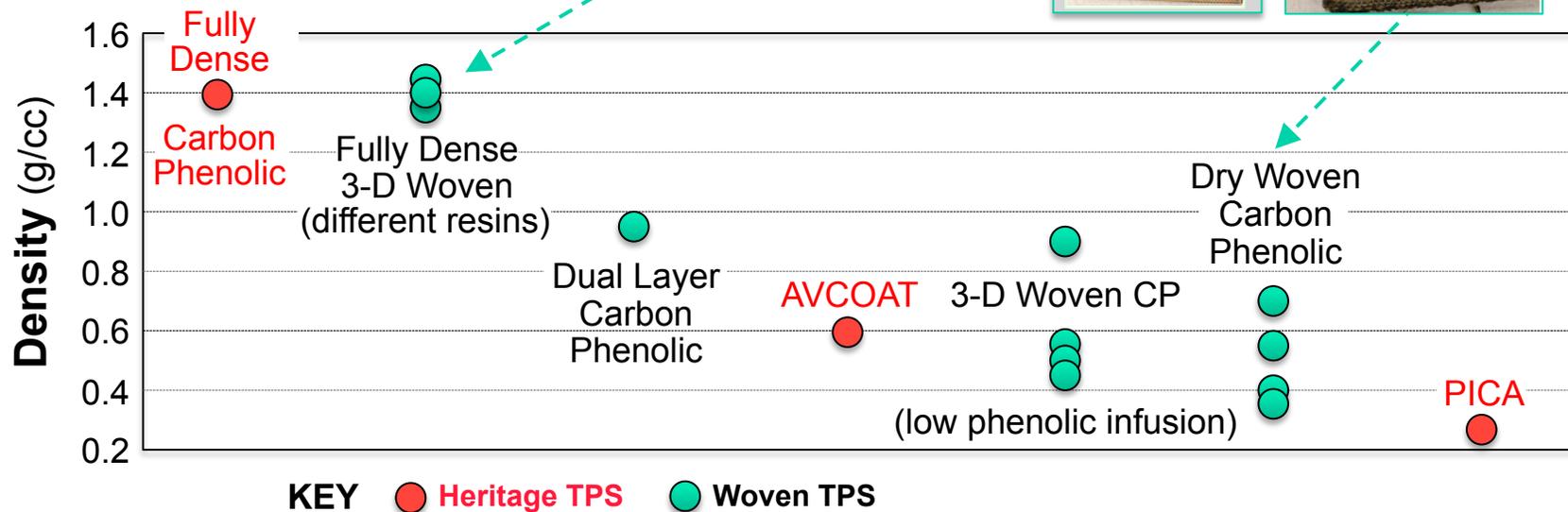
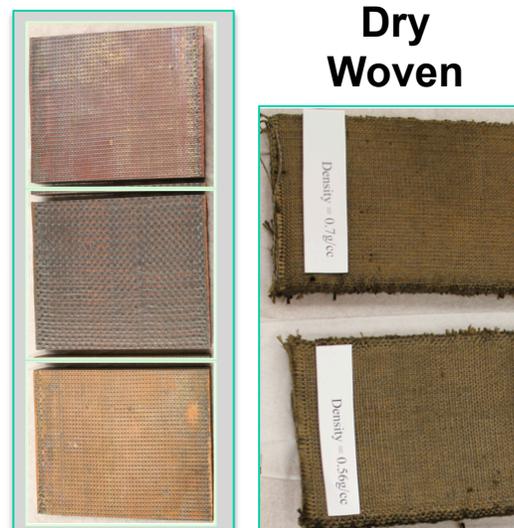
- **Manufacture a variety of WTPS materials**
 - Different yarn compositions, weave constructions, levels of resin infiltration, etc.
- **Obtain preliminary property database**
- **Perform arc jet tests on selected samples**
 - Explore and establish heat flux capability range
 - Compare thermal performance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



Range of WTPS Materials Manufactured

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

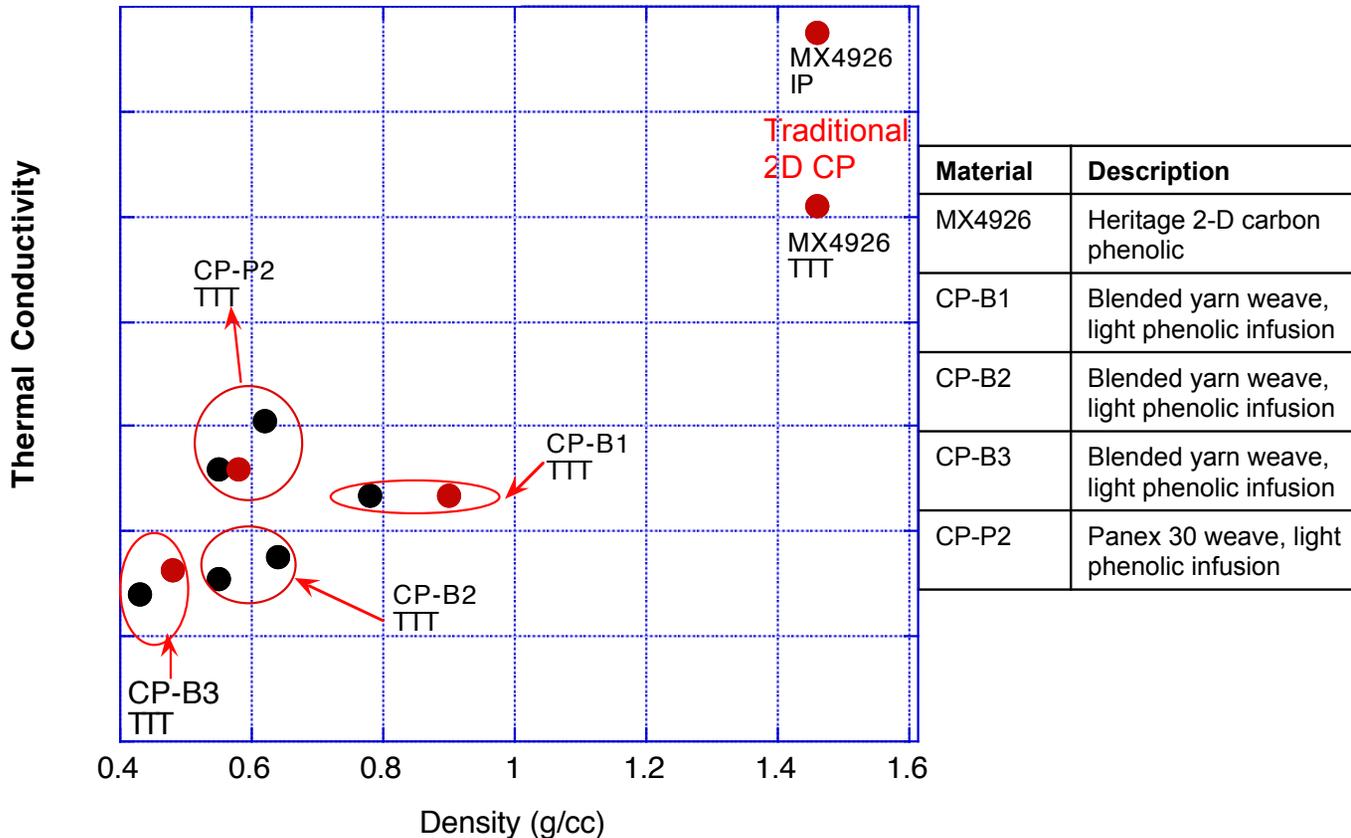
- Efficient ablator candidate for mid-density gap
- Potential replacement for highest density CP





Thermal Conductivity is Tailorable

Laser Flash technique
CRA technique

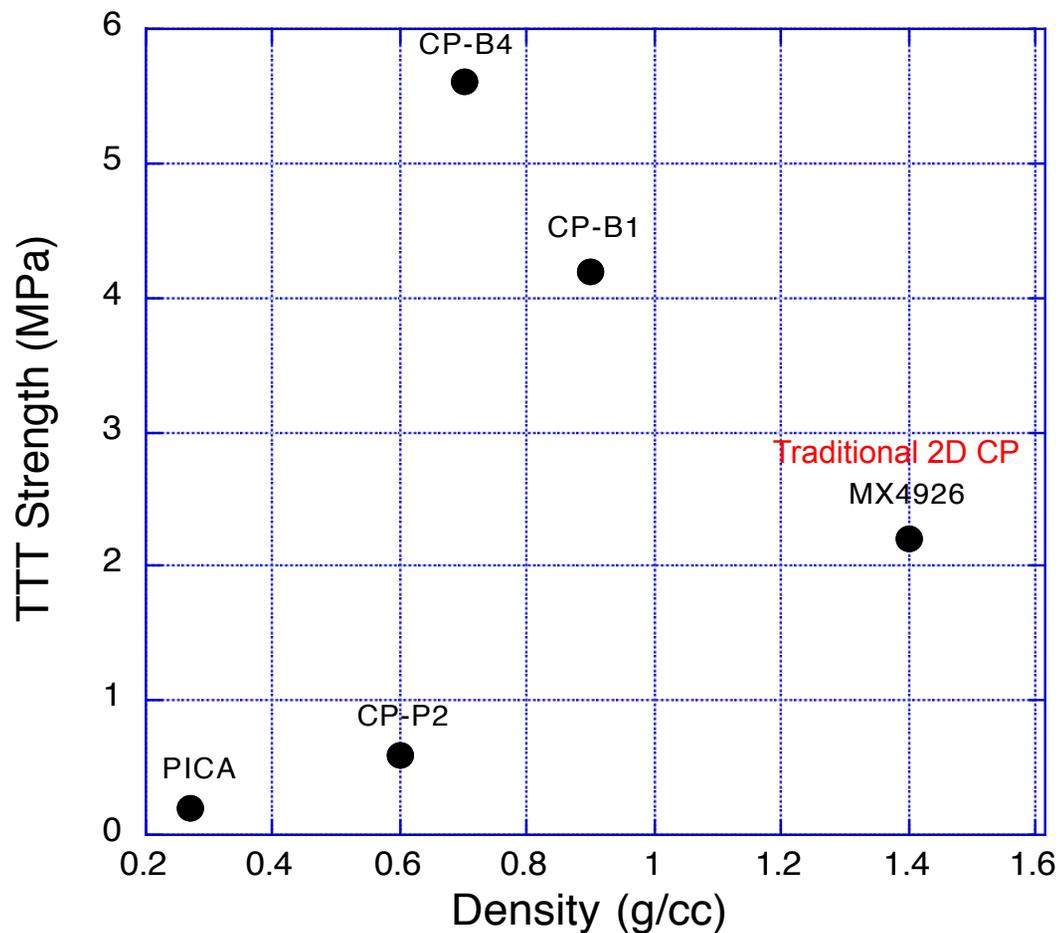


- *Thermal conductivity effectively controlled by weave architecture and yarn constituents*



TTT Mechanical Performance

- *Advantages of a layer-to-layer architecture in improving TTT strength observed*



- 2D CP (shingled or tape wrapped) exhibits ply separation in the AEDC wedge testing
- As a 3D material, Woven TPS is not prone this failure mode

**AEDC Wedge:
2D CP**



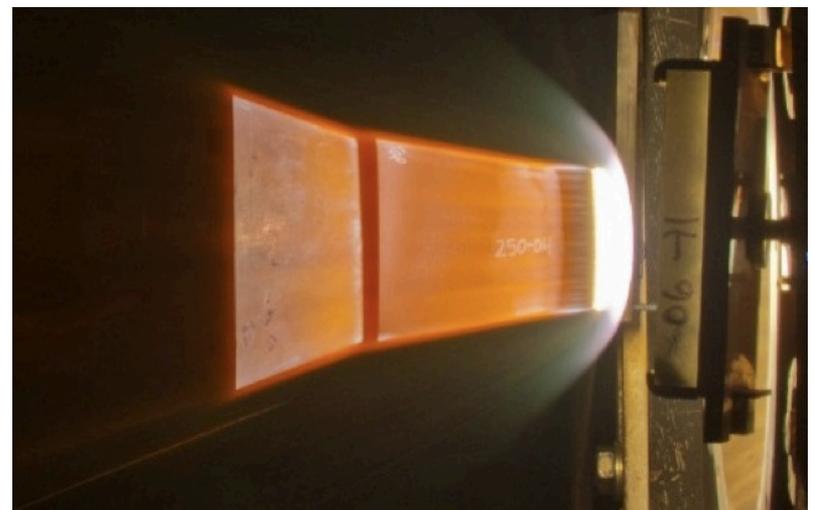
**mARC test: 0° shingle
angle 2D CP**





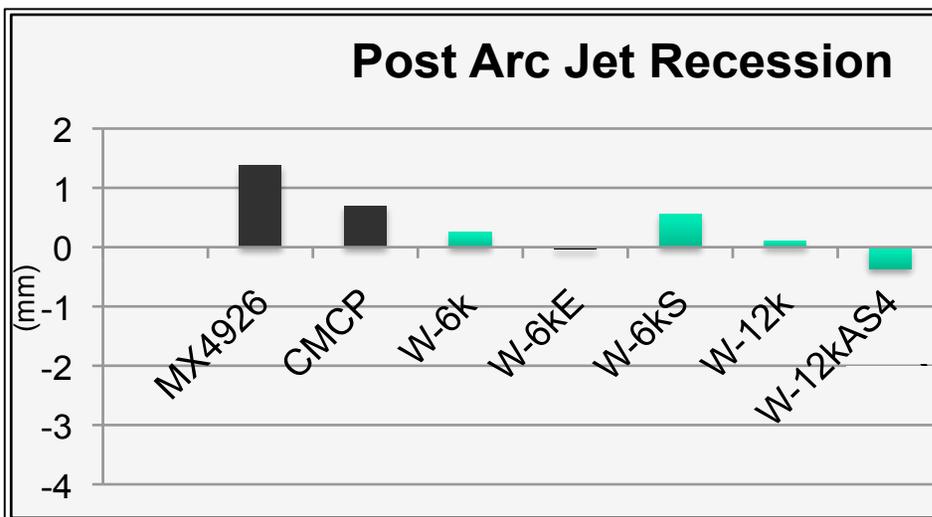
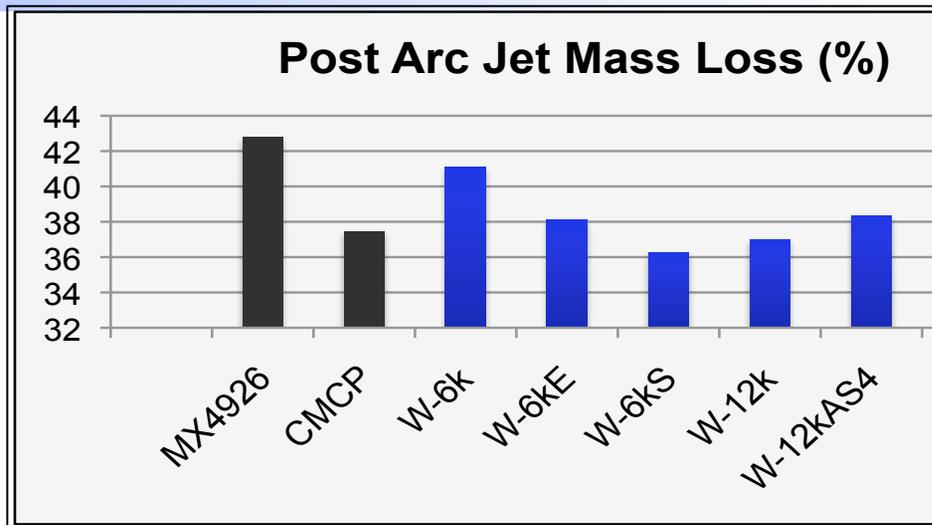
IHF Arc Jet testing Summary

- 1670 W/cm², 1.3 atm
- 2" dia. flat face model
- Duration
 - Fully dense: 20 s (11 models)
 - Low–Mid dense: 7 s (6 models)
- Backface TC or lightpipe
 - Model configuration not well-suited for temp. comparison (sidewall heating)





IHF Arc Jet testing: Fully-Dense WTPS



3-D Carbon Phenolic Variants

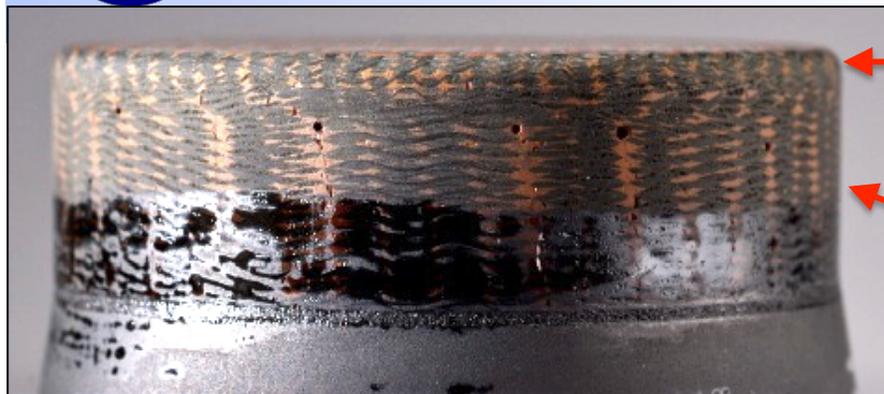
Lower recession & mass loss compared to 2DCP (MX4926)

- TWCP MX4926N (20° shingle) reference mtl
- CMCP from industry, funded by NASA

Significance: 3-D WTPS CP variants performed comparable (or better than) traditional 2-D CP



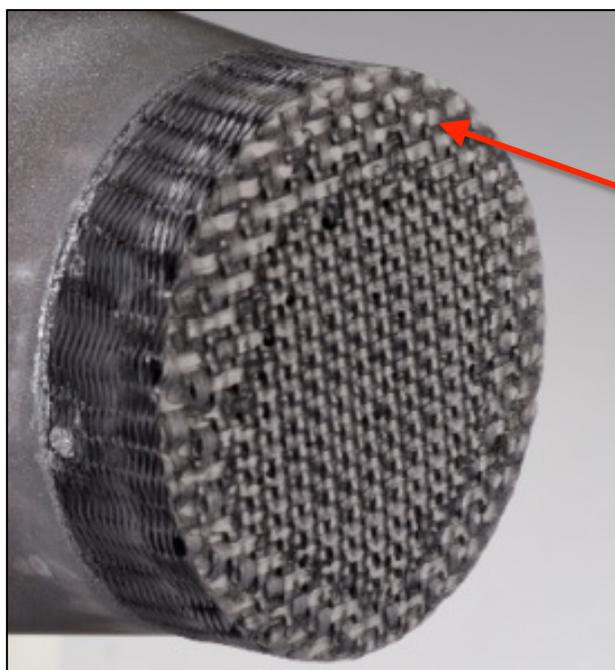
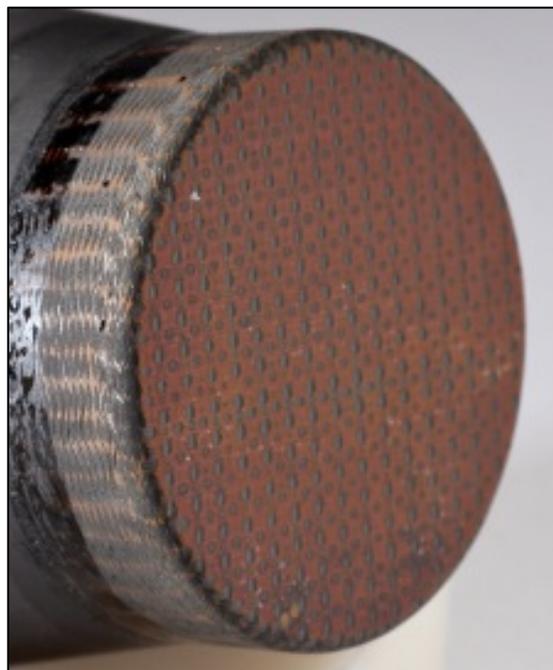
Fully Dense IHF Model



- Fine weave at top for surface-roughness control
- Coarse weave below ablation zone for efficient weaving cost & time

Pre-Test

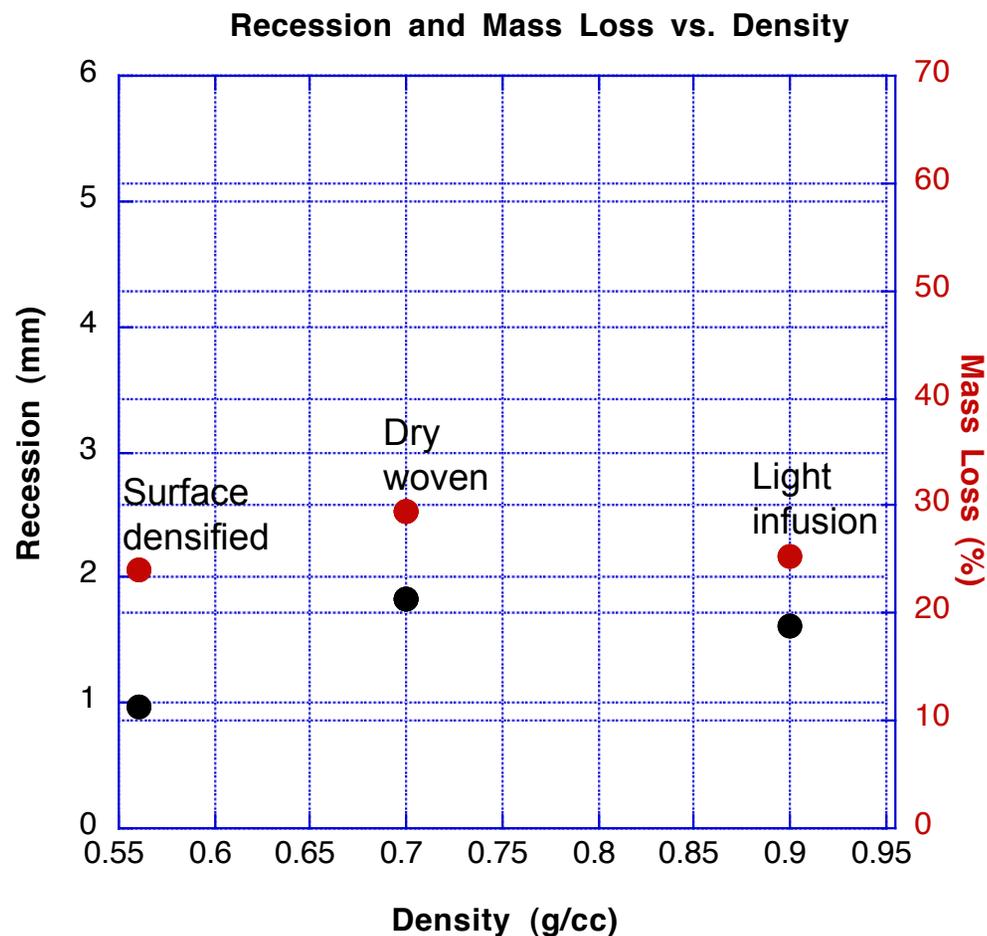
Post-Test



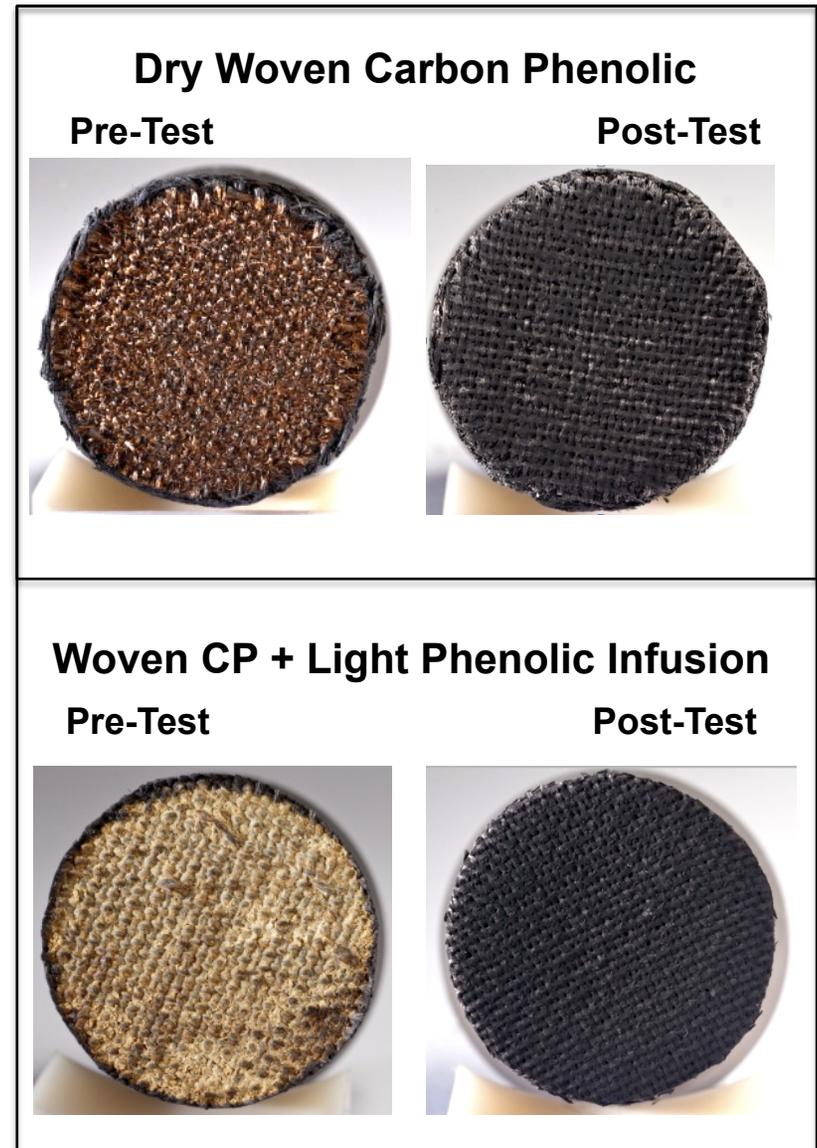
- Model edge condition was more severe
- Higher ablation exposed coarse weave at edges
- Layer to layer weave is robust - transition from coarse weave to fine weave did not result in unusual ablation



IHF Arc Jet testing: Surface Densified and Mid-Dense WTPS Variants



- Lowest recession was for surface-densified woven CP at 0.56 g/cm^3





AEDC Arc Jet Post Test Images of Select Samples

Traditional Carbon Phenolic



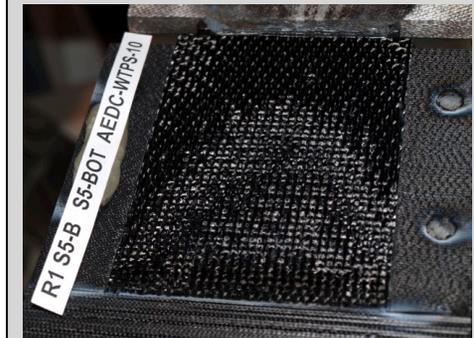
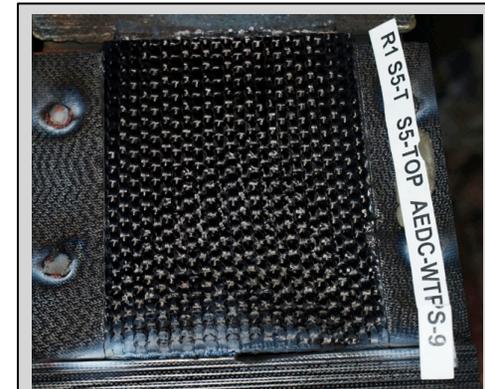
Tape Wrapped Carbon Phenolic



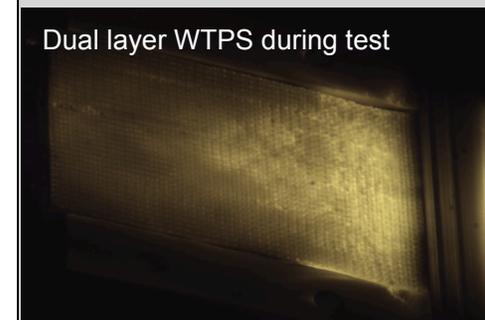
Chop Molded Carbon Phenolic

- 12 different Woven TPS types
- Chop molded and tape wrapped carbon phenolic tested
- Tested at DoD standard conditions used to evaluate traditional 2D CP materials at AEDC (turbulent with high shear)

Woven TPS



Dual layer WTPS during test



3-D Woven TPS

Significance: Feasibility of a dual layer WTPS concept



WTPS Summary

- Exciting new approach to TPS development
- Sustainable manufacturing approach
 - Leverage domestic 3D weaving industry
 - Key manufacturing processes are common (not NASA-unique)
 - High production-volume constituent fibers evaluated
- Successful demonstration of large variety of 3D woven materials
 - Flexible, dry woven TPS (carbon or carbon/phenolic yarns)
 - Low-loading resin infiltrated and surface densification
 - Full densification with various resin types
- High confidence that 3D Woven TPS will prove to be superior in performance and robustness, and help fill the TPS Gap
- A CP 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.



Acknowledgments – it takes a village!

Bally Ribbon Mills

NASA ARC:

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NASA Game Changing Development Program & Space Technology Program



Evolution of WTPS – FY'13 & Beyond

Jan, 2012

Woven TPS CIF

FY11,
Preliminary feasibility
studies weave design
and resin infiltration

Composite Yarn (Carbon+Phenolic)



Impregnated 3-D Woven CP



Post Arcjet Tested Coupons Resin Infiltrated



100 sec., ~600 W/cm²;
625 psf pressure (JSC
Arcjet Test in Dec'11)

Woven TPS GCT BAA

FY12,
Weave design
Resin Infusion
Material Property Testing
Arcjet Testing

HEEET Formulation

August, 2012

Heatshield for Extreme Entry Environment Technology (HEEET)

Development to enable Science Robotic and
Human missions

- Venus and outer planets
- Human return from beyond lunar

Integration on MPCV Compression Pad for FY17 Lunar Return Flight Test

June, 2012

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

Phase 1: 6 month,
Phase 2: 12 months,
Candidate material for MPCV
compression pad for beyond LEO missions.

