Woven TPS – Enabling Missions Beyond Heritage Carbon Phenolic

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Outline

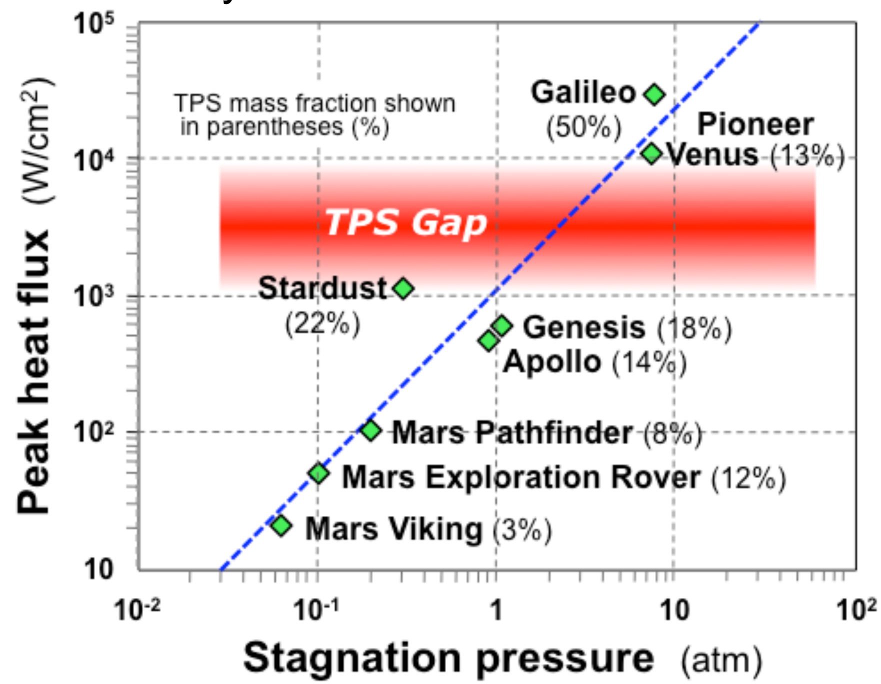
- Motivation
  - TPS from a Mission Constraint to a Mission Enabler
  - TPS Gap
- Woven TPS – The Concept
- Manufacturing and Testing
  - Thermal and Mechanical Performance
  - Arc-jet Testing
- Summary and Future Efforts

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



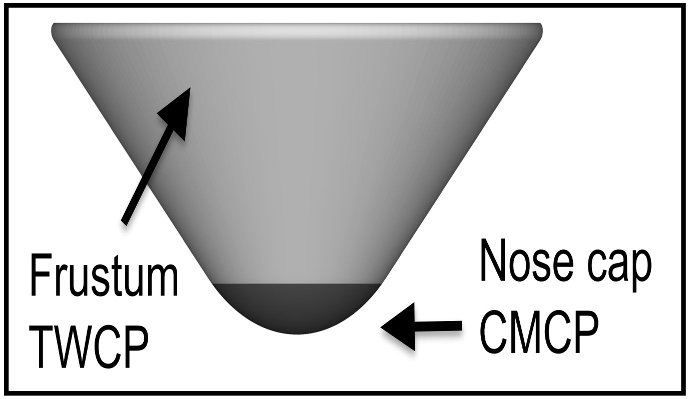
For typical Entry Systems Missions

at high heat fluxes (~ 7,000+ W/cm²), CP is an efficient TPS. Below ~ 2,000 W/cm², PICA and other ablators perform well.

There is no efficient TPS option in the gap!

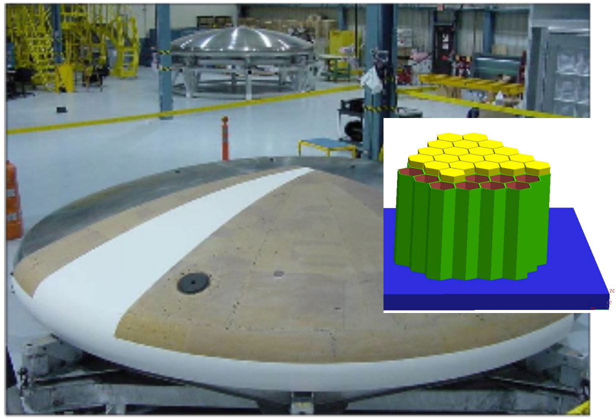
Challenges with State of the Art TPS

Tape-wrapped & chop-molded carbon phenolic

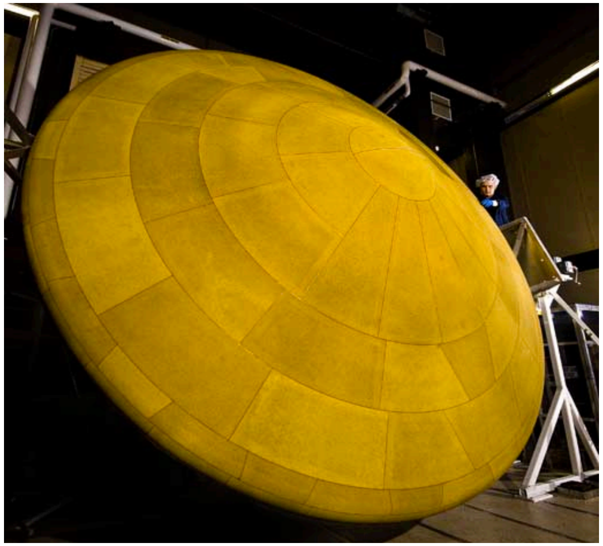


- Challenges for using traditional CP
  - Heritage CP used for entry no longer available (Avtex)
  - New CP material would need to be certified
  - Chop-molded CP has not be used for NASA application since 1980s

Sustainability and Life Cycle Costs

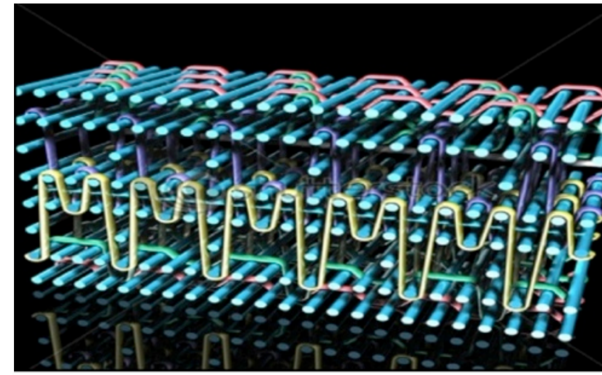


AVCOAT

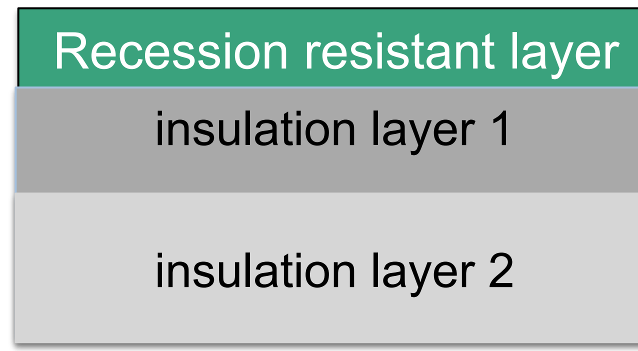


PICA MSL

Woven TPS Concept



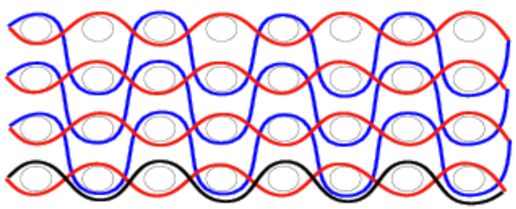
- **Automated 3D weaving technology is very flexible and customizable:** there are *MANY* variables that can be changed within a single preform
  - Fiber composition (e.g. carbon, polymer, glass)
  - Fiber denier (fineness)
  - Weave density (fiber volume fraction)
  - Weave type (e.g. layer-to-layer, orthogonal)



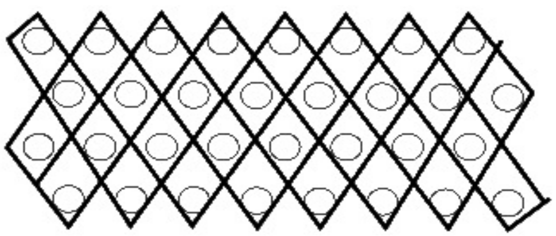
- Resin infusion can also be tailored
  - No resin (dry weave)
  - Partial infusion &/or surface densification
  - Full densification
- Manufacturing flexibility allows for the optimization of a material for a given mission
- WTPS leverages a ***sustainable*** weaving technology (not NASA-unique)

How Tailorable is the WTPS Architecture?

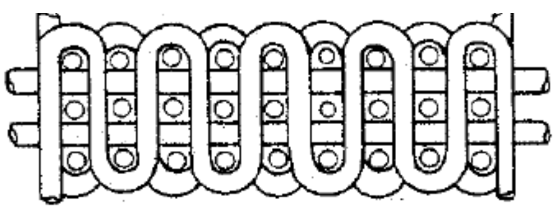
The Woven Substrate



Layer-to-Layer



Through the Thickness



3D orthogonal

The Yarn

Denier

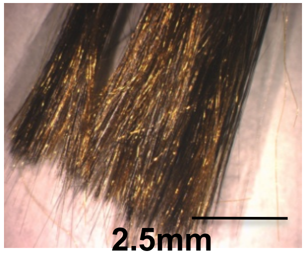
Continuous /Spun

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**

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**

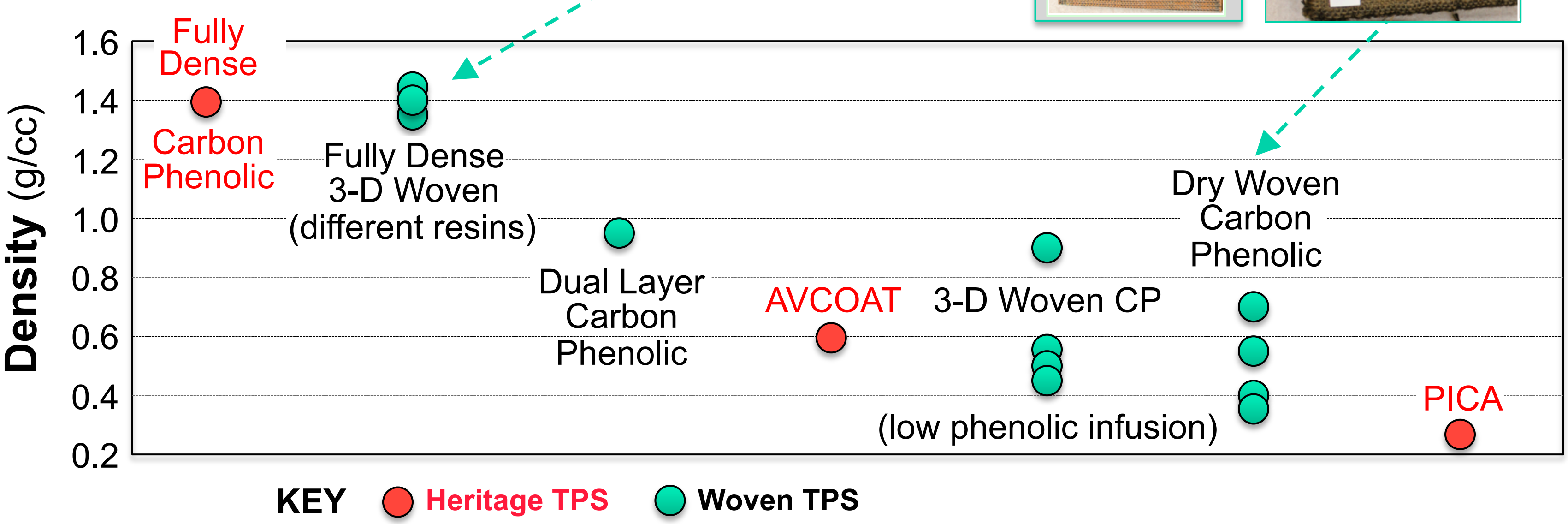
Range of WTPS Materials Manufactured

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

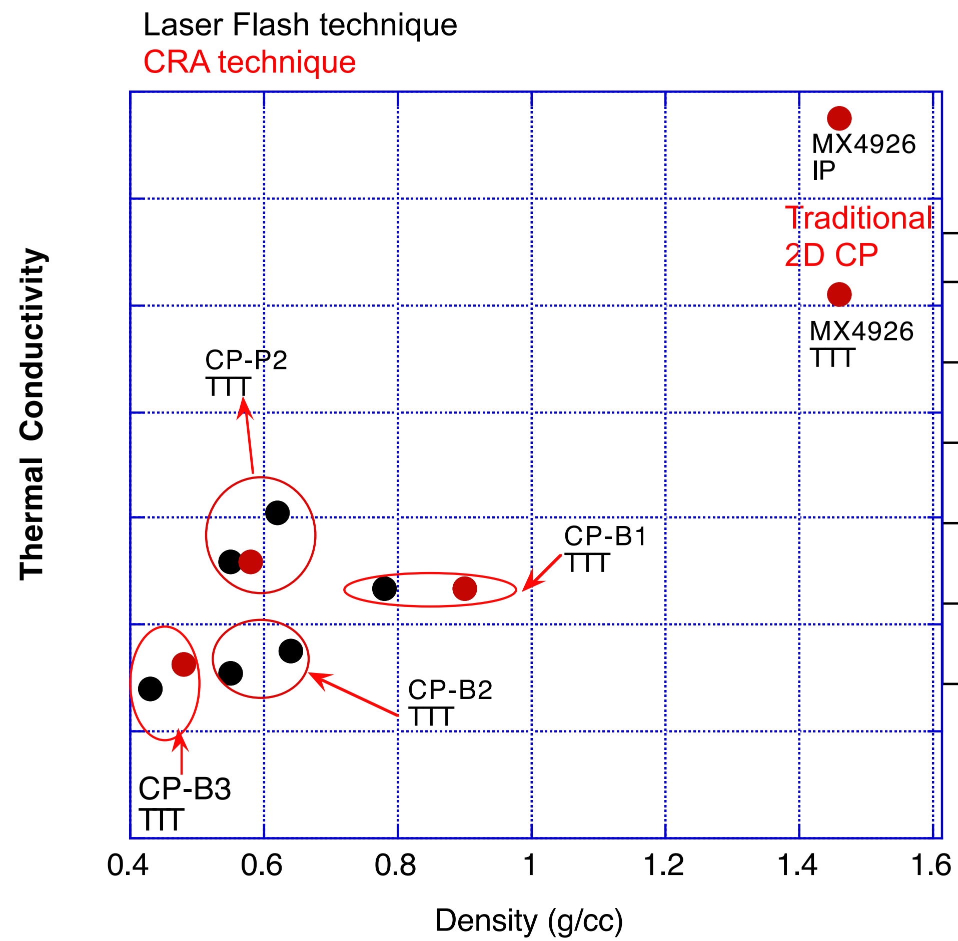
- Efficient ablator candidate for mid-density gap
- Potential replacement for highest density CP

Fully Dense 3-D Woven with different resins

Dry Woven



Thermal Conductivity is Tailorable

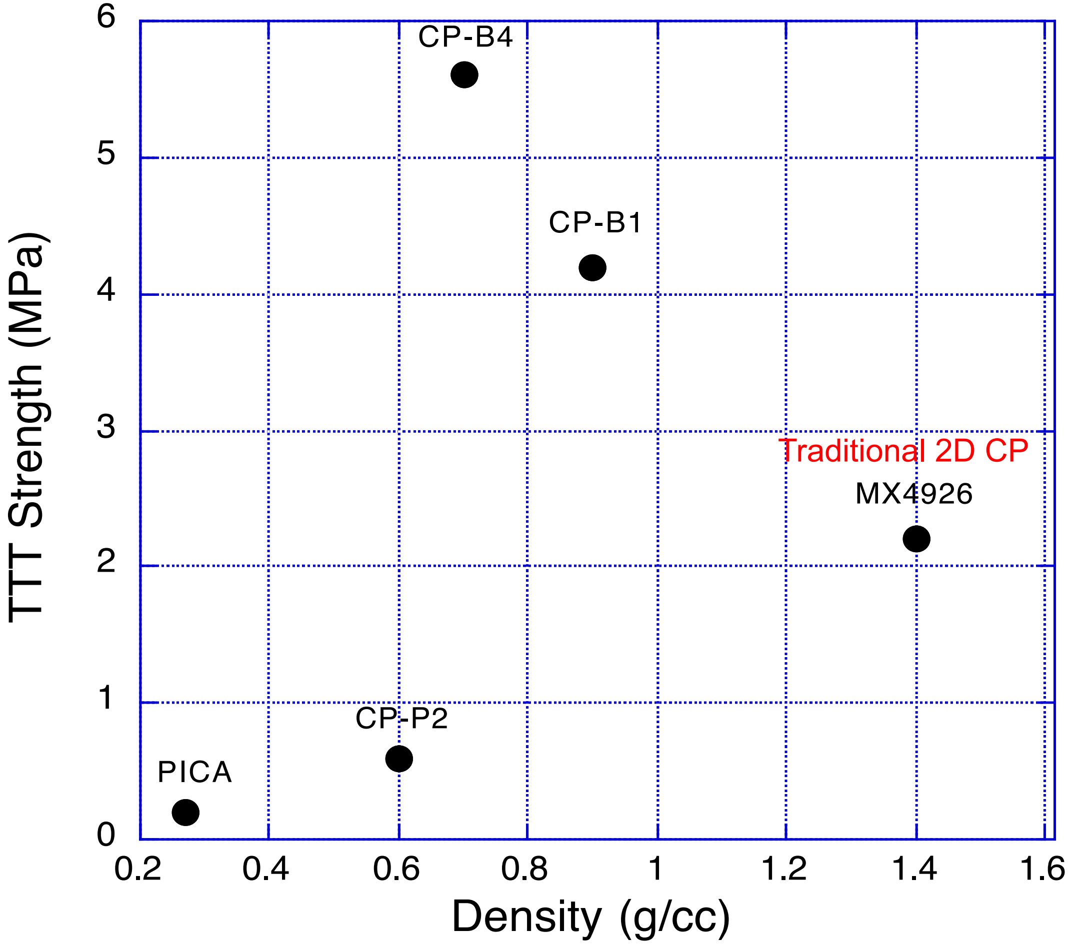


Material	Description
MX4926	Heritage 2-D carbon phenolic
CP-B1	Blended yarn weave, light phenolic infusion
CP-B2	Blended yarn weave, light phenolic infusion
CP-B3	Blended yarn weave, light phenolic infusion
CP-P2	Panex 30 weave, light phenolic infusion

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

TTT Mechanical Performance

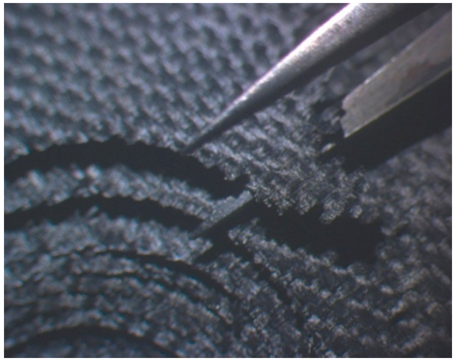
- *Advantages of a layer-to-layer architecture in improving TTT strength observed*



- 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

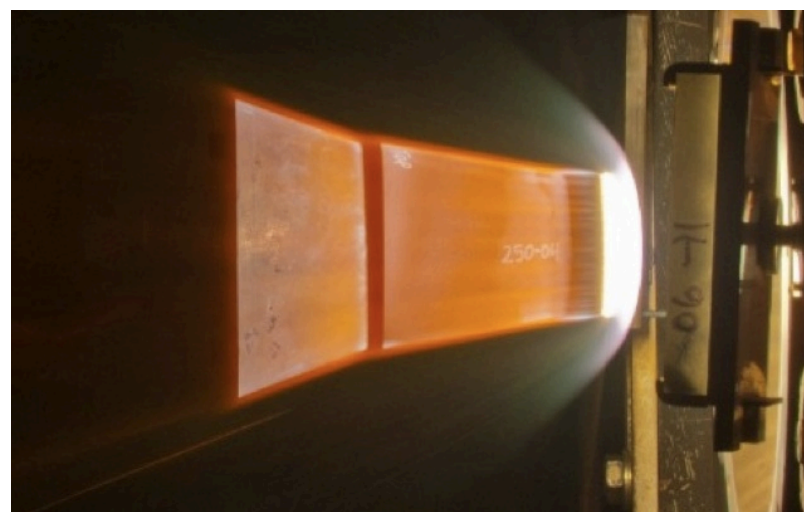
AEDC Wedge: 2D CP

mARC test: 0° shingle angle 2D CP

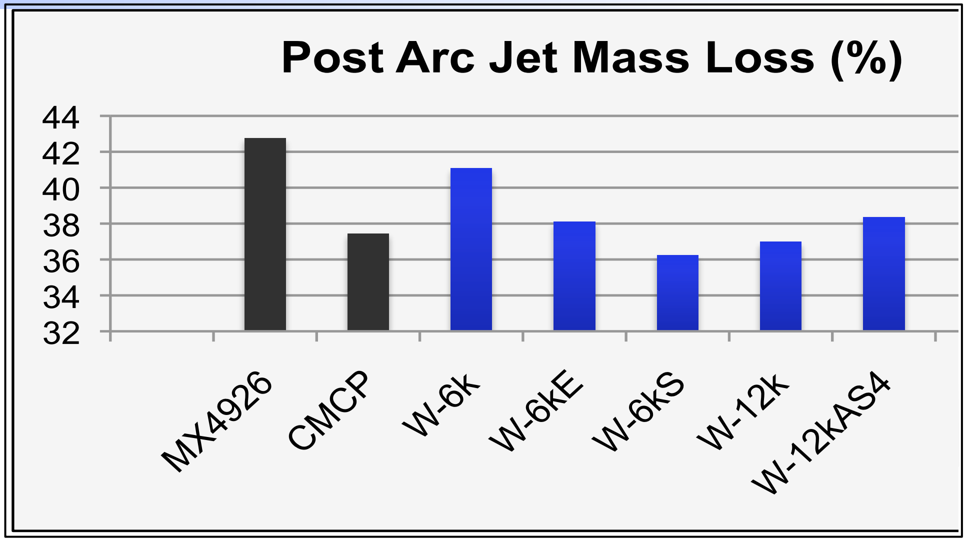


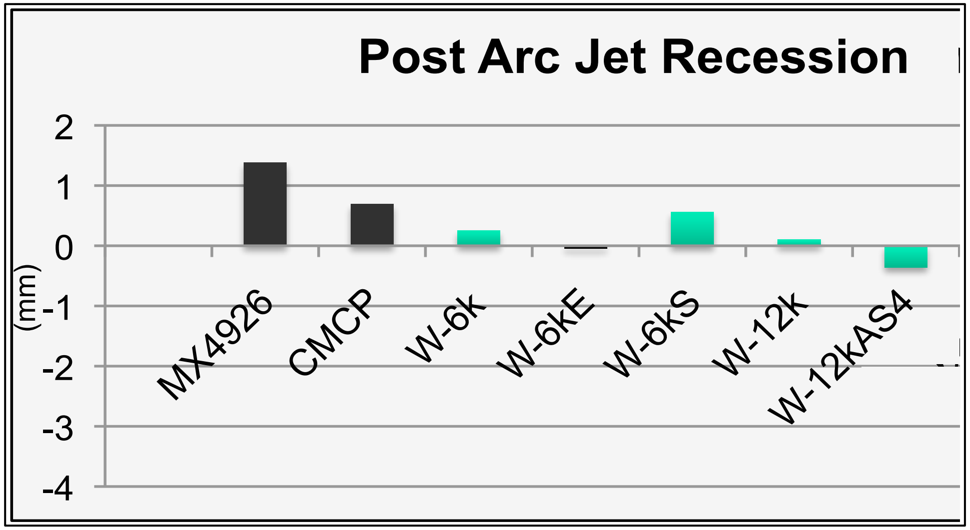
IHF Arc Jet testing Summary

- 1670 W/cm^2, 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





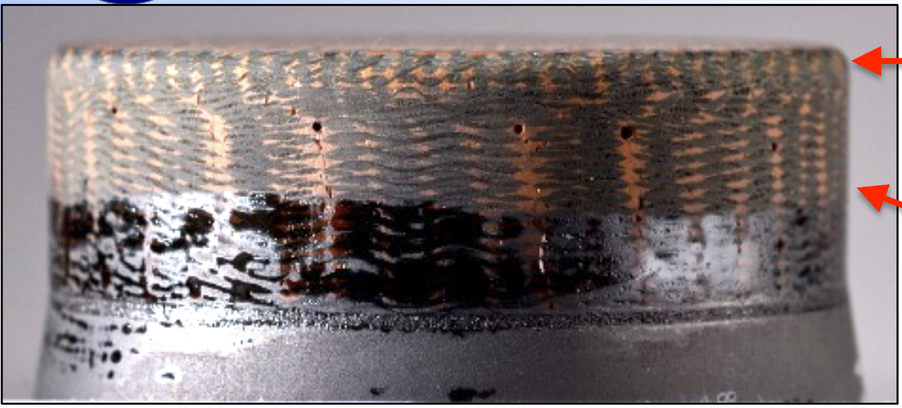
3-D Carbon Phenolic Variants

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

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

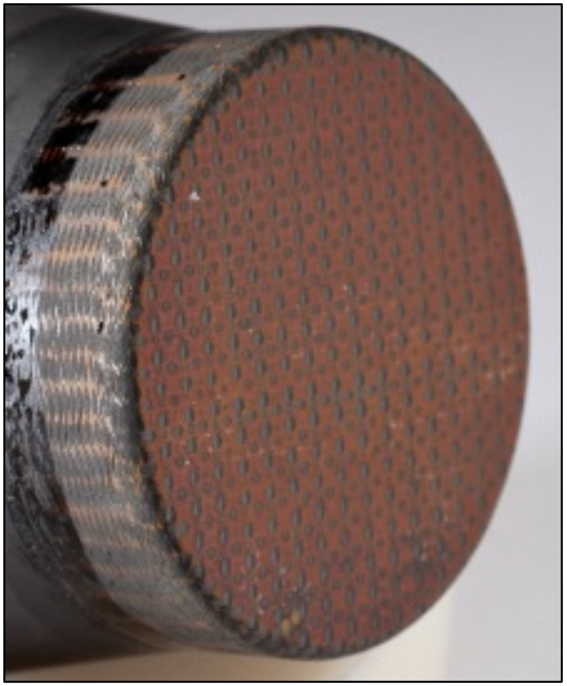
Significance: 3-D WTPS CP variants performed comparable (or better than) traditional 2-D CP

Fully Dense IHF Model

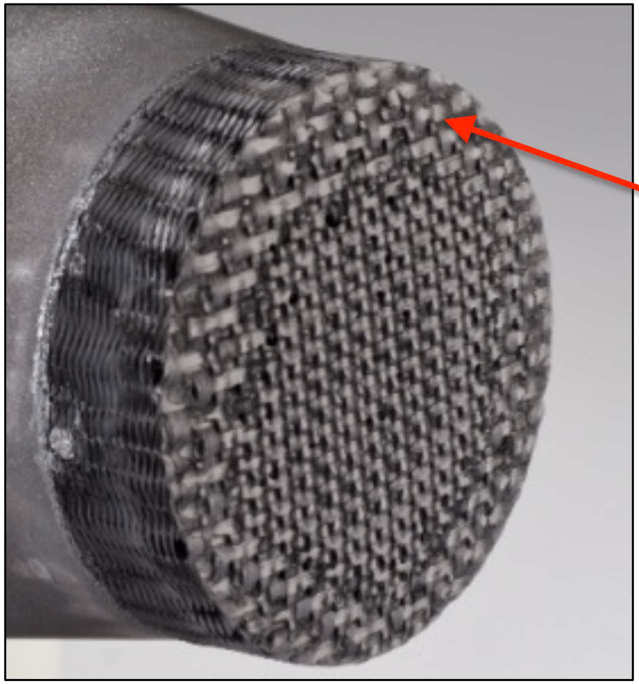


- Fine weave at top for surface-roughness control
- Coarse weave below ablation zone for efficient weaving cost & time

Pre-Test

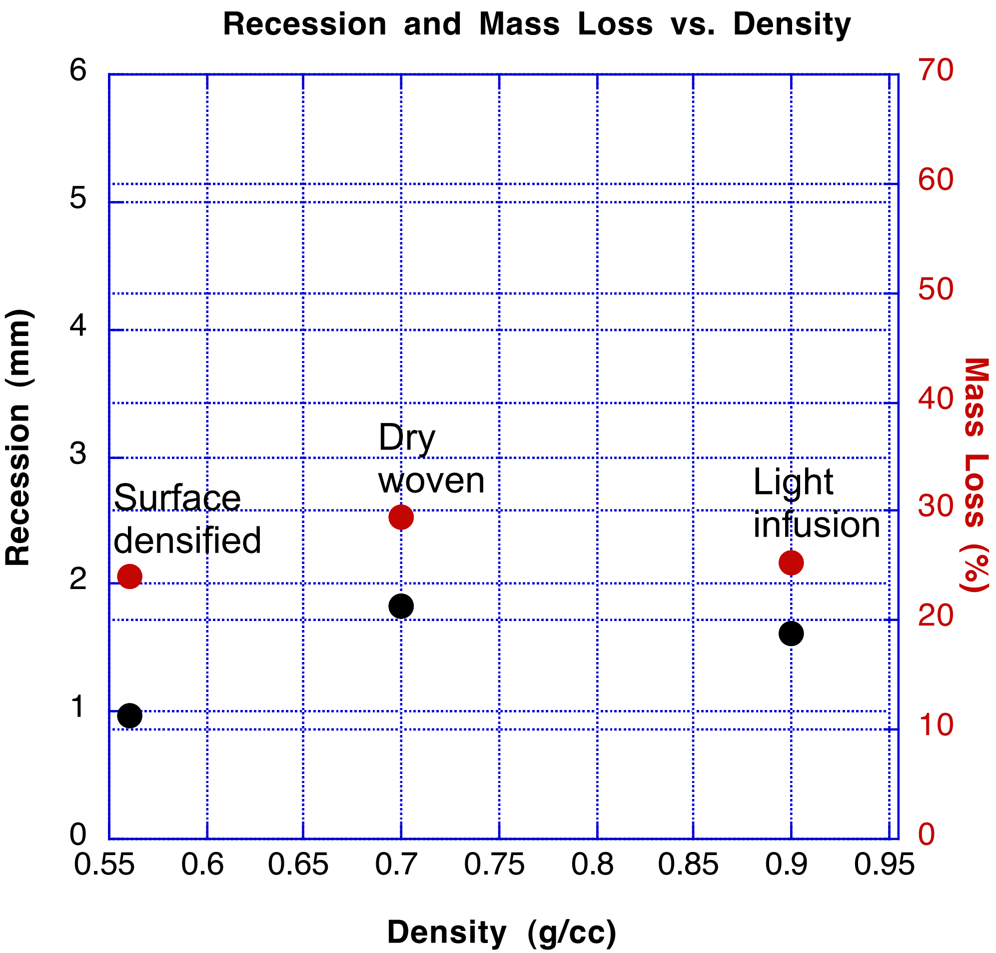


Post-Test

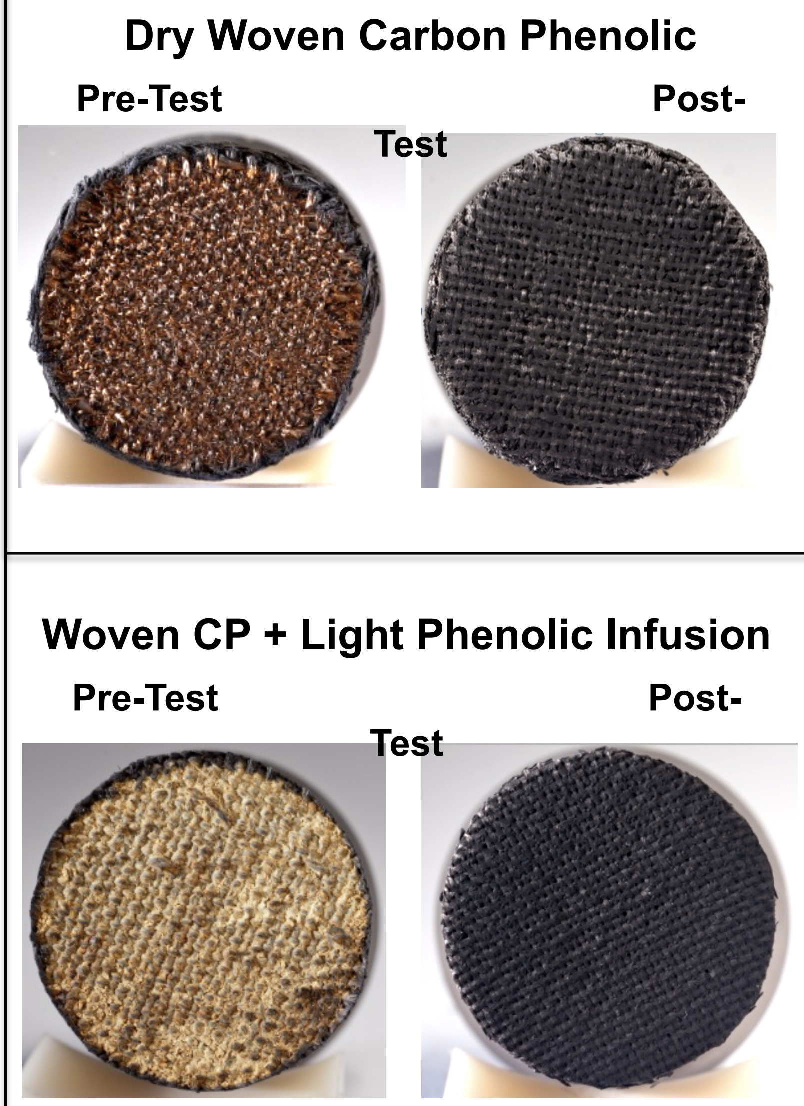


- Model edge condition was more severe
- Higher ablation exposed coarse weave at edges
- Layer to layer weave is robust - transition from coarse weave to fine weave did not result in unusual ablation

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

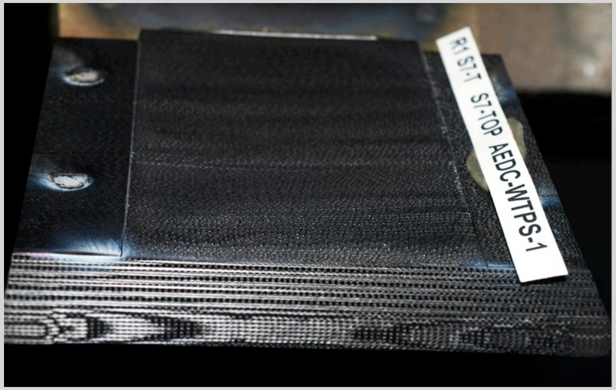


- Lowest recession was for surface-densified woven CP at 0.56 g/cm^3



AEDC Arc Jet Post Test Images of Select Samples

Traditional Carbon Phenolic

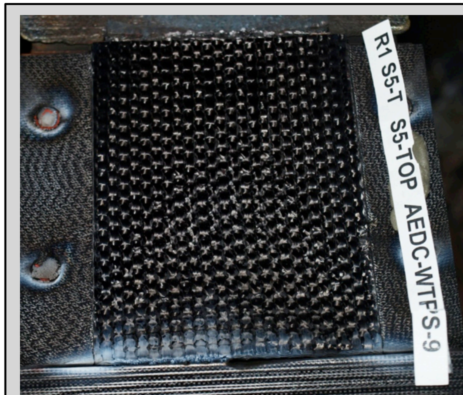


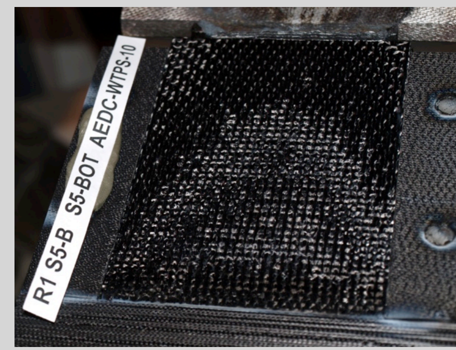
Tape Wrapped Carbon Phenolic

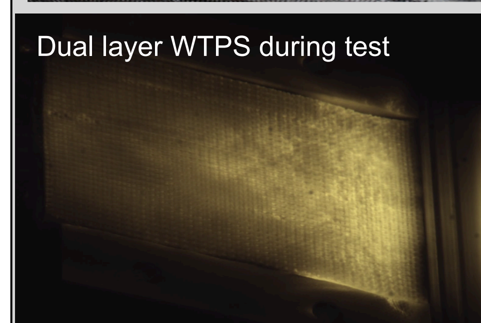
Chop Molded Carbon Phenolic

- 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







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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AEDC:

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NASA Game Changing Development Program & Space Technology Program

Evolution of WTPS – FY'13 & Beyond

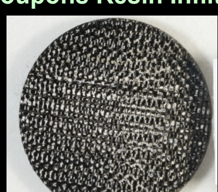
Jan, 2012

Woven TPS CIF
FY11, $84K
Preliminary feasibility studies weave design and resin infiltration

Composite Yarn (Carbon+Phenolic)

Impregnated 3-D Woven CP

Post Arcjet Tested Coupons Resin Infiltrated

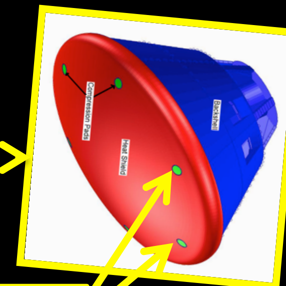


100 sec., ~600 W/cm^2; 625 psf pressure (JSC Arcjet Test in Dec'11)

Woven TPS GCT BAA
FY12, $1,125K
Weave design
Resin Infusion
Material Property Testing
Arcjet Testing

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, $450K (FY12-13)
Phase 2: 12 months, $1,500K (FY13-14)
Candidate material for MPCV compression pad for beyond LEO missions.

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