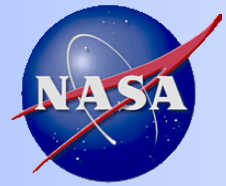


# **Woven TPS – Enabling Missions Beyond Heritage Carbon Phenolic**

**Mairead Stackpoole and Ethiraj Venkatapathy  
NASA Ames Research Center**

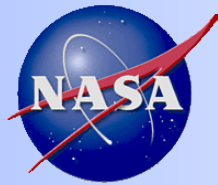
**Jay Feldman  
ERC Inc. at NASA Ames Research Center**

**NSMMS, June 24-27, 2013, Bellevue, Washington**



# 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



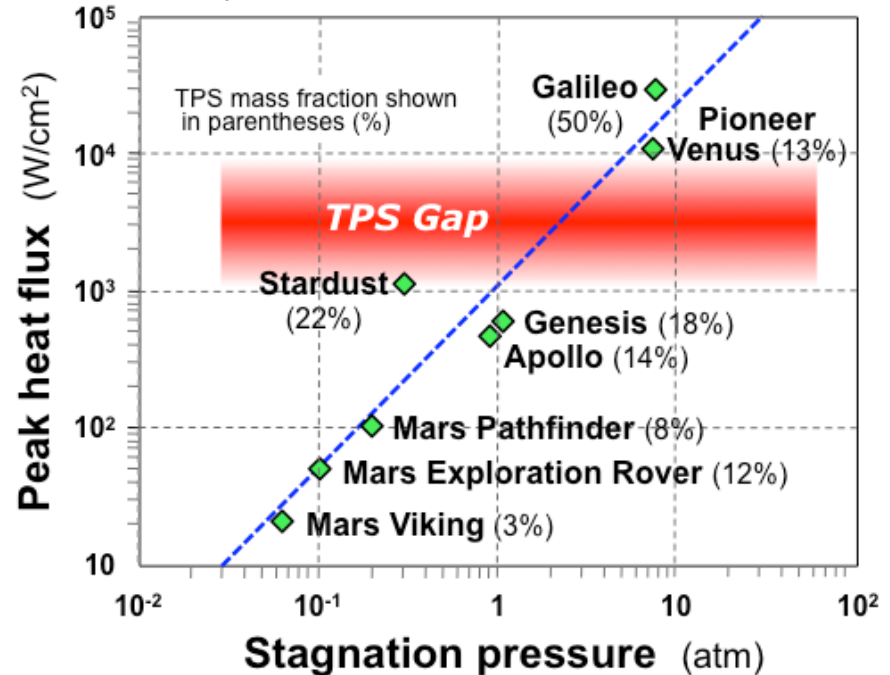
# TPS Challenges for Venus, Saturn, Neptune, Uranus, Jupiter and High Speed Sample Return Missions

- **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

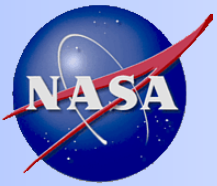
### Historical TPS Mass Fraction by Heat Flux and Pressure



### For typical Entry Systems Missions

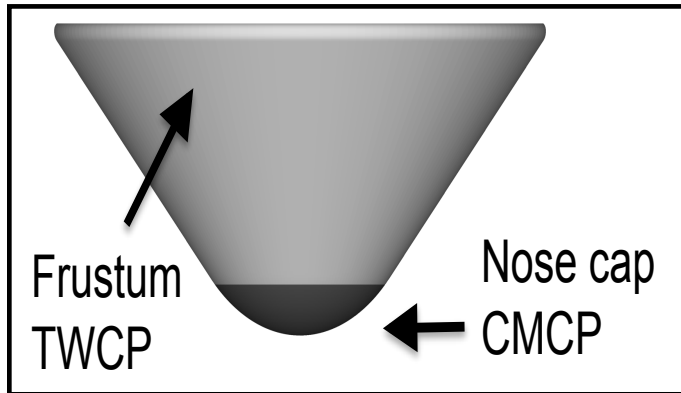
at high heat fluxes ( $\sim 7,000+$  W/cm<sup>2</sup>), CP is an efficient TPS. Below  $\sim 2,000$  W/cm<sup>2</sup>, PICA and other ablators perform well.

**There is no efficient TPS option in the gap!**



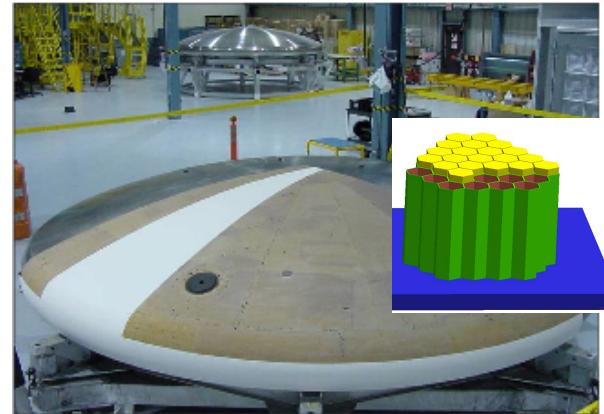
# Challenges with State of the Art TPS

## Tape-wrapped & chop-molded carbon phenolic

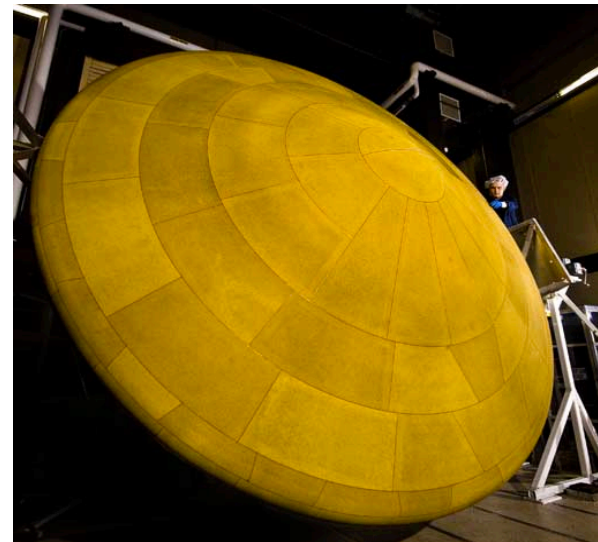


- Challenges for using traditional CP
  - Heritage CP used for entry no longer available (Avtex)
  - New CP material would need to be certified
  - Chop-molded CP has not be used for NASA application since 1980s

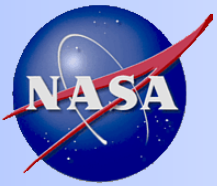
## Sustainability and Life Cycle Costs



AVCOAT

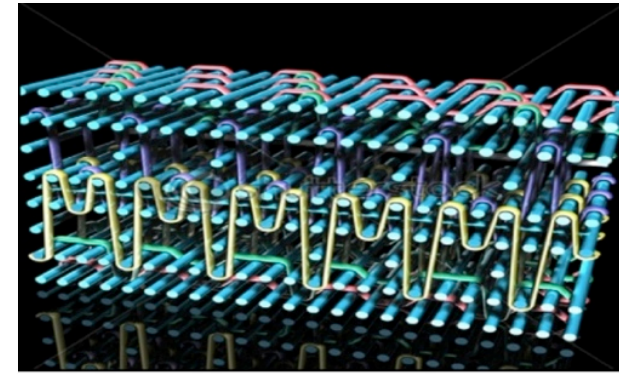


PICA MSL



# Woven TPS Concept

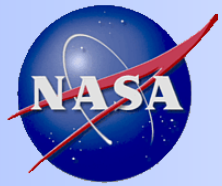
- **Automated 3D weaving technology is very flexible and customizable:** there are *MANY* variables that can be changed within a single preform
  - Fiber composition (e.g. carbon, polymer, glass)
  - Fiber denier (fineness)
  - Weave density (fiber volume fraction)
  - Weave type (e.g. layer-to-layer,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

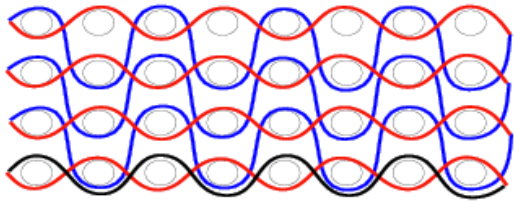
insulation layer 1

insulation layer 2

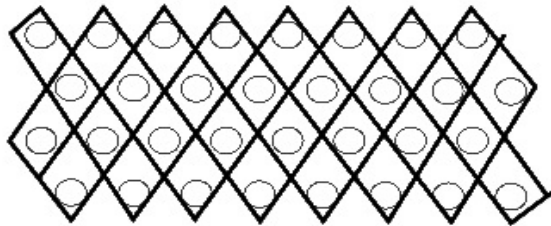


# How Tailorable is the WTPS Architecture?

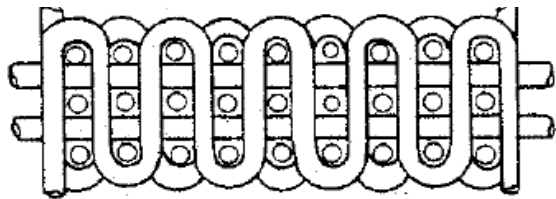
## The Woven Substrate



Layer-to-Layer



Through the Thickness



3D orthogonal

## The Yarn

Denier

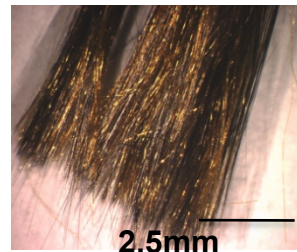
Continuous /Spun

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:

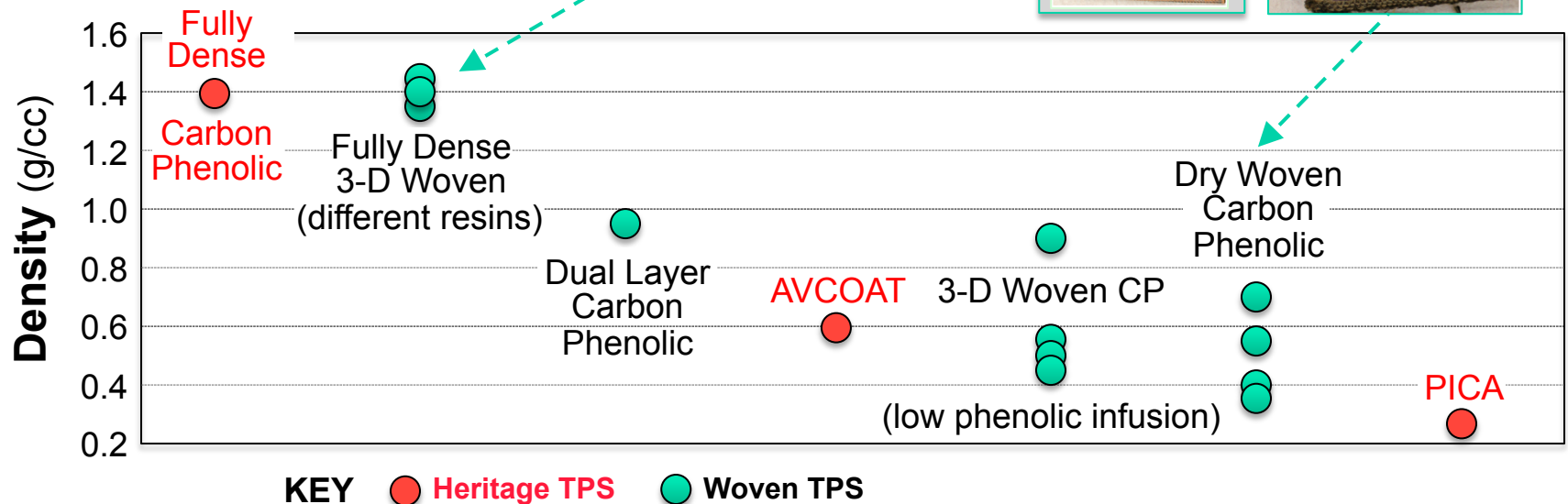
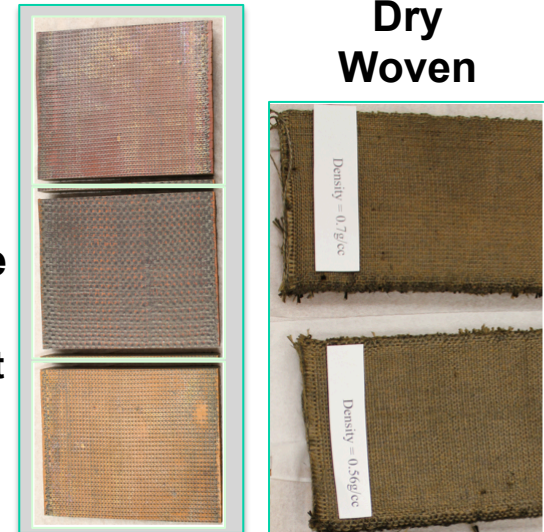
- **Manufacture a variety of WTPS materials**
  - Different yarn compositions, weave constructions, levels of resin infiltration, etc.
- **Obtain preliminary property database**
- **Perform arc jet tests on selected samples**
  - Explore and establish heat flux capability range
  - Compare thermal performance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



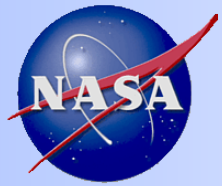
# Range of WTPS Materials Manufactured

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

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

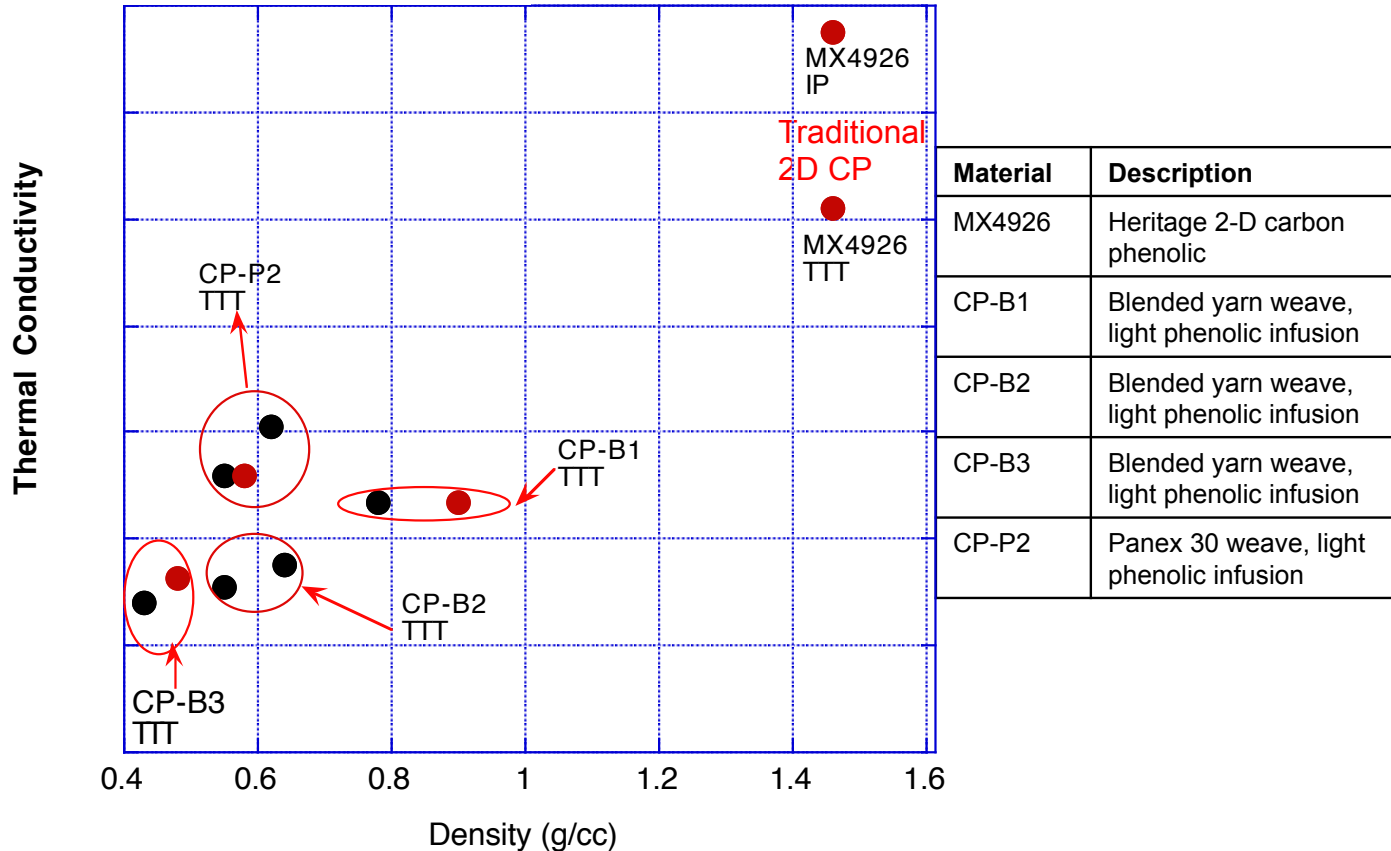




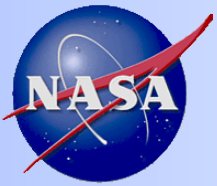


# Thermal Conductivity is Tailorable

Laser Flash technique  
CRA technique

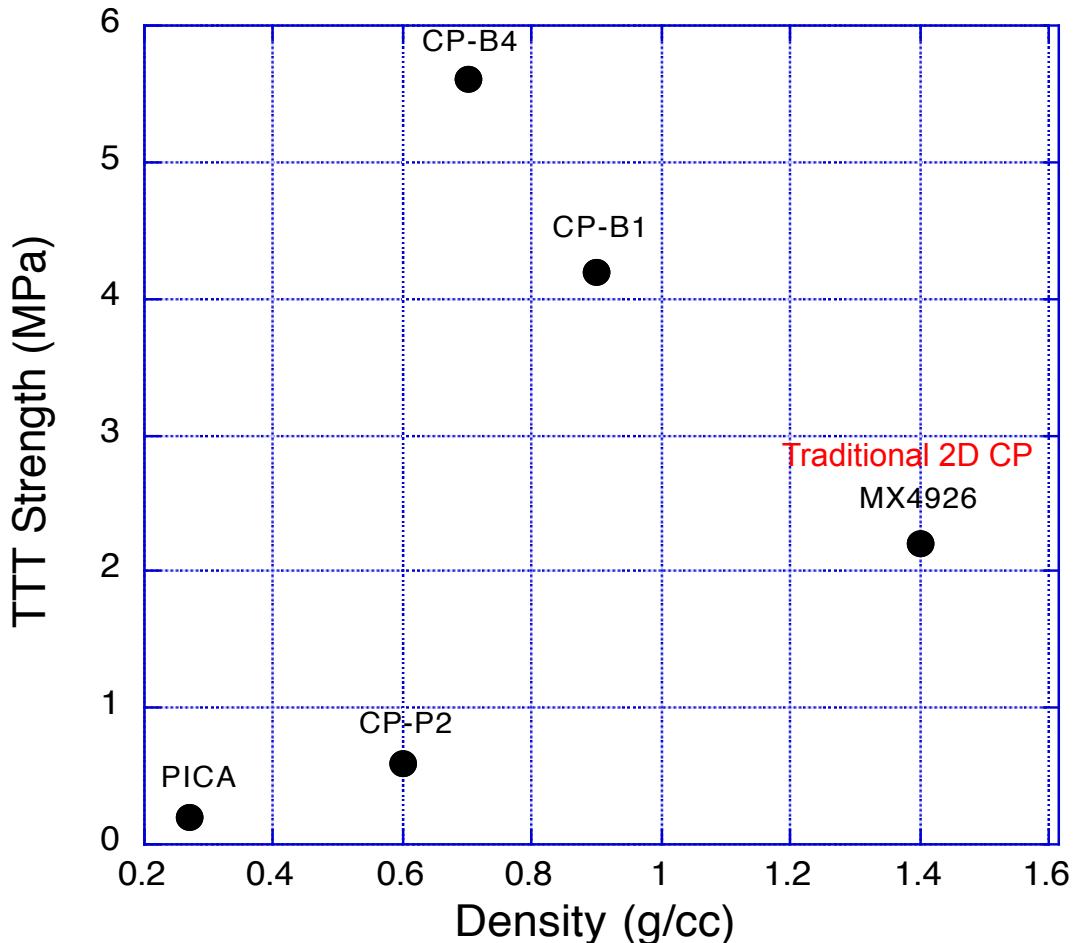


- *Thermal conductivity effectively controlled by weave architecture and yarn constituents*



# TTT Mechanical Performance

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



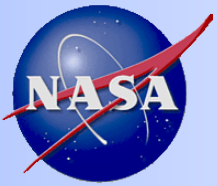
- 2D CP (shingled or tape wrapped) exhibits ply separation in the AEDC wedge testing
- As a 3D material, Woven TPS is not prone this failure mode

AEDC Wedge:  
2D CP



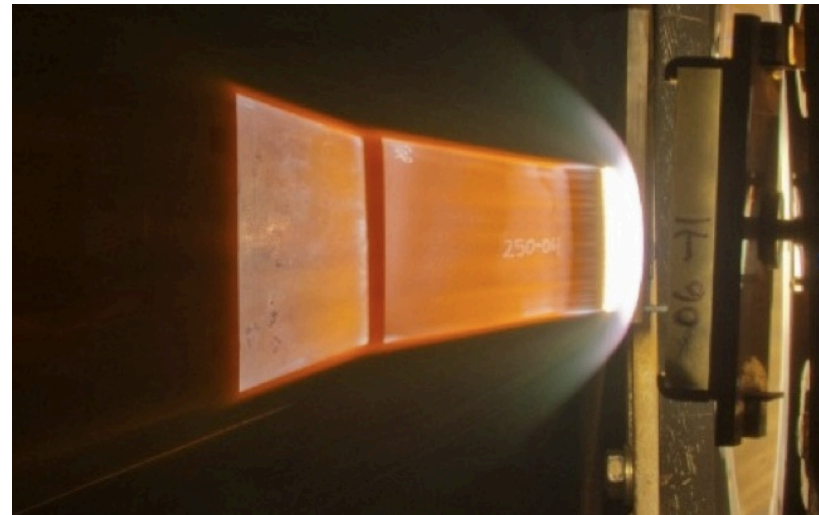
mARC test: 0° shingle  
angle 2D CP





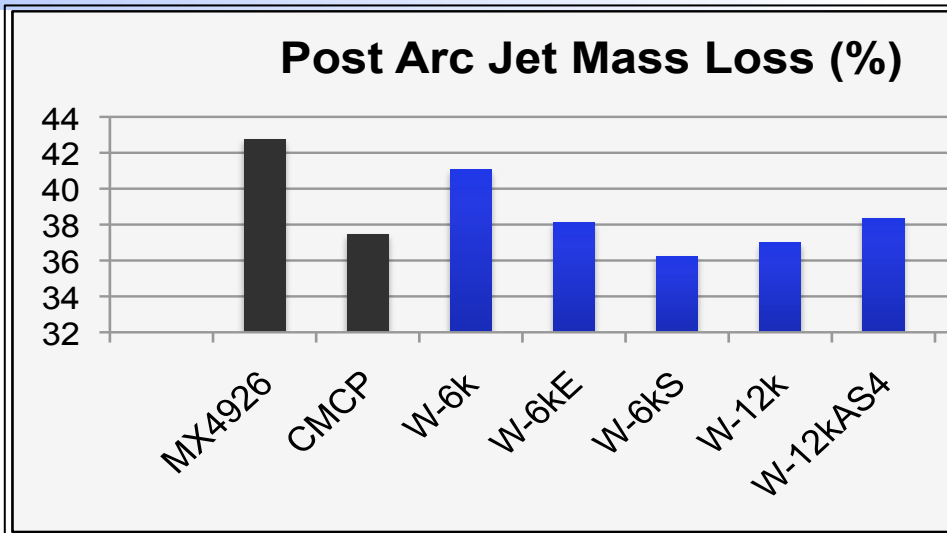
# IHF Arc Jet testing Summary

- 1670 W/cm<sup>2</sup>, 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)





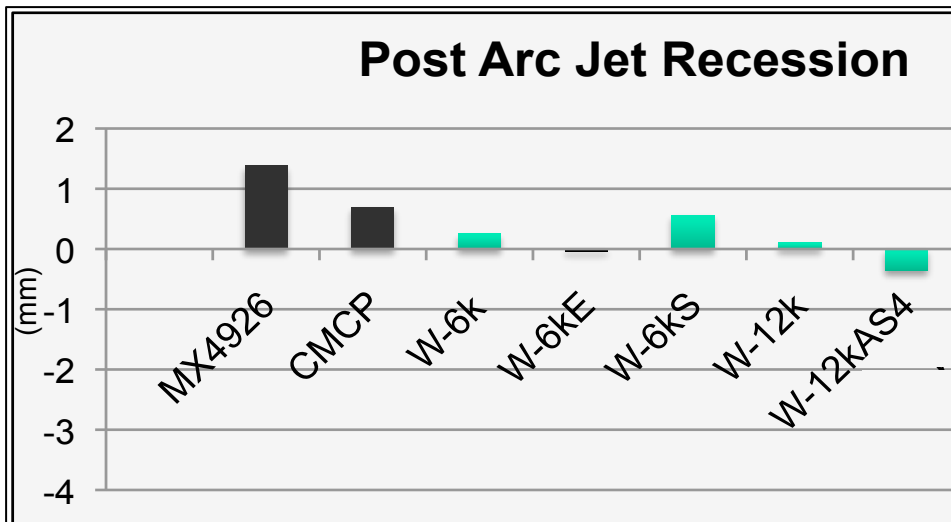
# IHF Arc Jet testing: Fully-Dense WTPS



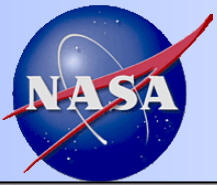
## 3-D Carbon Phenolic Variants

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

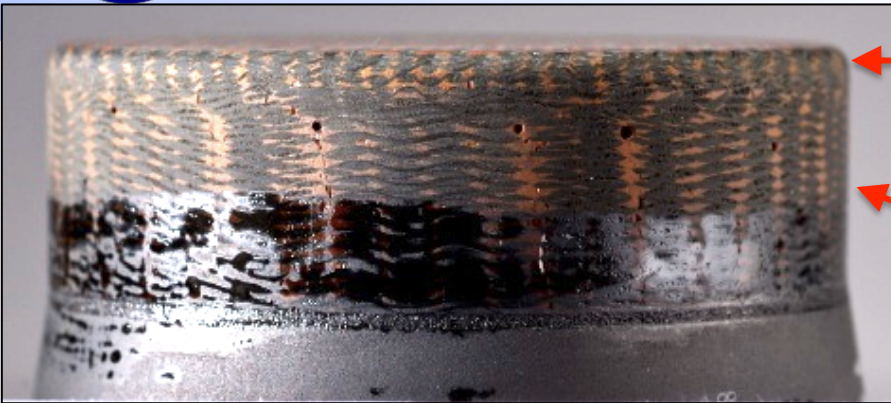
- TWCP MX4926N (20° shingle) reference mtl
- CMCP from industry, funded by NASA



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

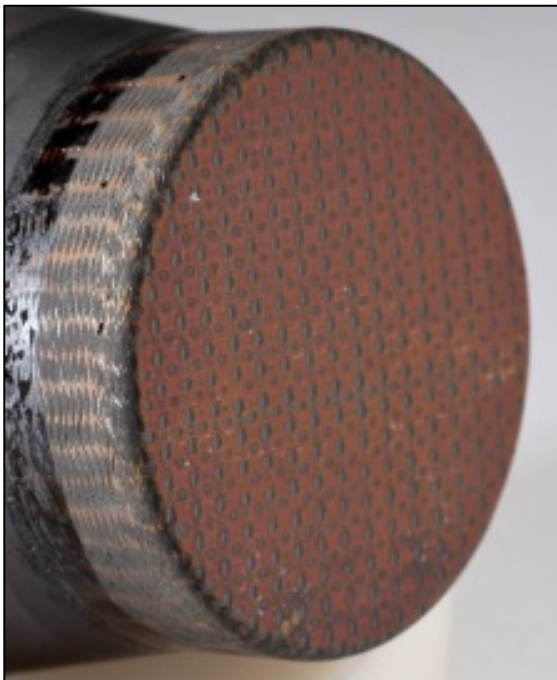


# Fully Dense IHF Model

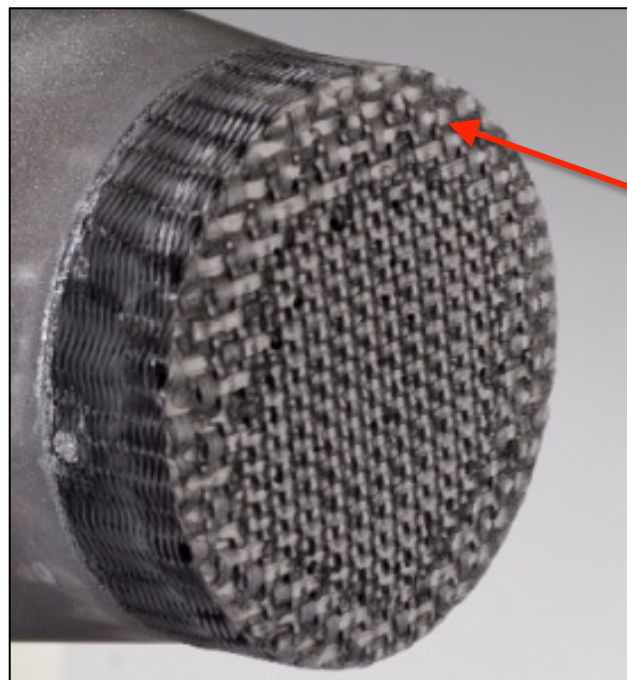


- Fine weave at top for surface-roughness control
- Coarse weave below ablation zone for efficient weaving cost & time

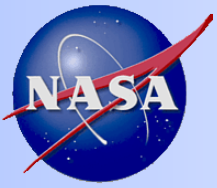
**Pre-Test**



**Post-Test**

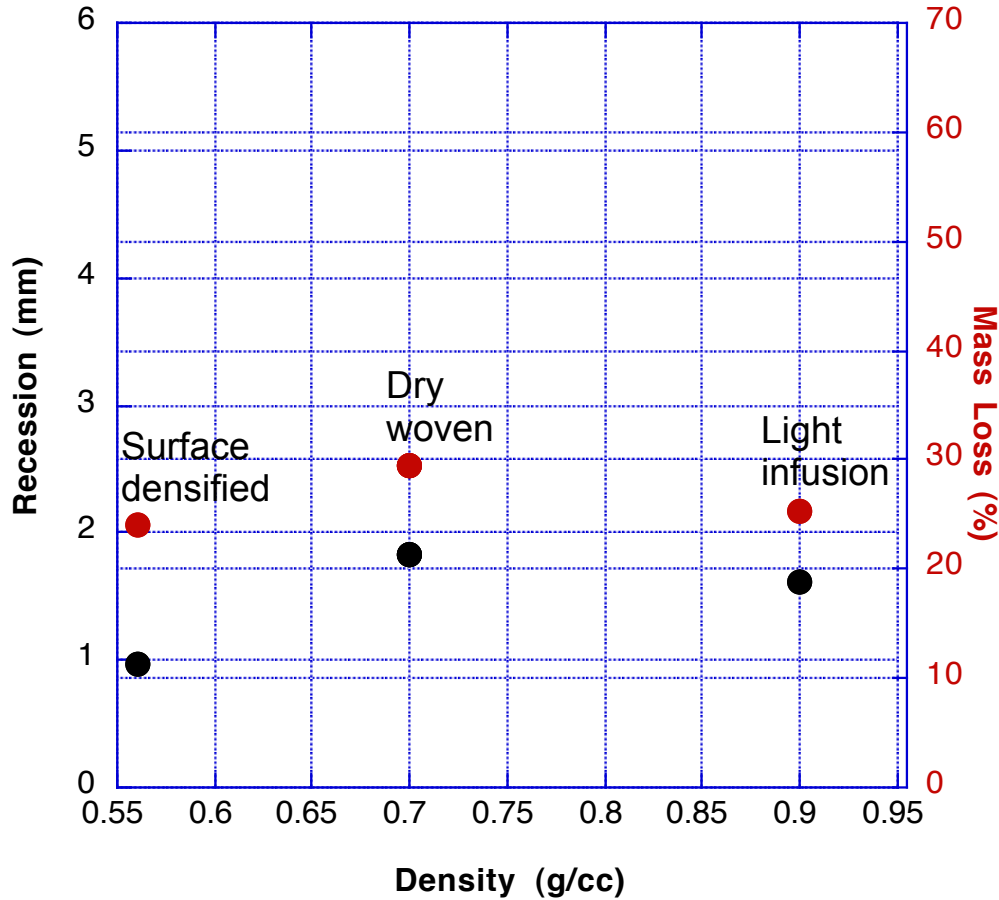


- Model edge condition was more severe
- Higher ablation exposed coarse weave at edges
- Layer to layer weave is robust - transition from coarse weave to fine weave did not result in unusual ablation

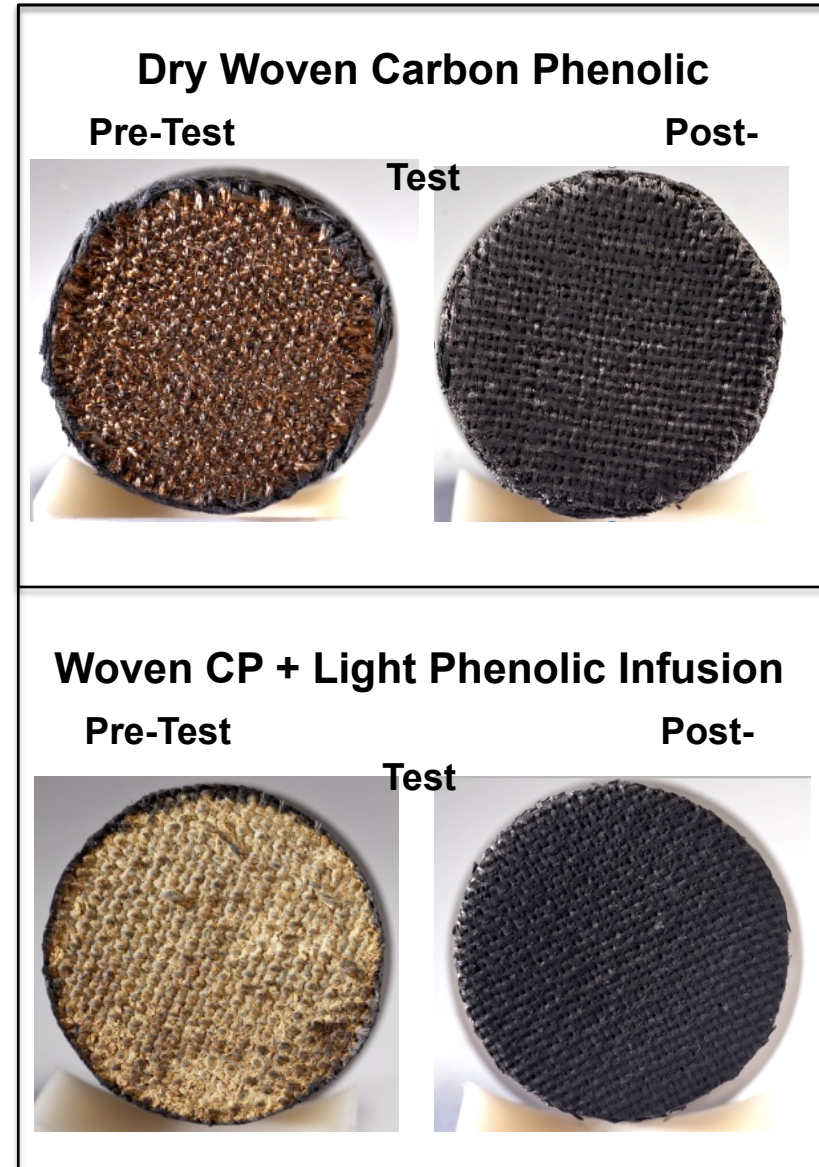


# IHF Arc Jet testing: Surface Densified and Mid-Dense WTPS Variants

Recession and Mass Loss vs. Density



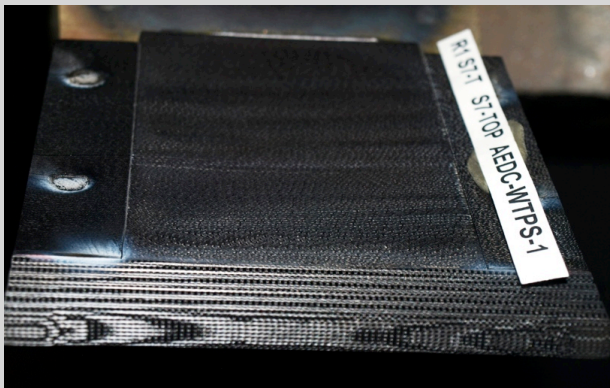
- Lowest recession was for surface-densified woven CP at  $0.56 \text{ g/cm}^3$





# AEDC Arc Jet Post Test Images of Select Samples

## Traditional Carbon Phenolic



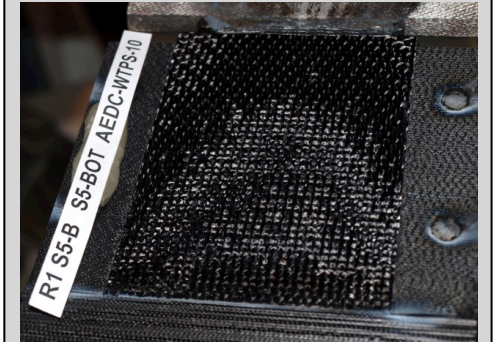
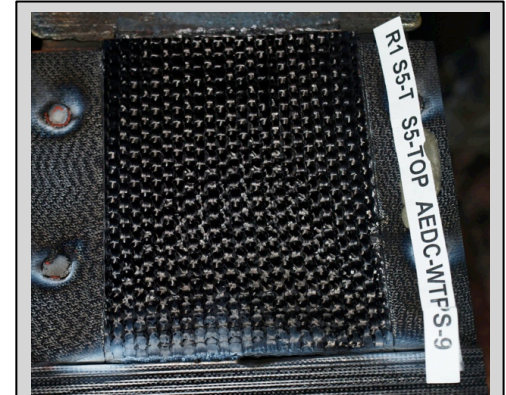
Tape Wrapped Carbon Phenolic



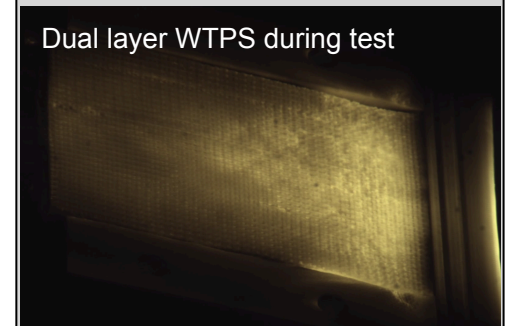
Chop Molded Carbon Phenolic

- 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

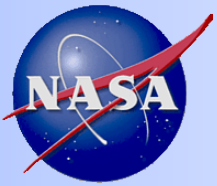


Dual layer WTPS during test



3-D Woven TPS

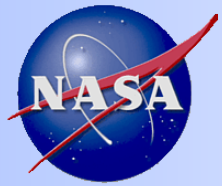
**Significance:** Feasibility of a dual layer WTPS concept



# 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:

Ron Chinnapongse, Don Ellerby Jerry Ridge, Mike Olson, Greg Gonzales, Grant Rossman, arc jet crew, Adam Beerman, Keith Peterson, Tane Boghozian, Erika Rodriguez, Vince Qu, David Kao, Matt Switzer, Jose Chavez-Garcia, Matt Gasch, Y-K Chen, Frank Milos

Other NASA Centers:

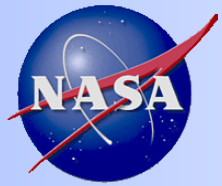
Mike Fowler, Anthony Calomino, Steven Del Papa,

AEDC:

Hank Moody, Mark Smith, arc jet crew

NASA GRC polyimide group, Compositex, Southern Research Institute

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

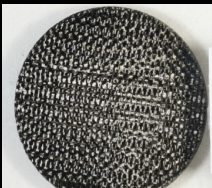
## Composite Yarn (Carbon+Phenolic)



Impregnated 3-D Woven CP



Post Arcjet Tested Coupons Resin Infiltrated



100 sec., ~600 W/cm<sup>2</sup>; 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

## 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, \$450K (FY12-13)

Phase 2: 12 months, \$1,500K (FY13-14)

Candidate material for MPCV compression pad for beyond LEO missions.

