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
• 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

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
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
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

- 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

<table>
<thead>
<tr>
<th>Material</th>
<th>TTT Strength (MPa)</th>
<th>Density (g/cc)</th>
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<tbody>
<tr>
<td>CP-B4</td>
<td>6.0</td>
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<td>MX4926</td>
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<tr>
<td>PICA</td>
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</table>

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/cm³

![Graph showing recession and mass loss vs. density for different materials and densities.](image)
**AEDC Arc Jet Post Test Images of Select Samples**

### Traditional 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)

### 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

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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
1 cm

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

HEEET Formulation

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.

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

Post Arcjet Tested Coupons Resin Infiltrated
100 sec., ~600 W/cm²; 625 psf pressure (JSC Arcjet Test in Dec’11)