



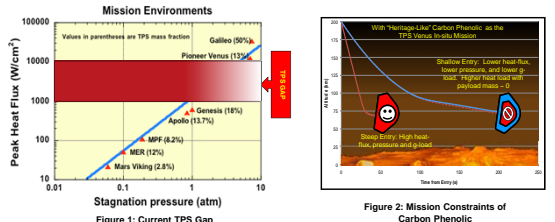
Comparison of Failure Modes in 2-D and 3-D Woven Carbon Phenolic Systems

Grant A. Rossman¹, Mairead Stackpoole², Jay Feldman³, Ethiraj Venkatapathy² and Robert D. Braun¹

¹Georgia Institute of Technology, Atlanta, GA 30332
²NASA Ames Research Center, ³ERC Inc., Moffett Field, CA 94035

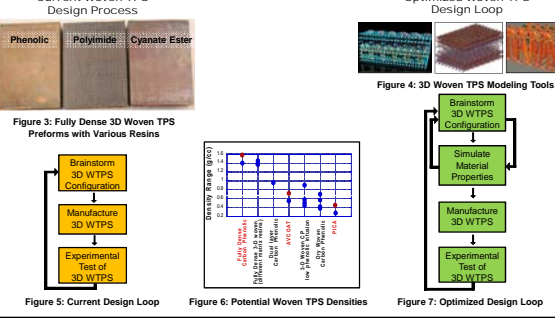


Woven TPS Background and Motivation



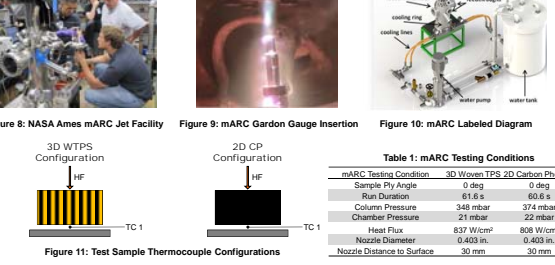
- Thermal Protection Systems (TPS) Background**
 - Thermal Protection Systems (TPS) protect an atmospheric entry vehicle from the harsh aerodynamic environment of re-entry
- Introduction to 3D Woven TPS (3D WTPS)**
 - Vision:** Close TPS Gap & enable future missions with TPS that is not mission constraining but enabling
 - Project Goal:** Explore feasibility and establish manufacturing of TPS using the textile industry and resin infusion techniques.
- What is 3D Woven TPS**
 - 3D Woven TPS is an approach to the design and manufacturing of **ablative TPS**
 - 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 requirements
- Carbon Phenolic is mission constraining**
 - Mission design with CP and acceptable payload mass leads to:
 - Steeper trajectories
 - High heat-flux, high pressure and high g-loads
- Advantages of 3D Woven TPS**
 - 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 **Heritage Like 2D Carbon Phenolic (2D CP)**
 - Mission concepts have had no other option but to baseline Carbon Phenolic (CP)
 - CP is very capable and robust
 - CP enabled Galileo and is flight proven
 - CP is the only option (no mid-high density TPS)

Woven TPS Design and Manufacturing Process



- Goal of Direct TPS Comparison Experiment**
 - Evaluate thermal response and failure mode evolution in both 3D WTPS and traditional 2D Carbon Phenolic TPS materials
 - Two 2 in x 2 in samples at 0°ply angles were cut and tested under similar conditions in the mARC Jet Facility to analyze thermal-material performance
 - Failure modes will be examined if they occur
 - Test hypotheses that 3D Woven TPS is a viable TPS and a potential carbon phenolic replacement material
- Potential Woven TPS Density Trade Space**
 - Woven TPS shows its tailorability in Figure 6 by providing TPS options at many density ranges including mid-density TPS options
- Current Woven TPS Design Loop Disadvantages**
 - Relies solely on experiments for decision-making
- Optimized Woven TPS Design Advantages**
 - Simulates material properties of candidate WTPS designs for quick initial screening
 - Large cost savings from reduced test samples
 - Converge on final design faster

3D WTPS Experimental Comparison to 2D CP

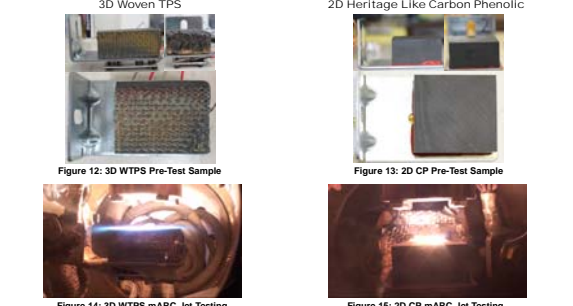


- Introduction to the mARC Jet Facility**
 - Small-scale arc jet that heats flow by running current between electrodes in the arc chamber
- mARC Testing Capabilities**
 - Approx. 30 kW of power and 0.45 g/s mass flow rate of air
 - 3D WTPS and 2D CP samples tested and compared
 - Table 1 shows that all testing conditions were matched
- mARC Experiment Setup**
 - Directly compare thermal response performance of 3D Woven TPS to 2D Carbon Phenolic
- Thermocouple (TC) Configuration for Test Samples**
 - TC's placed between sample backface and L-Bracket

References

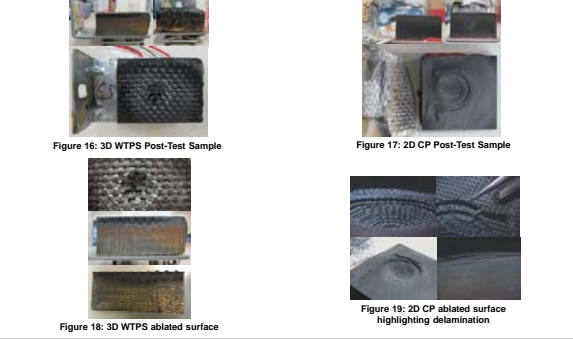
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3D Woven TPS vs. 2D CP Pre-Test Photos



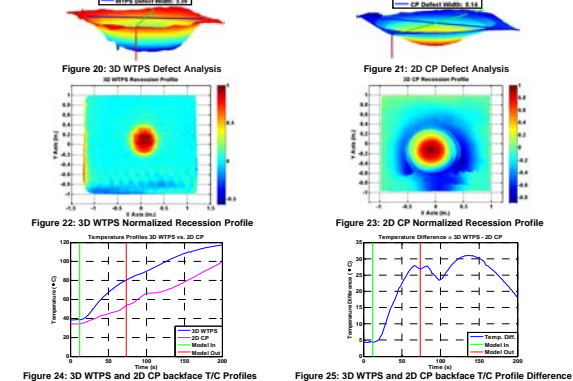
- 3D Woven TPS Pre-Test Characteristics**
 - Weave consisted of coarser tows set in phenolic resin
 - Thick 2-fibers (green-colored fibers) connect layers together forming a 3-D architecture
 - Mechanically fastened to L-Bracket sting arm
- 2D Carbon Phenolic Pre-Test Characteristics**
 - Finer tows set in phenolic resin
 - 2D carbon fiber layers are laminated together
 - Attached to L-Bracket sting arm with RTV sealant
 - Surface observed to "puff up" and deflate during testing – attributed to pressure build up in material followed by delamination

3D Woven TPS vs. 2D CP Post-Test Photos



- 3D Woven TPS Post-Test Characteristics**
 - Smaller, more well contained defect area
 - Evidence of free gas flow through sample
 - No delamination observed – attributed to 3-D architecture
 - Char, pyrolysis, and virgin zones clearly visible
- 2D Carbon Phenolic Post-Test Characteristics**
 - Larger, more widespread defect area
 - Gas build-up resulted in ply separation
 - Clear delamination of surface and defect layers
 - Catastrophic failure mode observed at 0°ply angle

3D Woven TPS vs. 2D CP Post-Test Analysis



Conclusions

- An un-optimized WTPS material was compared to a traditional 2D CP in the mARC facility at NASA Ames.
- At a 0° ply orientation the 2D Carbon Phenolic delaminated during the test while the 3D Woven TPS did not display the failure mode prevalent in 2D carbon phenolic
- 2D carbon phenolic must be tested at a certain ply angles to avoid delamination
- Depth analysis in Figure 20, Figure 21 shows a deeper defect depth for 3D WTPS than seen in 2D CP
- Recession analysis in Figure 22, Figure 23 shows a smaller defect area for 3D WTPS than seen in 2D CP
- Temperature response analysis in Figure 24 measured from embedded TC's shows a slightly higher temperature profile for 3D WTPS than seen in 2D CP, as a result of the higher conductivity fibers used in this weave
- Next steps including testing the 2D CP material at different shingle angles and testing different WTPS variants

Acknowledgements

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