SYSTEM LEVEL AEROTHERMAL TESTING FOR THE ADAPTIVE DEPLOYABLE ENTRY AND PLACEMENT TECHNOLOGY (ADEPT).

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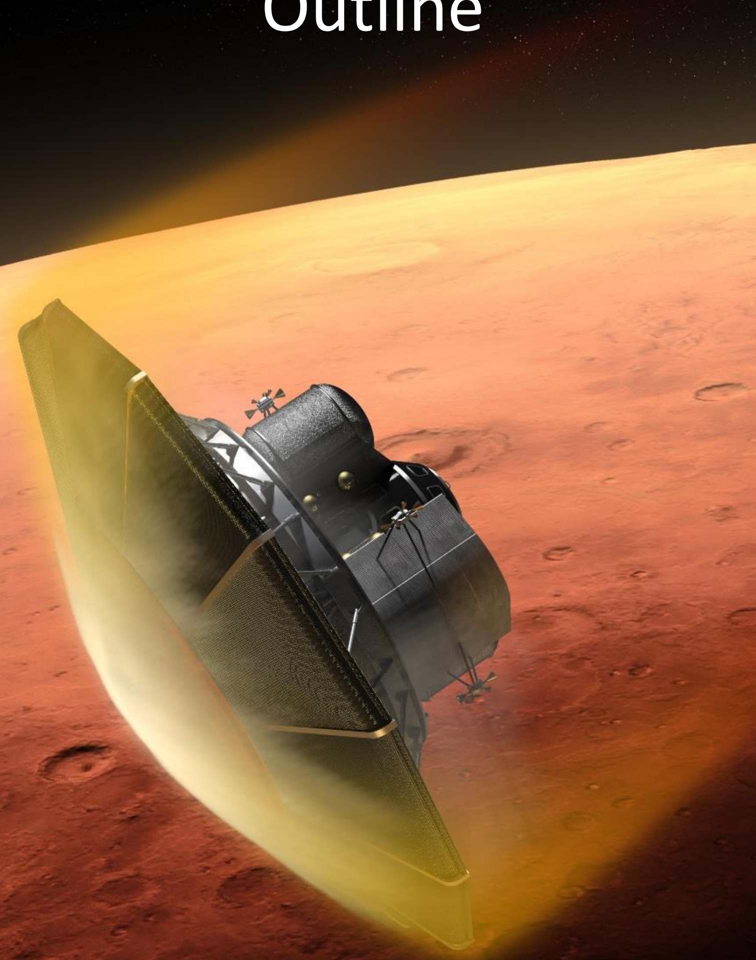
Outline



ADEPT Overview

Test Objectives

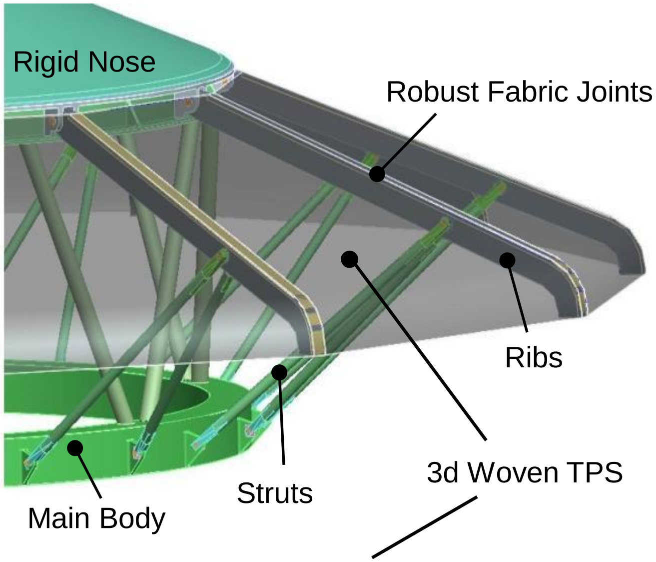
Test Design

Results

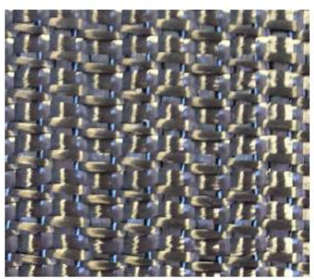
Lessons Learned & Future Work

Adaptive Deployable Entry and Placement Technology

Key ADEPT Components



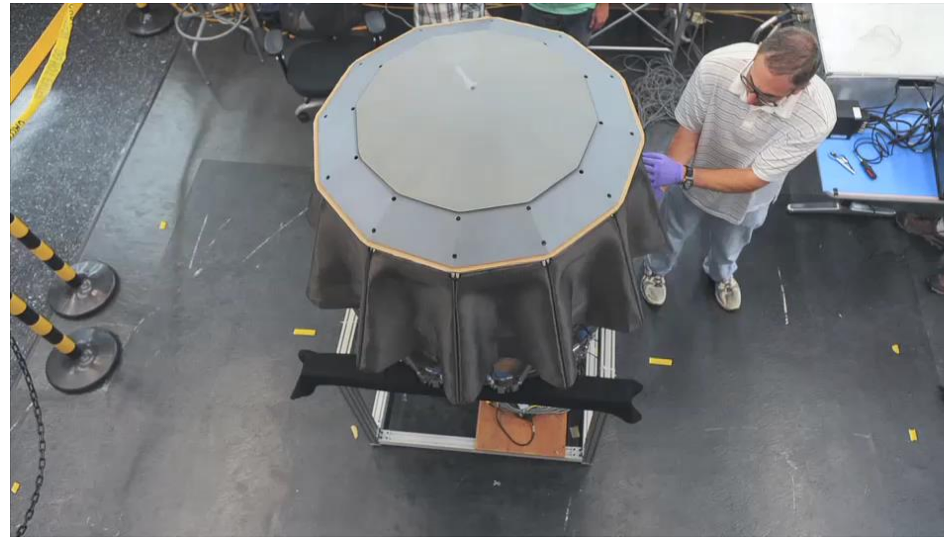
Front Surface- Plain Weave



Aft Surface- Ortho Weave

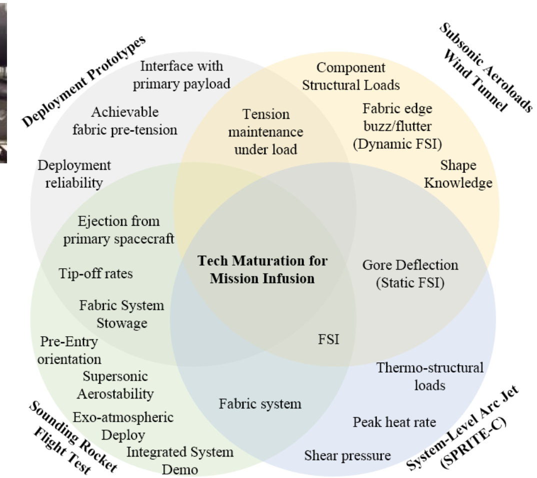
- **Develop and integrate technologies for a mechanically deployable decelerator for missions to Venus, Mars, and other destinations.**

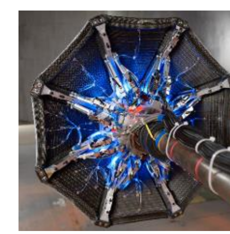
Deployment Prototype Time Lapse Video



1 m Class Technical Maturation

See: B.P. Smith et al "Nano-ADEPT: An Entry System for Secondary Payloads" IEEE Aerospace Conf., 2015





Test Objectives

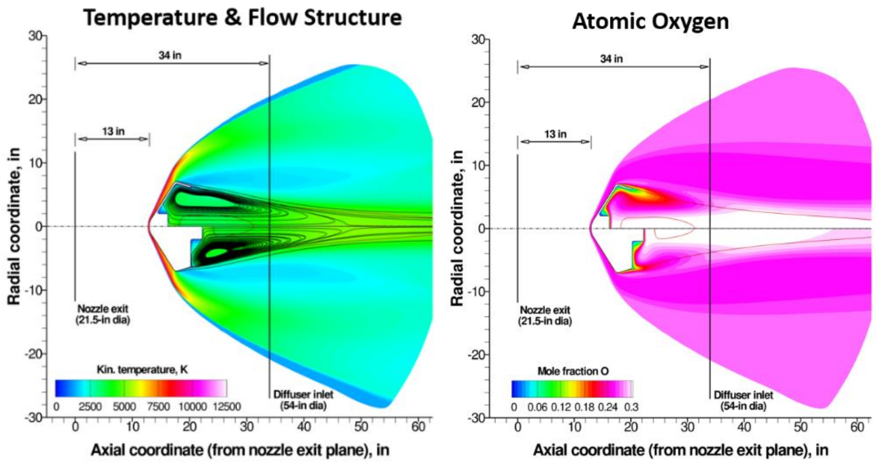
Primary Objective:

Demonstrate ***simplified*** ADEPT SPRITE-C configuration maintains integrity during test.

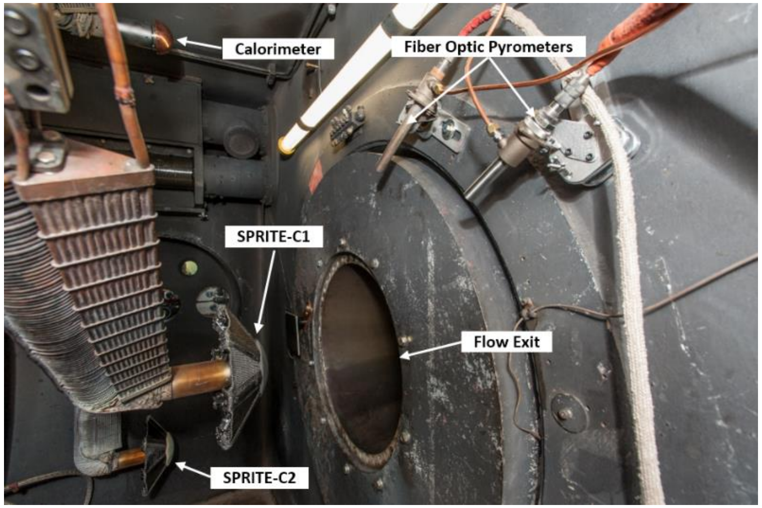
Secondary Objectives:

1. Monitor temperatures of key design features.
2. Evaluate fabric joint designs.
3. Measure recession.
4. Measure carbon fabric aft side temperature.
5. Determine if rigid nose ablation products effect downstream design features.

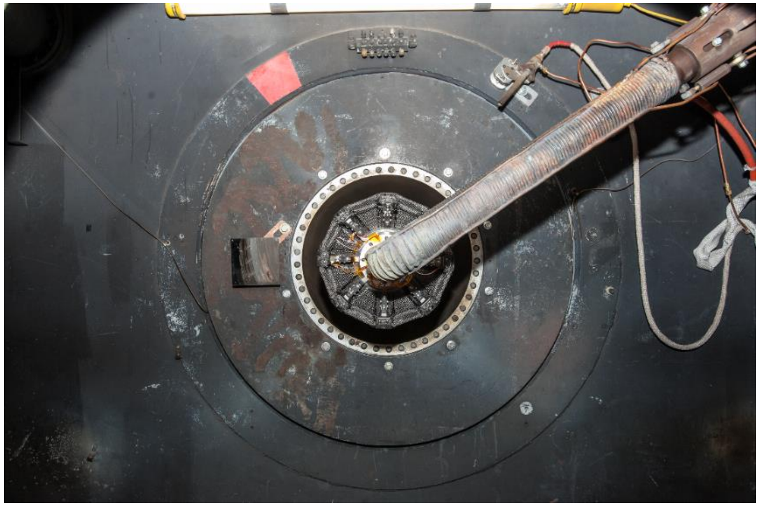
Arc Heated Flow Simulations



Chamber Set-Up

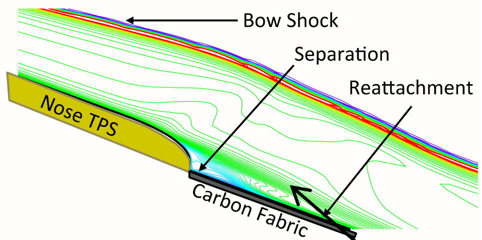


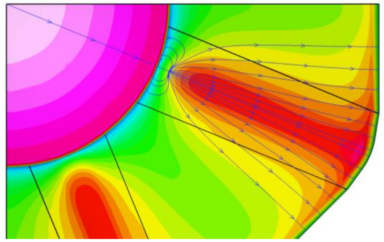
Test Article Alignment



Key TPS Design Features

FLOW FEATURES

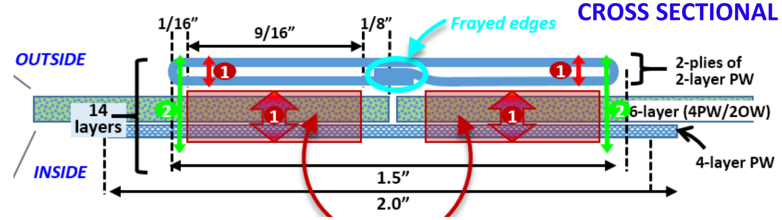




Streamlines & Heating Contours

JOINT ANATOMY

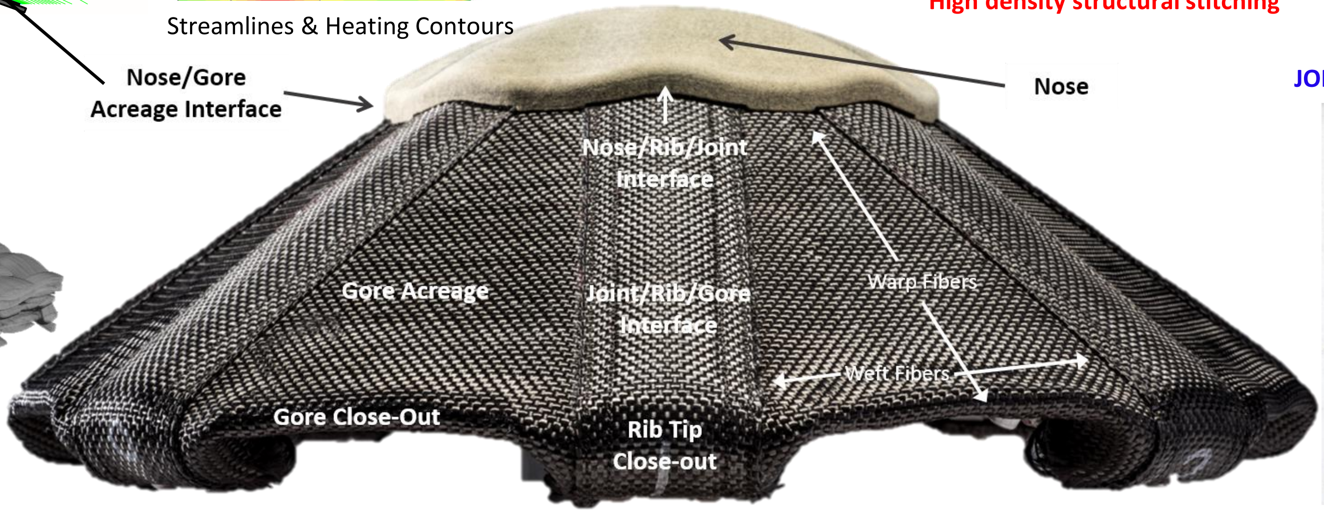
CROSS SECTIONAL VIEW



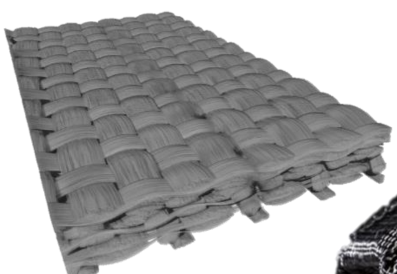
High density structural stitching

Nose/Gore Acreage Interface

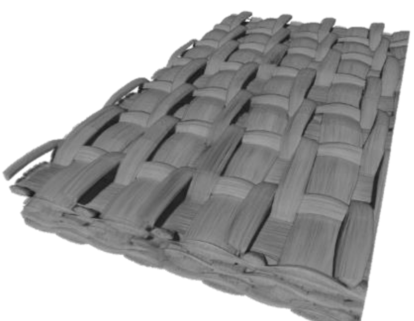
Nose



3D WOVEN FABRIC



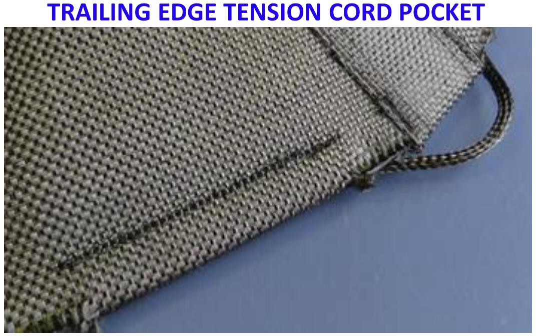
TOP VIEW ACREAGE



BOTTOM VIEW ACREAGE

JOINT SHIELDING LAYERS

TRAILING EDGE TENSION CORD POCKET

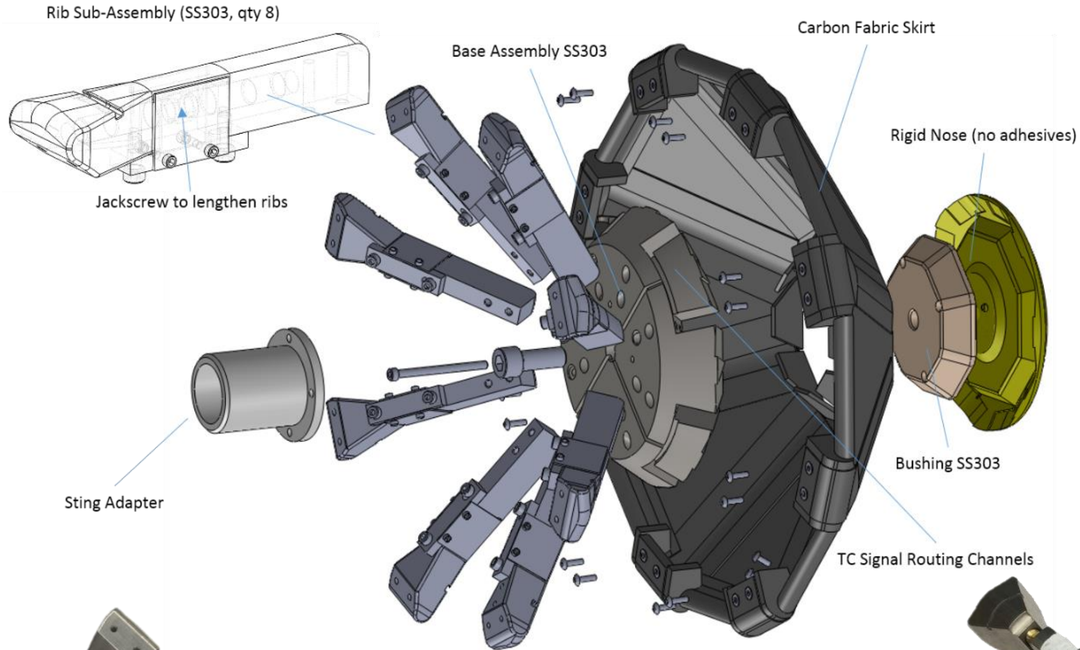


JOINT STITCHING & INSULATING LAYERS

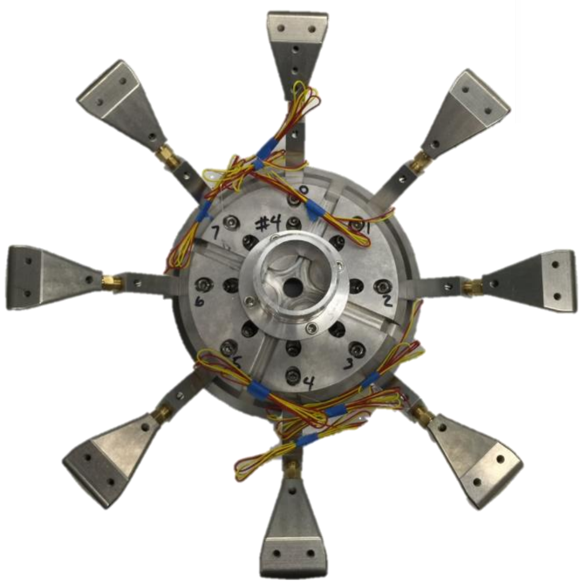
SHIELDING LAYER INFUSION

Test Article Description-Assembly

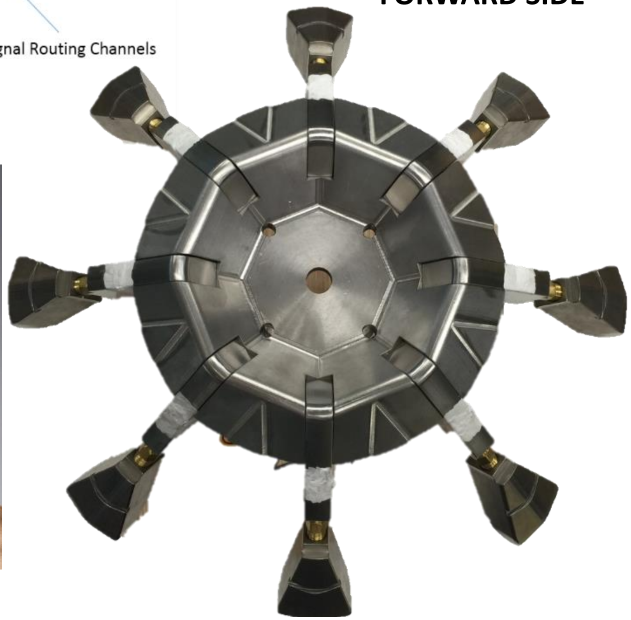
EXPLODED VIEW



AFT SIDE



FORWARD SIDE



Test Environment Predictions

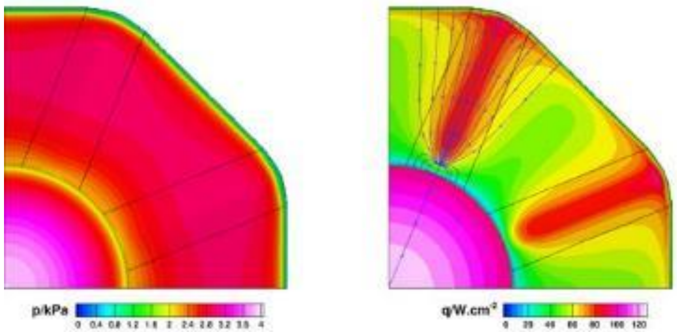
Condition 1

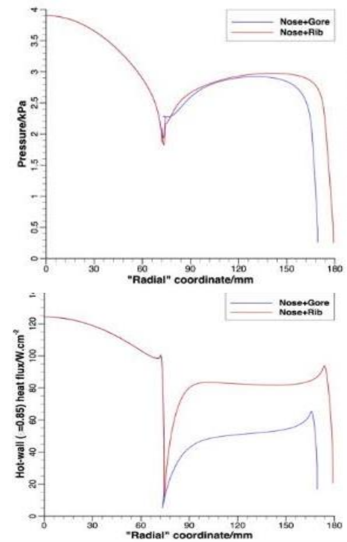
IHF 21.5-in nozzle, 10" from nozzle exit plane

I_{arc} = 2000 A

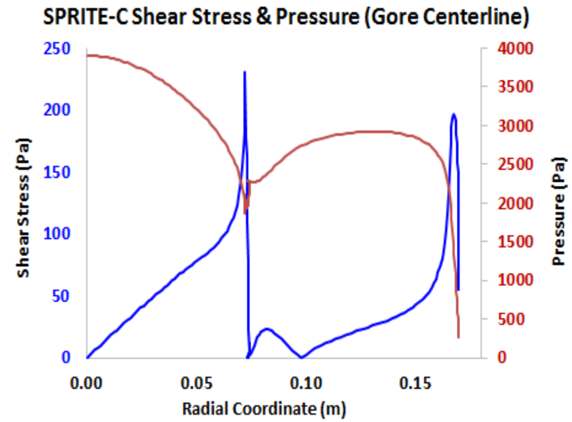
m_{air} = 200 g/s, m_{air+} = 55 g/s, m_{Ar} = 26 g/s

P_{arc} = 240 kPa





Shear Stress & Pressure Plots for Acreage Material



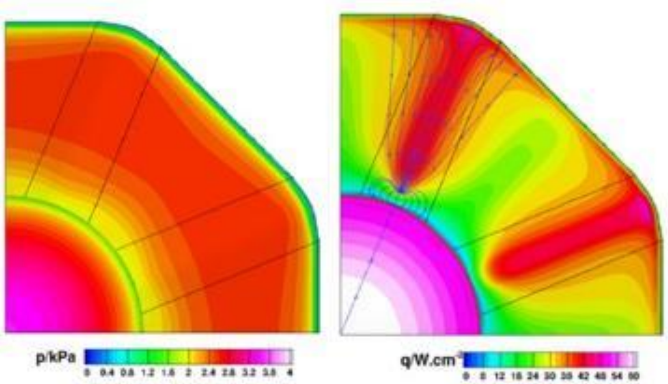
Condition 2

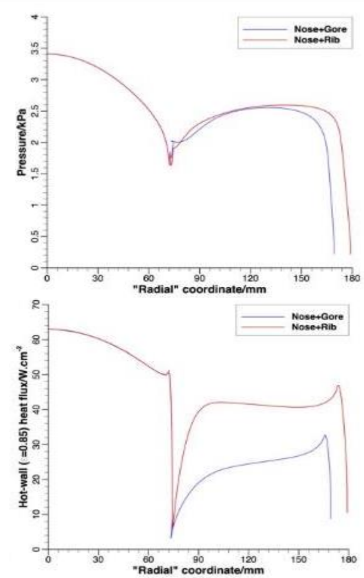
IHF 21.5-in nozzle, 10" from nozzle exit plane

I_{arc} = 2200 A

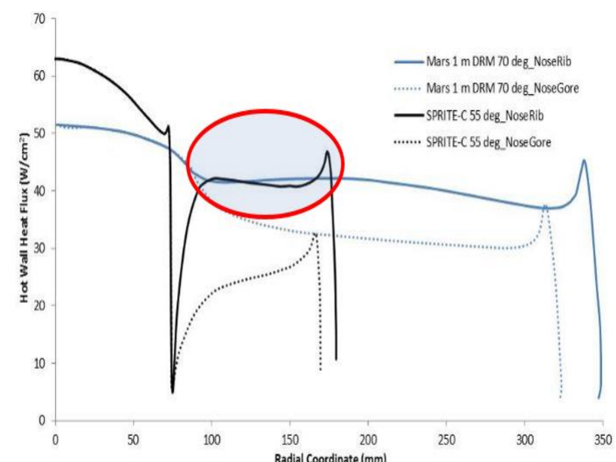
m_{air} = 110 g/s, m_{air+} = 160 g/s, m_{Ar} = 30 g/s

P_{arc} = 193 kPa



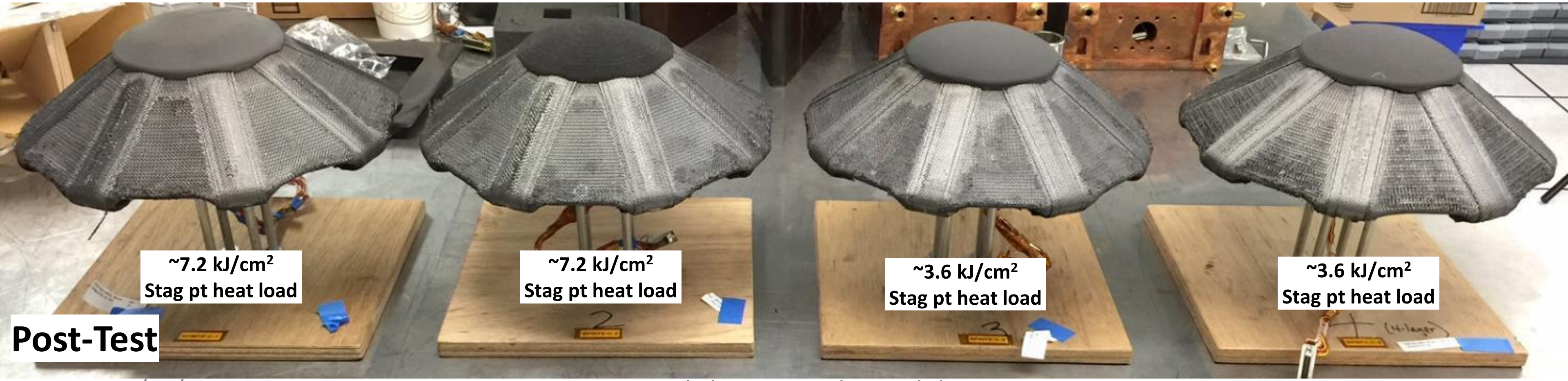


Test Conditions Match Mars DRM Predictions



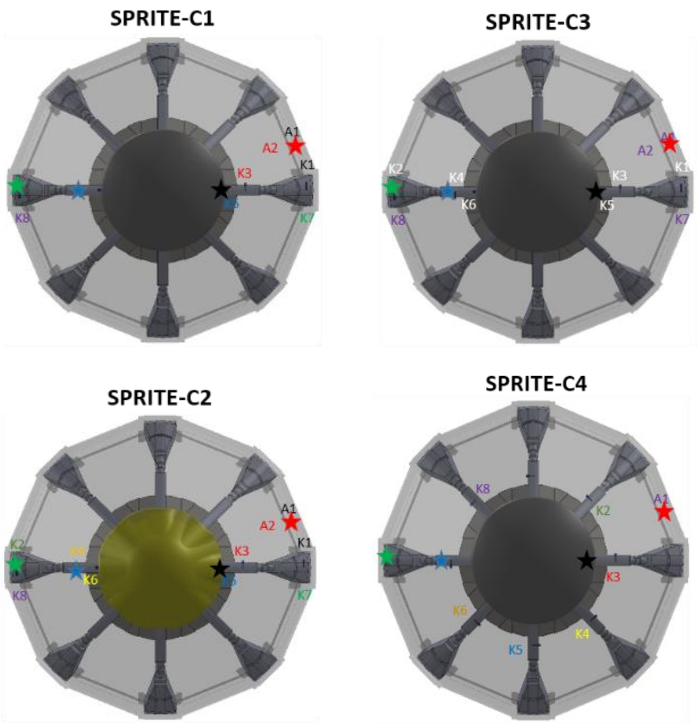
Test Article Description

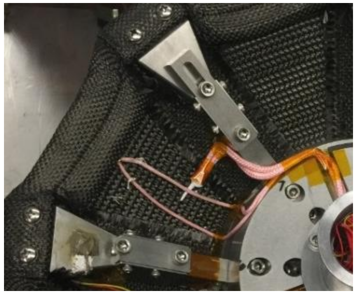
Test Article 1	Test Article 2	Test Article 3	Test Article 4
Condition 1 for 60 sec	Condition 1 for 40 sec Condition 2 for 40 sec	Condition 2 for 60 sec	Condition 2 for 60 sec
• Graphite Nose • Six Layer C-Fabric • Phenolic Infused Joints	• Conformal PICA Nose • Six Layer C-Fabric • Phenolic Infused Joints	• Graphite Nose • Six Layer C-Fabric • Various Resin Infused Joints	• Graphite Nose • Four Layer C-Fabric • Various Resin Infused Joints • Insulating Fabric at Rib Interface

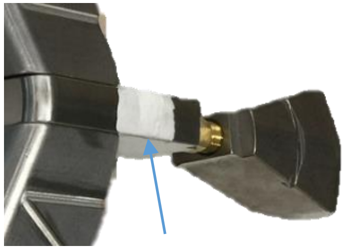


Instrumentation & Imagery

Thermocouple Locations & Pyrometer Pointing

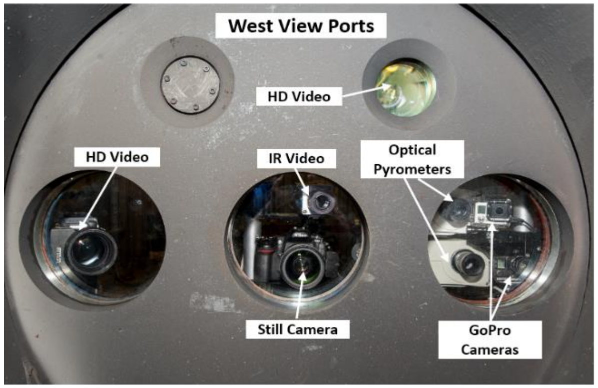


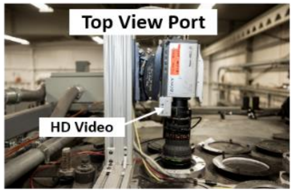


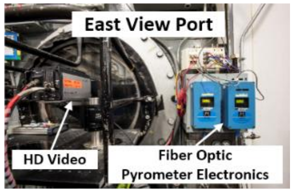


Thin Film TCs to monitor rib temperature

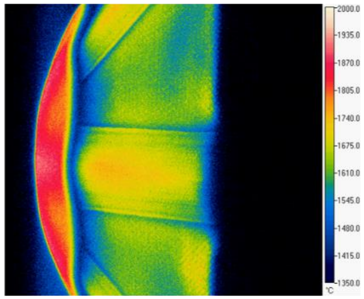
HD Video, Infrared Thermography & Pyrometry

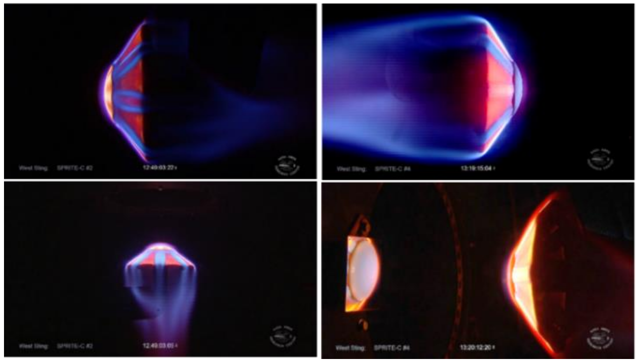


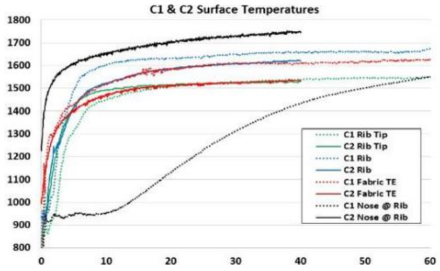


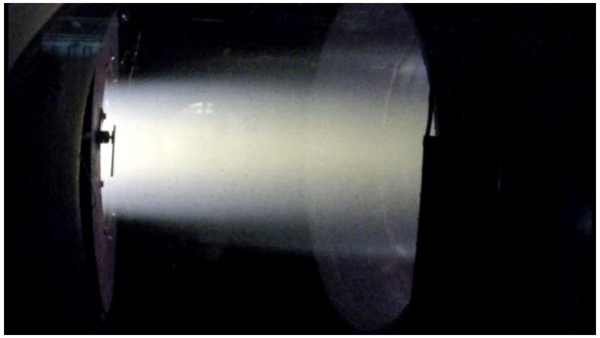


Test Article C2 @ 40 sec





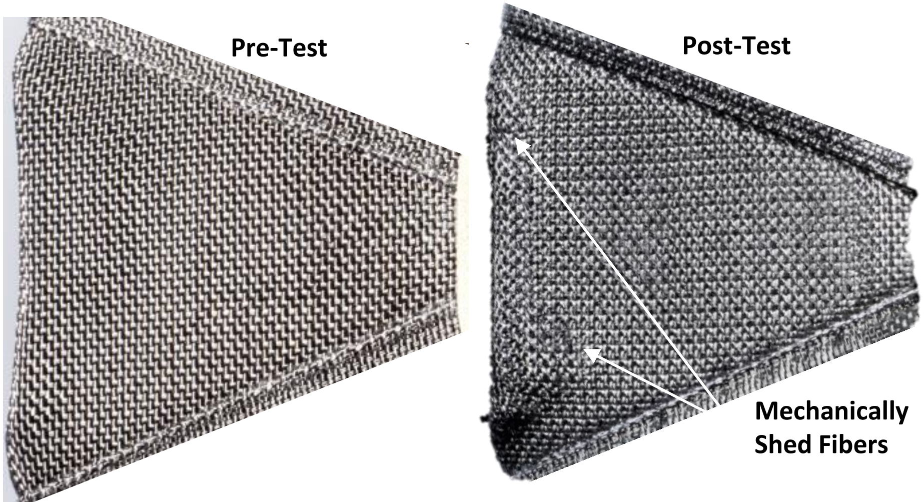




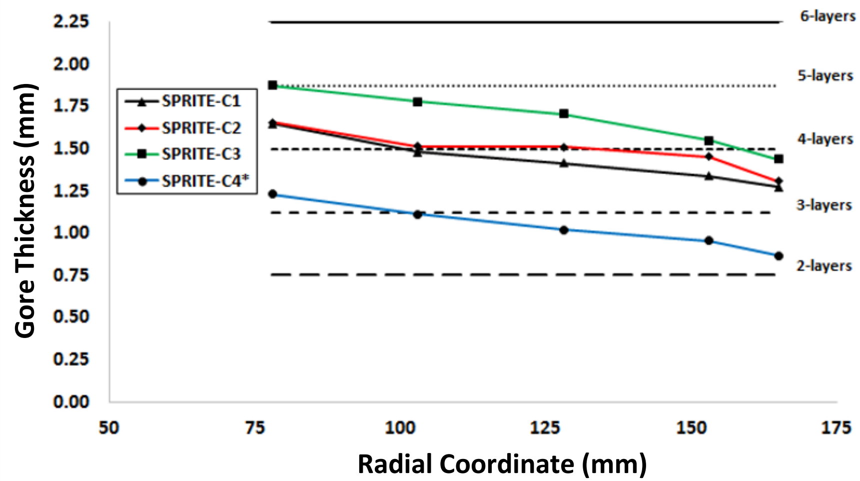
Results: Test Video- C2, Condition 1

Results: Fabric Performance

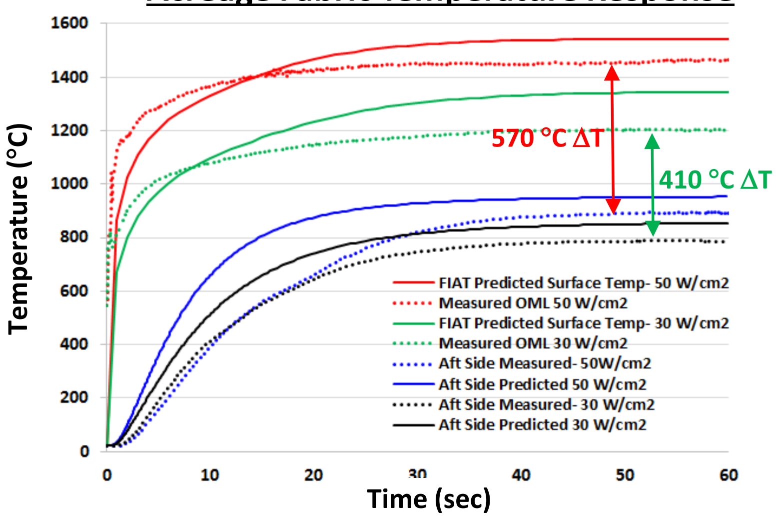
Acreage Fabric Observations



Recession Measurements Along Gore Centerline

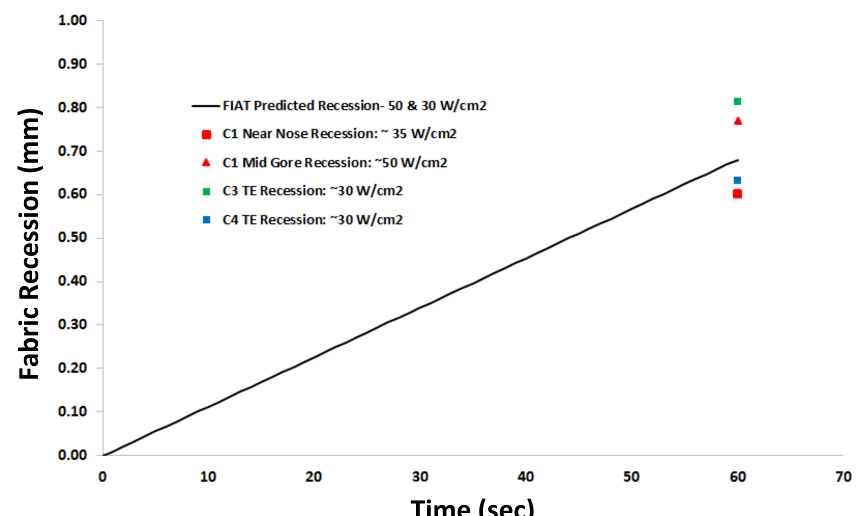


Acreage Fabric Temperature Response



Significant delta T between forward and aft surface of fabric.
Thermal analysis model correlates well with measurements.

Engineering Fidelity Response Model

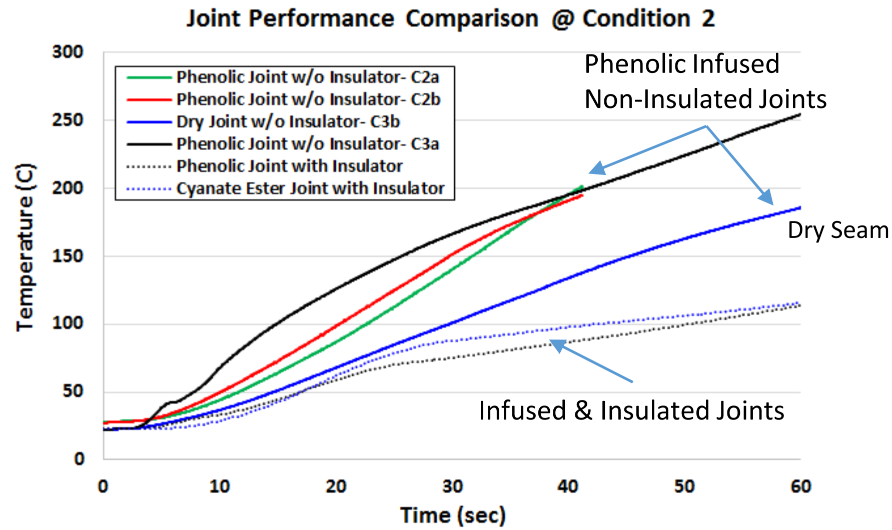


Engineering Response Model Predicts Recession (+/- 15%)

Results: Fabric Joint Performance

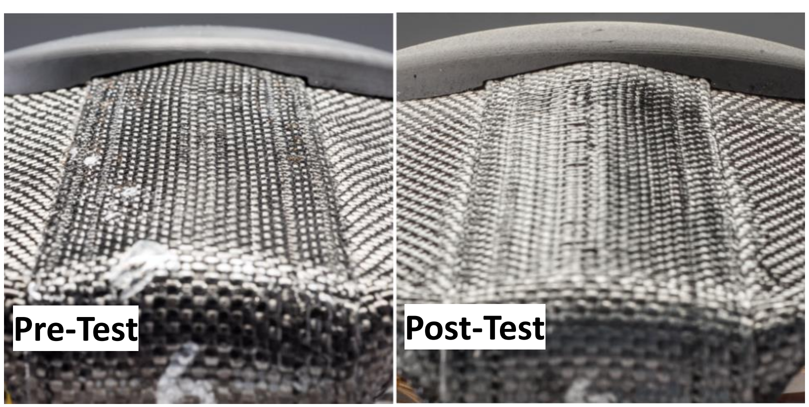
Infrared Imagery

Rib Interface Temperatures for Various Joint Configurations

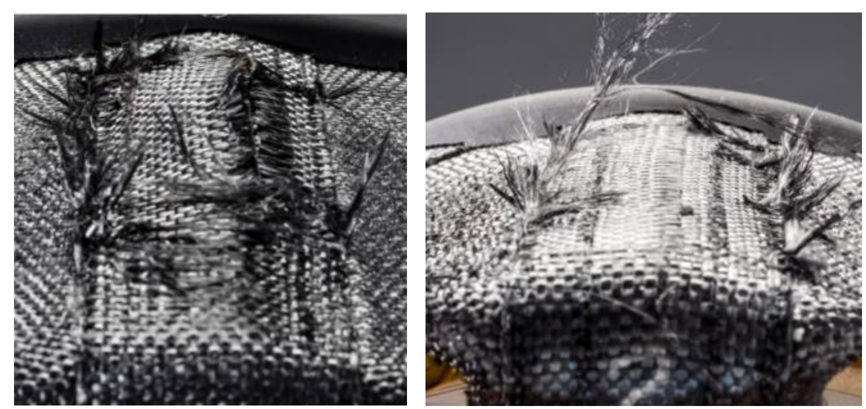


***Infused & Insulated Joint Showed Best Overall Performance.**

Resin-Infused Shielding Layers Are Robust Under These Environments



Non-Infused Shielding Layers Shed After Burning Through Top Plies

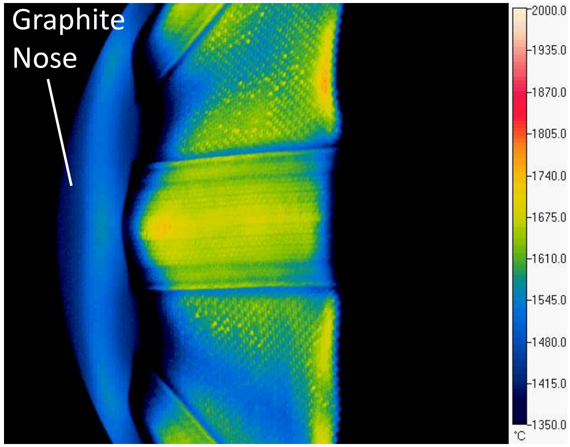


Results: Upstream Ablator & Dual Heat Pulse

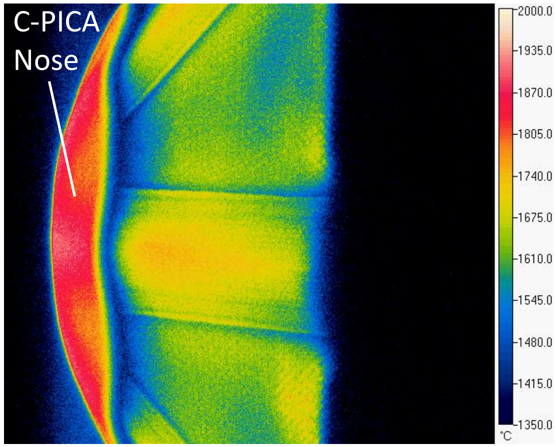
Graphite versus Conformal PICA Nose @ Condition 1

- Thermally massive graphite nose piece took time to reach thermal equilibrium, likely causing downstream temperature increases observed.

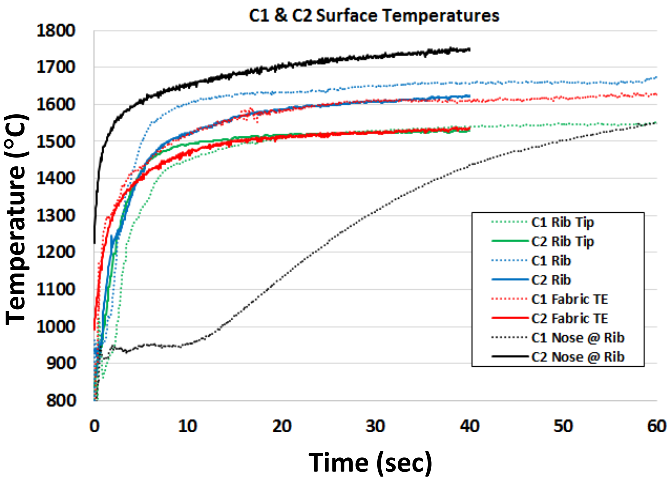
TEST ARTICLE C1 @ 40 SEC



TEST ARTICLE C2 @ 40 SEC



SURFACE TEMPERATURE COMPARISON



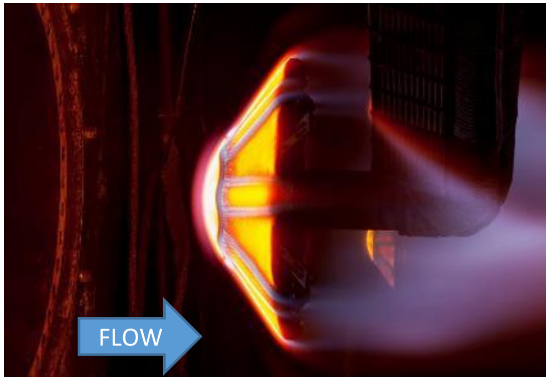
Ablator upstream of fabric does not have much effect on performance of fabric.

Dual Heat Pulse Capability Demonstrated- SPRITE-C with C-PICA nose TPS

- 1st pulse- Heat Rate 120 W/cm^2 (stag point), duration 40 sec (test article left overnight in test chamber)
- 2nd pulse- Heat Rate 60 W/cm^2 (stag point), duration 40 sec

PRE-TEST

ARC JET TEST (2 EXPOSURES)



POST-TEST

Lessons Learned & Future Work

Lessons Learned

1. **More Instrumentation**
   - Facility is generally limited to 12-channels per test article
   - Modify design to incorporate custom miniaturized data acquisition systems

2. **Develop more robust TC mounting technique**.
   - 5 out of 32 of the foil TCs did not survive assembly

3. **Develop better handling procedures**.
   - Fabric skirt was prone to shifting/geometry changes during preparation and handling, need more consistent geometry, especially at the free trailing edge.

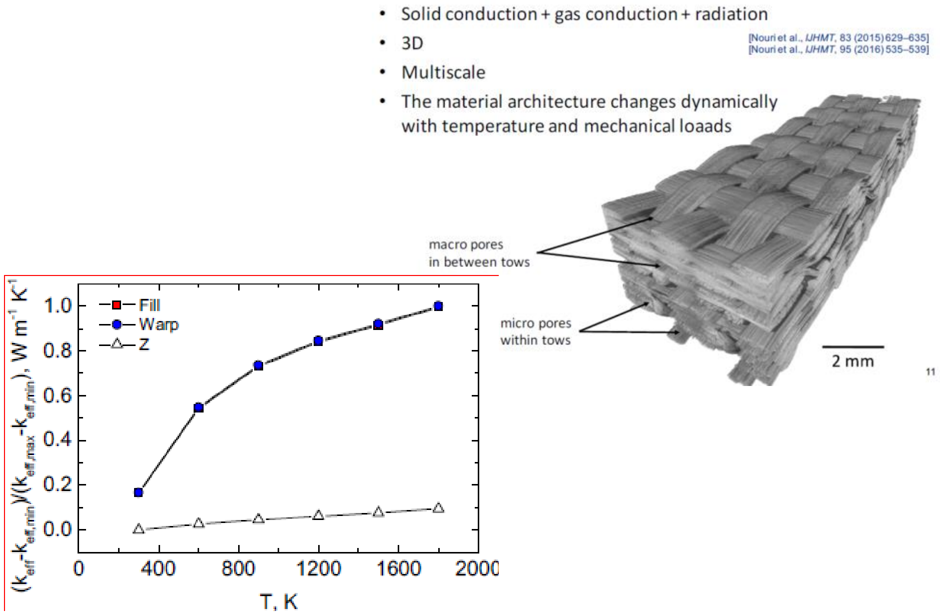
4. **Develop insulating joint concept**, especially for less severe entry environments (i.e.-Mars).
   - Quartz fabric at joint/rib interface shows promise for limiting conduction into structure

5. **Understand 'payload' environment better**, including heat transfer, contamination (outgassing and decomposition of the fabric skirt) and fabric permeability.

Future Work

1. **Design Flight-Like Arc-Jet Test Article**
   - Incorporate Flight-Like Structural Features, Payload Simulator & Seals.
2. **Load Test Post-Heated Joints to Failure**.
   - Evaluate various designs for ultimate load strength.

3. **Utilize Computed Tomography Imaging to Aid in Material Properties Characterization**.
   - See Panerai et al "Thermal Conductivity of Woven Thermal Protection System Materials" 8th European Workshop on TPS & Hot Structures, 19-22 April, 2016.



Acknowledgements

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- Ames Research Center Innovation Fund

ADEPT Team Members Past & Present

- Brandon Smith, Owen Nishioka, Greg Swanson, Cole Kazemba, James Arnold, Ethiraj Venkatapathy, Peter Gage

Industry Partners

- Bally Ribbon Mills
- Thin Red Line Aerospace

Facility

- Arc Jet Test Crew
- STAR Labs

Computed Tomography-Lawrence Berkeley National Laboratory

- Francesco Panerai
- Nagi Mansour