Arcjet Testing of Woven Carbon Fabric Joints for Use on Adaptive Deployable Entry Placement Technology

ADEPT

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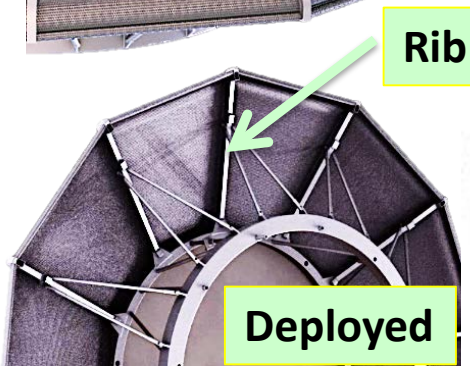
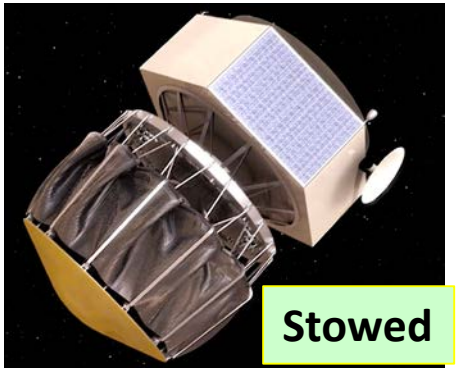
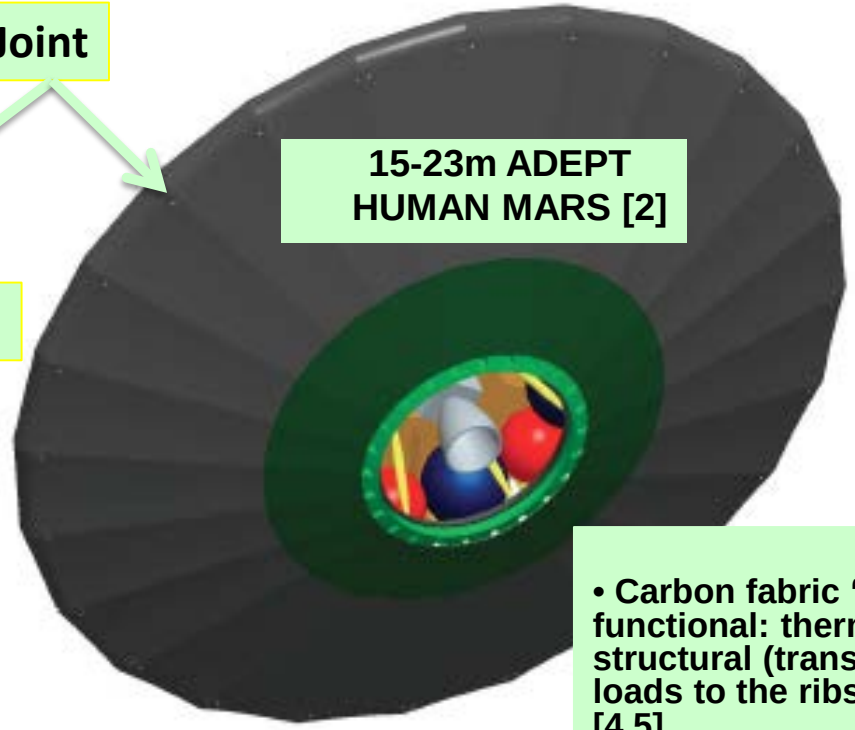
ADEPT: Venus and Mars Classes

6m ADEPT-VITaL*
(Venus) [1]







1m Nano-ADEPT
(Mars) [3]

- **Carbon fabric "Skin" is multi-functional: thermal protection and structural (transfers aerodynamic loads to the ribs). Demonstrated in [4,5].**
- **Need: Demonstrated technology to join carbon fabric gores that is robust to both aerothermal and aerodynamic loads. Joints required because of loom sizes.**
- **Present work addresses this need.**

***Venus Intrepid Tessera Lander (VITaL)**

Objective of Present Work

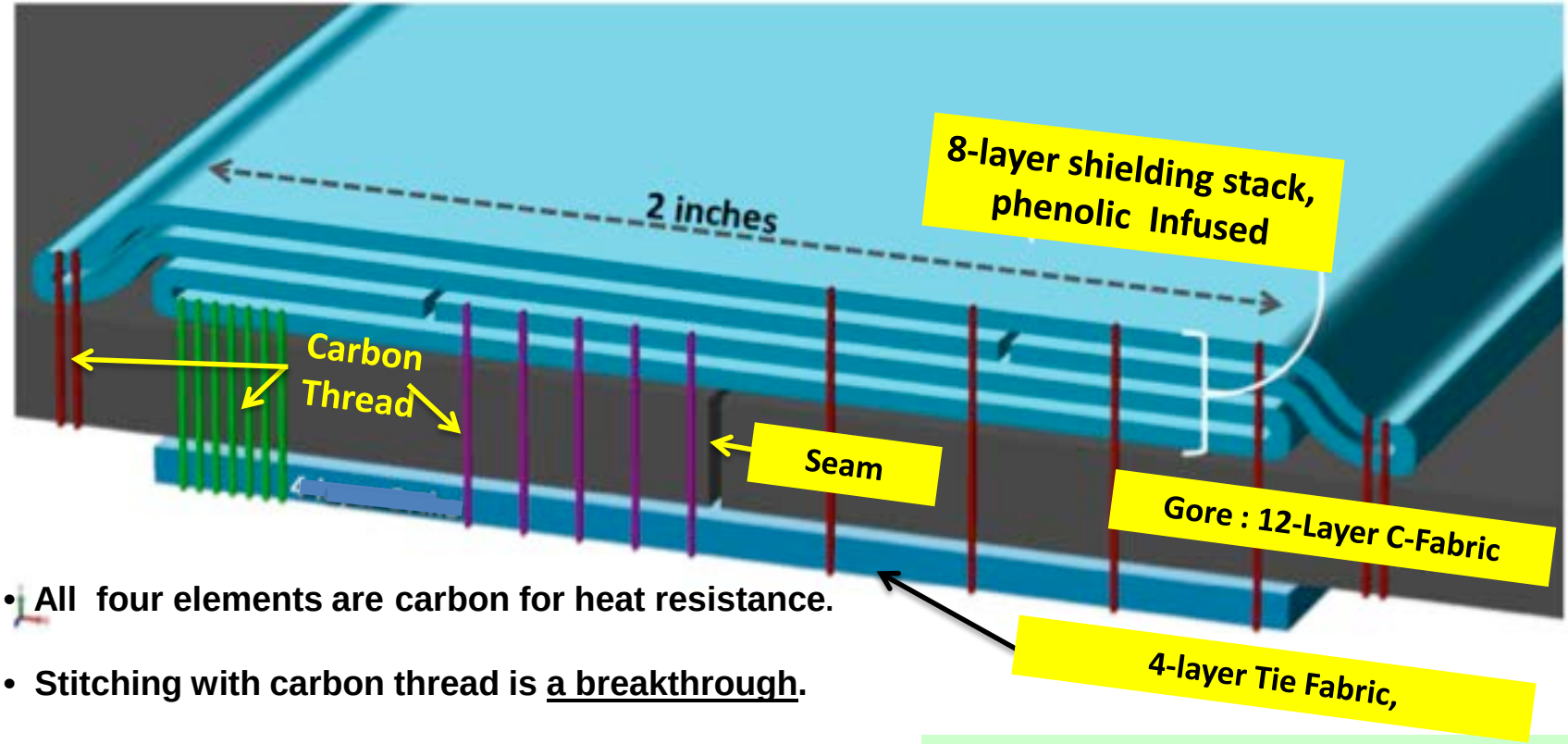
- **Demonstrate stitching-based technology that meets ADEPT's need to join gores of 3 D woven carbon fabric.**

> **Aerothermal heating requires that all elements of joint be made of carbon – *Requires stitching with carbon thread.***

> **Testing to be done in combined aerothermal and structural loading environments similar to work reported in [5].**

➢ **Tensile strength of control (no heating) and arcjet heated samples to be measured.**

Joint Anatomy and its Four Elements

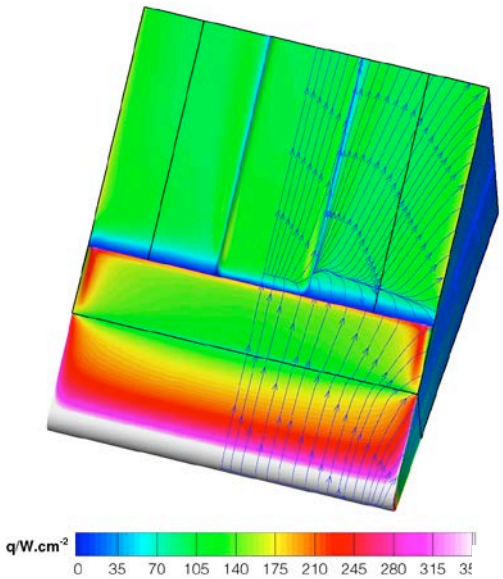


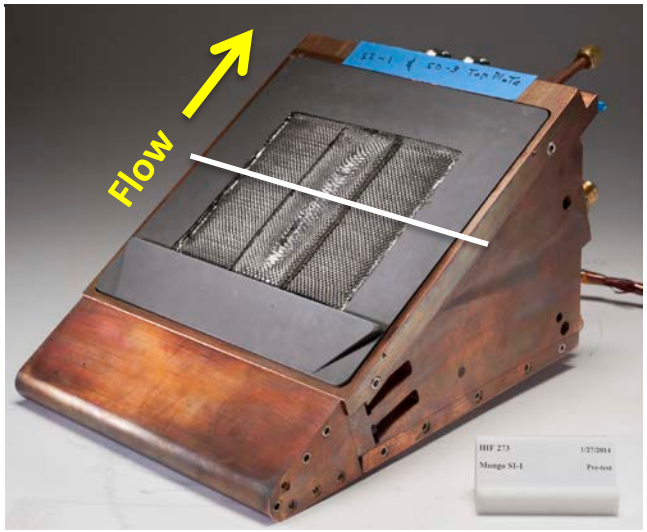
- All four elements are carbon for heat resistance.
- Stitching with carbon thread is <u>a breakthrough</u>.
- Shielding stack infused with phenolic for robustness to aerothermal heating and recession
- 2/5 scale joint width with target loading of 245 lbf/in enables simultaneous observation of joint and gore recession during arcjet heating
- Joint is 2 inches wide by ~ 0.27 inches thick.

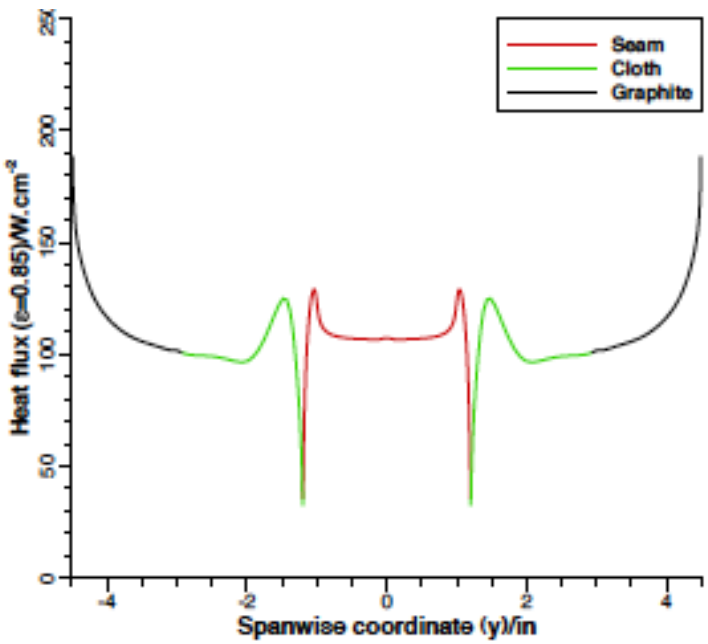
<u>Partners</u>

Thin Red Line Aerospace (TRLA)
(Stitching)
Bally Ribbon Mills (BRM)
(Weaving)

Aerothermal: CFD Prediction of Arcjet Flow

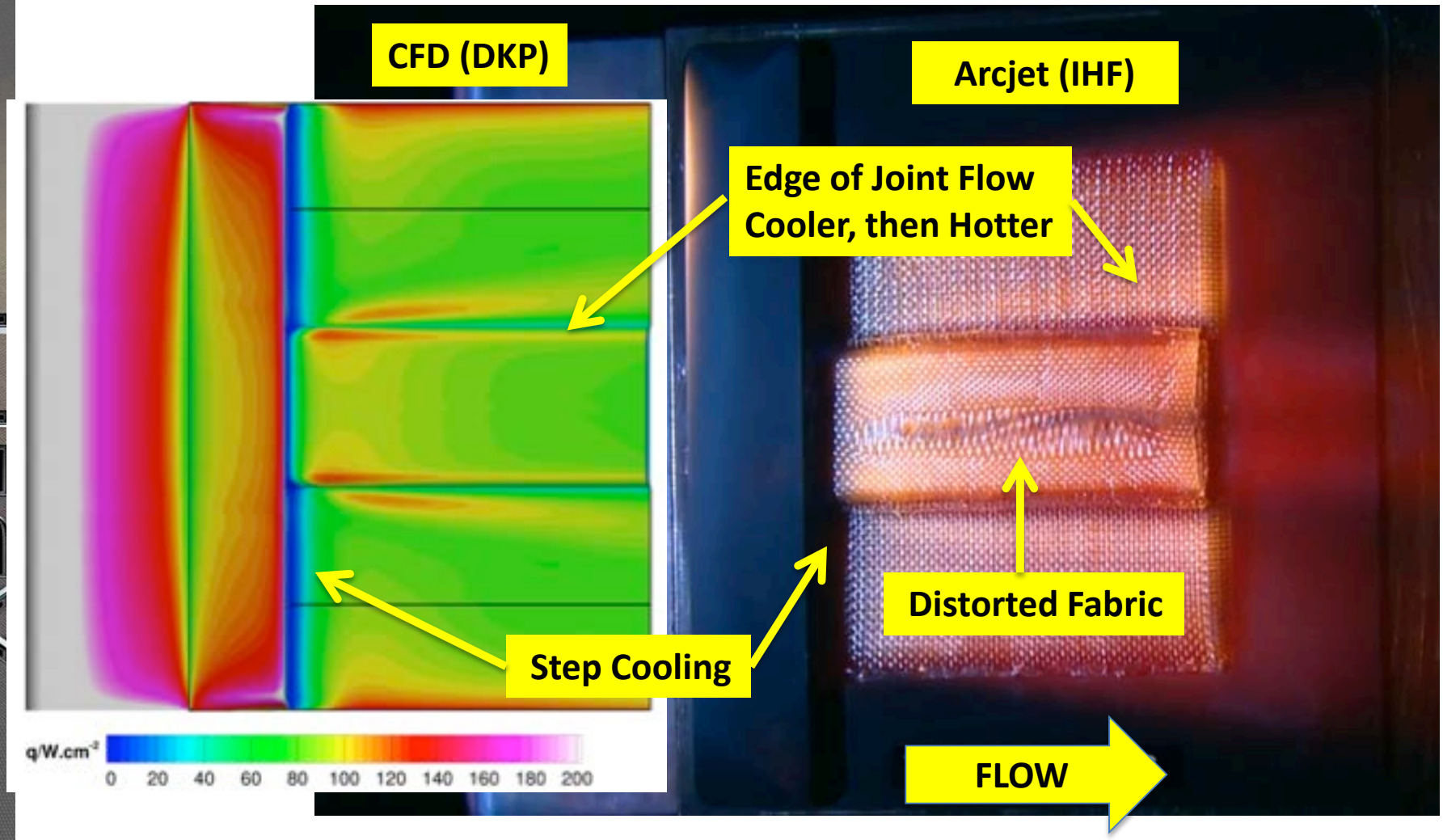






- CFD designed rearward facing step.
- Spanwise cut shows a "dip" in heating at joint edges.
- Arcjet test validates CFD design tools.
- Validated CFD to be used for *Flight Design.*

CFD and Arcjet Test Results

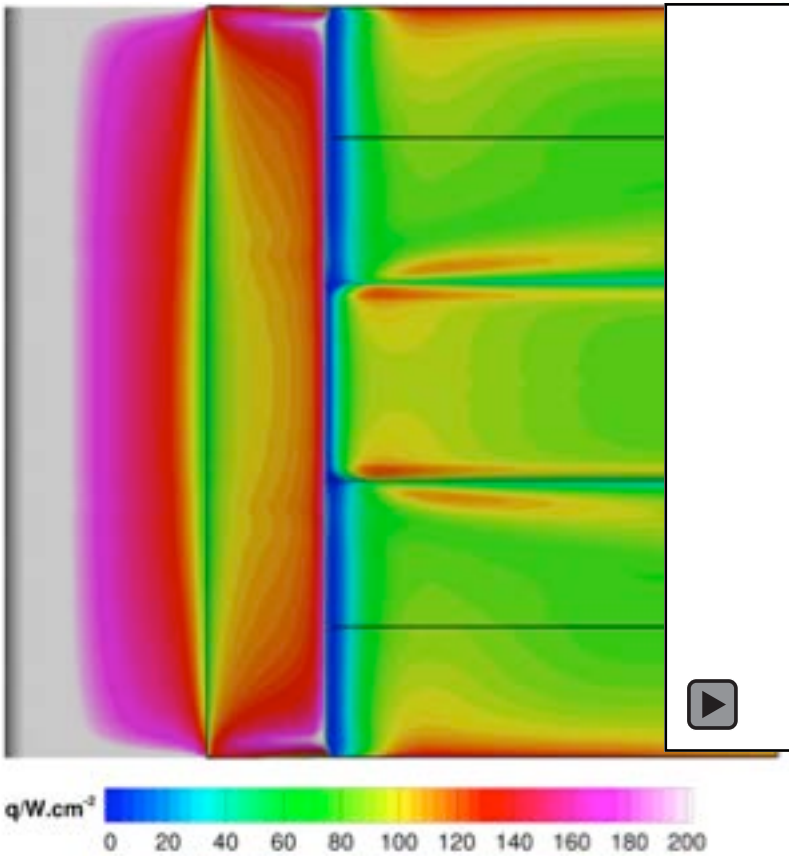


Aerothermal: CFD and Arcjet Test Results

CFD (DKP)

FLOW

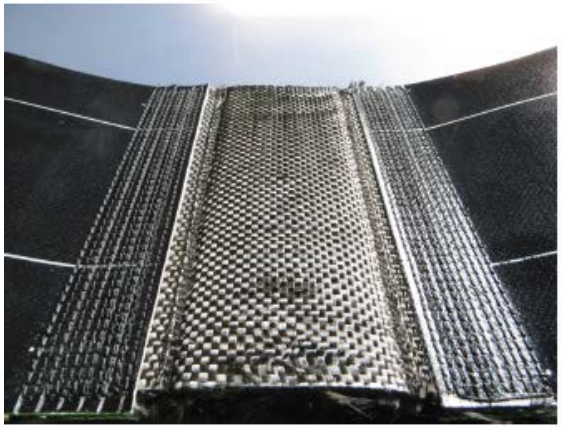
Model SI-1 Run (Sped Up 7.5 X)



- Phenolic infused joint shielding stack recession < 12 Layer gore.
- CFD validated for rearward step and joint edge flight designs.

Structural: Sub-Scale (2/5)Joint Tensile Testing

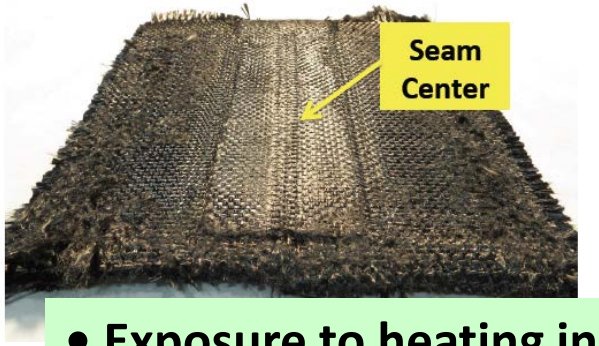
Control: unheated, infused (wet) seam. 1120 lbf/Inch

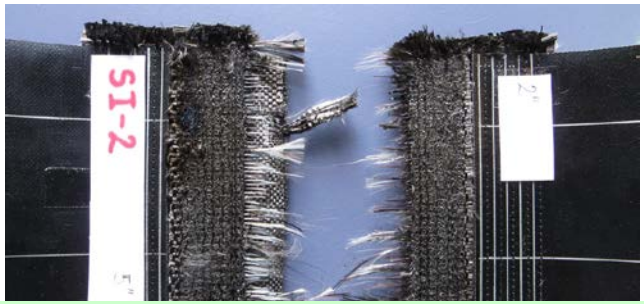


Model SI-1 arcjet heated, wet joint. Pre-Tensile test

Model SI-2 arcjet heated, wet joint. Tensile tested

Joint Sample	Tensile lbf/inch
"Dry", unheated	807
Wet, unheated	1120
SI-1, wet, heated	200.2
SI-2, wet, heated	181.6





- Exposure to heating in the arcjet flow causes large drop in tensile strength.
- Only element that failed was the tie fabric : "Combing" for the unheated and embrittlement for the heated samples.

Summary and Forward Work

Summary

- Carbon stitching did not fail. *A break through ! Learned how to infuse carbon fabrics.*

- As expected [4, 5] the gore carbon fabric did not fail or suffer pull out from stitching.

- Tie fabric failed for both control and arcjet tested samples. Solvable problem.

- "Wet" shielding stack more resistant to Venus entry heating than gore fabric.

- Joint tensile strength suffers large drop <u>after</u> arcjet heating.

- 2" wide joints are "there" for Nano-ADEPT (Mars) – Peaks are 100 W/cm^2 & 100 lbf/inch

- Confident that 4"-5" joints can meet ADEPT-VITaL (Venus) flight requirements.

Forward Work

- Evaluate possible solutions for loss of joint tensile strength:
  - *new tie fabric candidates.*
  - *Heat sinking joints to ribs.*
  - *TTT phenolic infusion of joint.*

- Resolve mechanical issues that obviated measuring tensile loads during arcjet heating

- Investigate physics of loss of tensile strength from heating:
  - *Change in crystal structure.*
  - *SEM of SI-1 & SI-2 joints to evaluate wicking into tie fabric.*

- Complete analysis of data from current arcjet and tensile tests : Pyrometer, IR camera and high definition videos of joint failure during tensile testing.

- Test Joint/Fabric Interfaces

Acknowledgment and References

This Research would not have been possible without work by Ames' Interaction Heating Facility (IHF) Operations Staff Led by Test Engineer, Ms. Imelda Terrazas-Salinas

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[2] Venkatapathy,E., et.al. *Transformable Entry System Technologies (TEST) Concept Feasibility Report,* NASA TM-2011-21597 2011

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[4] Arnold, J. O., Laub, B., Chen, Y-K, Venkatapathy, E., Prabhu, D. K., and Bittner, M. E., *Arcjet Testing of Woven Carbon Cloth for Adaptive Deployable Entry,* IPPW 10, San Jose State Univ. June *2013*

[5] Arnold, J. O, Peterson, K.H., Yount, B. C, Schneider, N., and Chavez – Gracia, J.,*Thermal and Structural of Woven Carbon Cloth for Adaptive Deployable Entry and Placement Technology*, AIAA Beach Decelerator Conference, Daytona Beach, FL. March 25-28 2013.