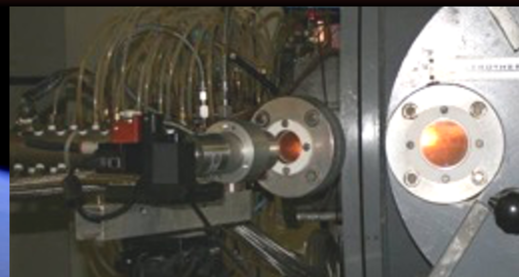
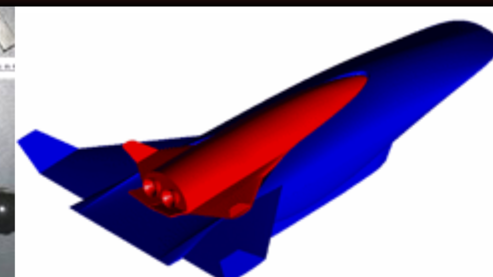
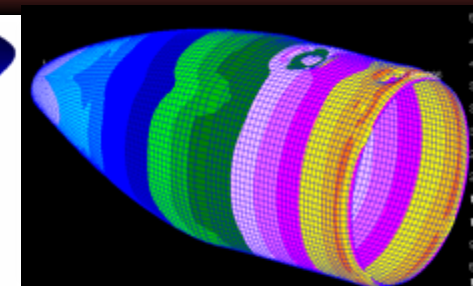





Hot Structure and High-Temperature Material Capability

Sandra Walker

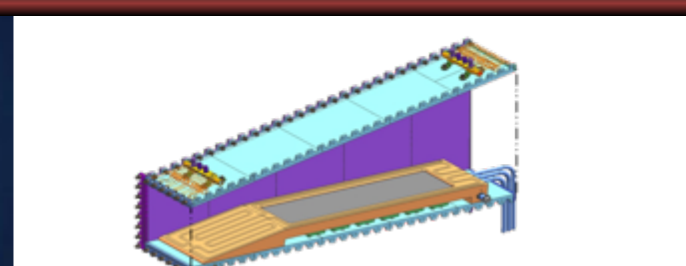
Structural Mechanics and Concepts Branch

NASA Langley Research Center

Hampton, VA

April 2021






Outline

- Overview
- Test Facilities
- Analysis Capability
- Recent Work
- Summary

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D305 Aerothermodynamics
Kelly Murphy, Head
Bill Wood, Asst. Head
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D308 Aeroelasticity
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Kamran Daryabeigi, Asst. Head
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Overview

NASA Langley Research Center (LaRC)
Hot Structure and High-Temperature Material Capability

- Technical expertise grounded in materials and processing, thermal and structures disciplines
- Utilizing in-house testing capability and other government/industry available experimental facilities
- Utilizing suite of analysis tools in research and development
- Utilizing SBIR program for basic research with Hot Structure Technology subtopic
- Advancing the state of the art in developing:
  - Hot Structure Concepts
  - Multi-Functional Concepts
  - Thermal Protection Systems
  - Insulation
  - Extreme Temperature Resin Synthesis and Composite Processing
  - Computational Modeling Guided Materials and Processing Development
  - High-Temperature Material Characterization
  - Improved Test Techniques
  - High Fidelity Thermal and Structural Analysis Methods
  - Damage Models/Fracture Mechanics based approach for Progressive Failure Analysis

8-Foot High-Temperature Tunnel (8-FT HTT)

- **Largest hypersonic aerothermal test facility in the US**
- **Accommodates large-scale 5-ft by 9-ft test models**
- **Provides testing capability at Mach 3, 4, 5, 6 and 7**
- **Simulates altitude: 20k ft to 120k ft**
- **Combustor stagnation pressure (up to 2000 psia)**
- **Vitiated air test gas (products of combustion, not just air)**
- **Visual data:**
  – IR imaging (high speed and low speed)
  – Photogrammetry
  – Engine diagnostic imaging
- **Radiant pre-heat lamps (up to 3000˚F)**
- **Utilized for testing hot structure and thermal protection system models**
- **Utilized for hypersonic engine testing**
- **Matched flight conditions for Hyper-X, HyFly, X-51**

8-FT HTT Facility

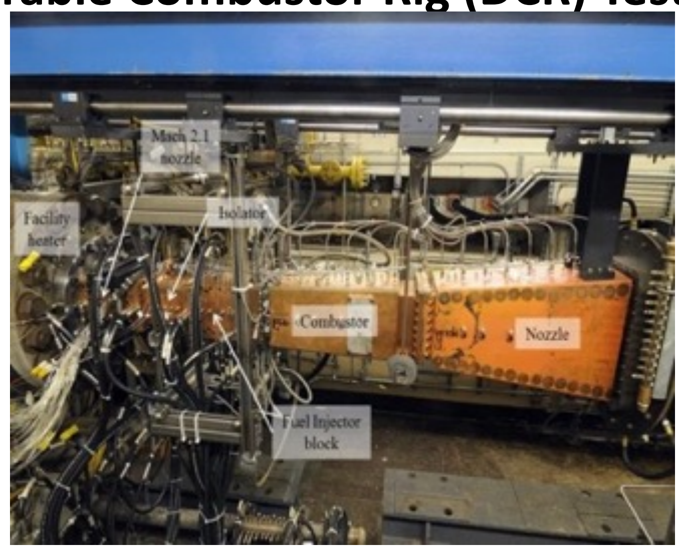
Hypersonic model in test chamber

[**POC**: Aaron Fuchs; aaron.w.fuchs@nasa.gov]

Direct-Connect Supersonic Combustion Test Facility (DCSCTF)

- Facility in LaRC Scramjet Test Complex
- Component Test Capability
- Mach: 4.5 – 7
- Total Temperature: 1300°R - 3000°R
- Test Time: 120 sec.
- Test Medium: Hydrogen-air combustion products with oxygen replenishment

The Durable Combustor Rig (DCR) Test Hardware

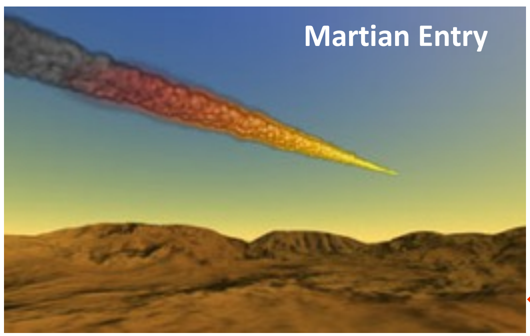


- The DCR hardware was fabricated for testing in the DCSCTF
- Provides a platform to test flight-weight, fuel-cooled, composite-heat-exchanger panels
- Assess structural and mechanical design capabilities

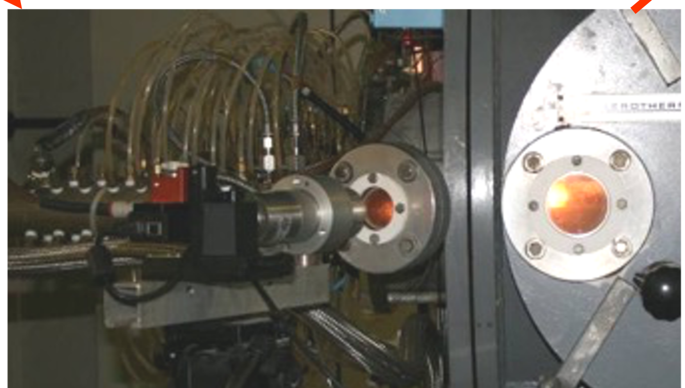
[**POC**: Bert Senter; hubert.h.senter@nasa.gov]

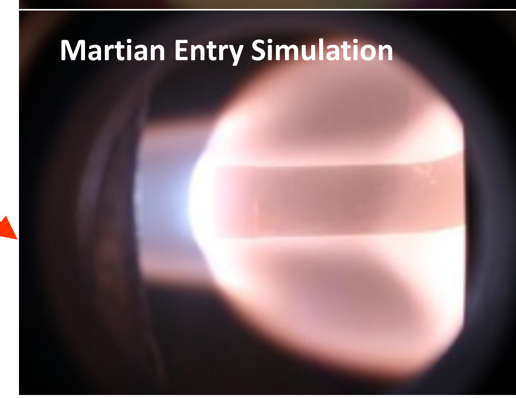
Hypersonic Materials Environmental Test System (HyMETS)

- Provides simulated hypersonic flight test capability for screening of material response



HyMETS Arc-jet Facility





Facility Characteristics

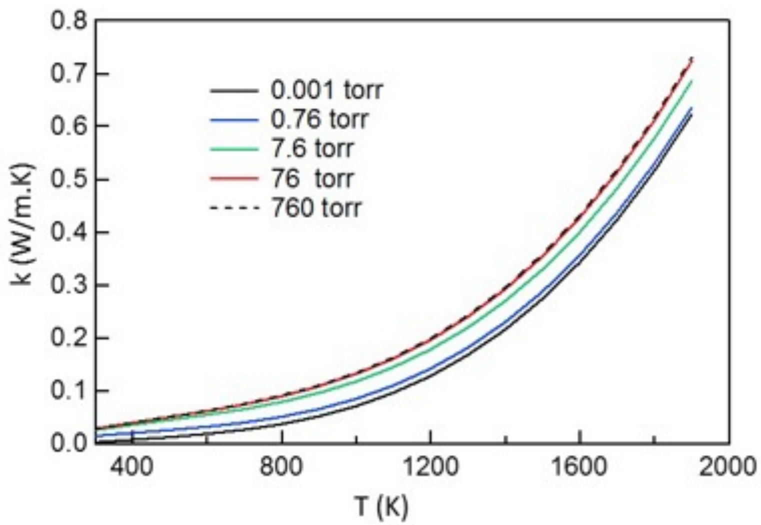
- Test Medium: Air, N_2, O_2, CO_2, mixtures
- Flow Mach Number: 5
- Temperature: 1800°F to 5000°F
- Stagnation Pressure: 0.018 atm to 0.072 atm
- Cold Wall Heat Flux: 100 BTU/ft^2 sec. to 400 BTU/ft^2 sec.
- Bulk Enthalpy: 2400 BTU/lbm to 12,000 BTU/lbm
- Test Specimen Size: 1-in. diameter; pucks (typical) or other geometries

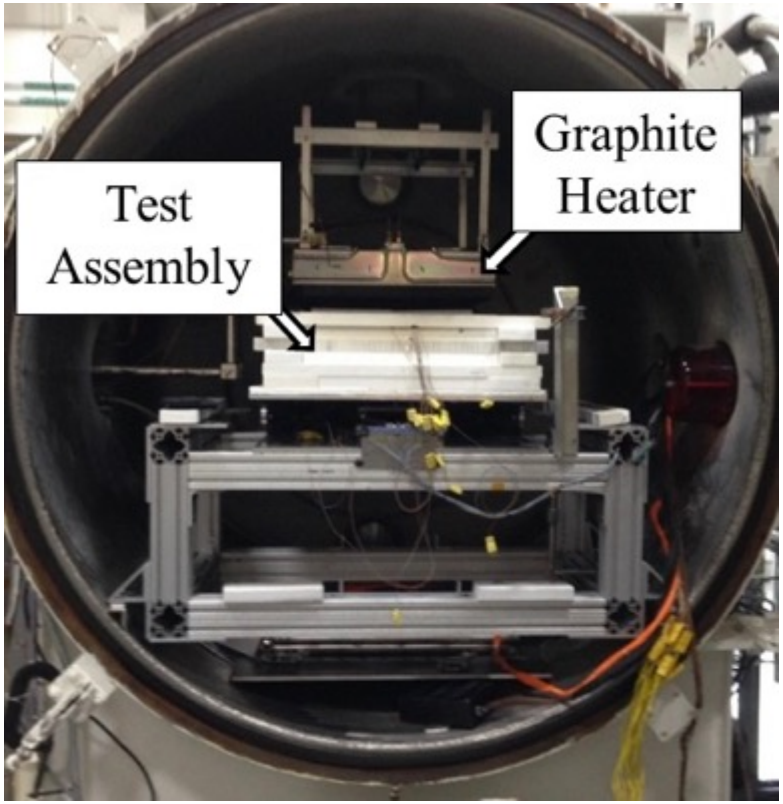
[**POC**: Scott Splinter; scott.c.splinter@nasa.gov]

Thermal Vacuum Chamber Facility

- Thermal property measurement of high-temperature insulation
  - Pressure range: 0.001 torr - 760 torr
  - Temperature range: 300 K – 1900 K
- Development of high-fidelity physics-based heat transfer models based on test data

Measured Thermal Conductivity of Alumina Paper Insulation



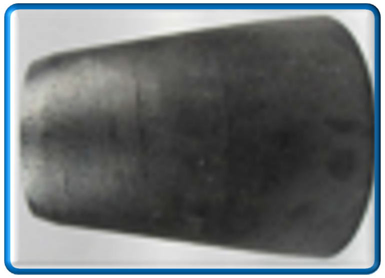


Thermal Vacuum Chamber

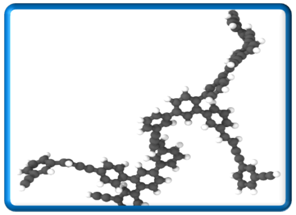
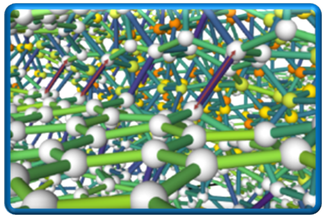
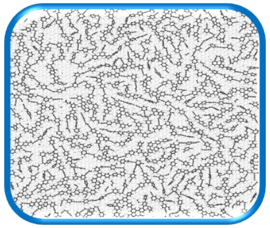
[**POC**: Kamran Daryabeigi; kamran.Daryabeigi-1@nasa.gov]

Carbon-Carbon Composites Materials and Processing Development

- Composite matrix development
  - Computational modeling of carbon-carbon precursors
  - Design and synthesis of matrices for carbon-carbon composites
- Composite processing development
  - Net shape composite design concepts
  - Process modeling
  - Process optimization
- Materials Testing
  - Polymer characterization
  - Composite testing
  - Environmental testing
- Carbon-carbon Composite Development Facilities
  - Synthesis hoods
  - Pyrolysis furnace
  - Graphitization furnace

Synthesis and Preform Concepts

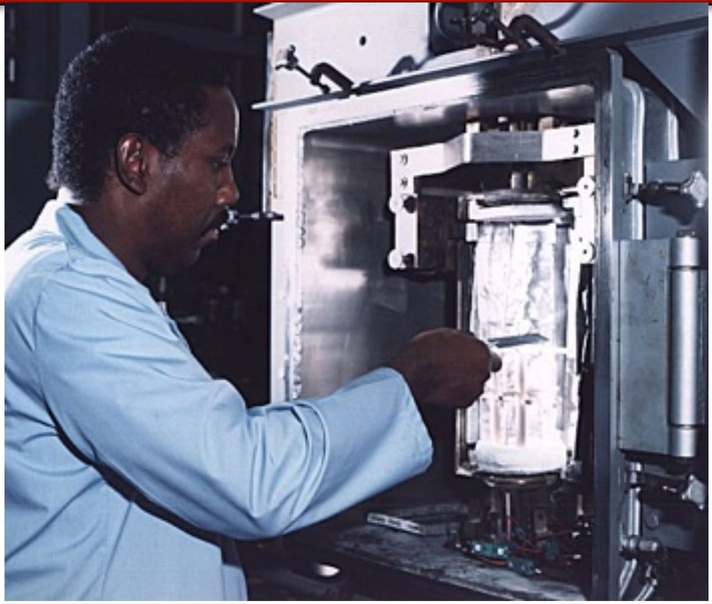
Computationally Guided Synthesis & C-C Composite Processing


Pyrolysis and Graphitization Furnaces

[**POC**: Emilie J. Siochi; emilie.j.siochi@nasa.gov]

Multiparameter Mission Simulation Facility

Applies simulated flight profile conditions to subcomponents for response evaluation



Types of Testing

- Simulate any subsonic, supersonic or hypersonic vehicle airframe temperature/pressure load profile within operational boundaries of facility
- Static exposure of materials
- Tensile stress oxidation exposure of materials
- Oxidation-protection coating evaluation
- Any metallic or composite material can be tested

Facility Characteristics

• Test medium	Air, Inert, Vacuum, CO_2
• Pressure	1×10^{-5} to 760 mm Hg
• Pressure control	0.1 to 760 mm Hg
• Temperature	70°F to 3100°F
• Load	0 to 5000 lbs tension
• Test Section diameter	5 in.
• Test Section Length	9 in.
• Max. specimen size	4 in. by 8 in.

Other Facility Features

- Three identical test chambers
- Cyclic exposure testing
- Real time temperature/pressure/load control
- Capability to test in absolute pressure oxidizing atmosphere environment up to 3100°F
- Test atmosphere can be supplied by compressed gas cylinders, allows for unique test atmospheres (Earth, Martian, etc.)

[**POC**: Valerie Wiesner; Valerie.L.Wiesner@nasa.gov]

Thermal / Mechanical Testing Capabilities

Load Frame Test Machines in B1148 and B1256C

- Specimen Size: coupon to 7-ft H by 5-ft W
- Tension/Compression/Cyclic/Creep Loading
  - 5 kip*
  - 22 kip
  - 50 kip
  - 100 kip inverted cryo^
  - 110 kip
  - 220 kip*
  - 300 kip*
  - 500 kip*
  - 600 kip*
  - 1 M lb*
- Environmental Chambers: -320°F to 600°F for specimen sizes up to ~ 1-ft

Impact Machines

- Drop Weight Impact
  - Max Height = 7 ft
  - Max Load = 25 lb
- Static Indentation: 5000 lb

Unique ad-hoc thermal-structural testing

22-Kip Test Machine

*Room temperature testing only; no environmental chambers currently operational

^Capability down to -420 °F with liquid helium

[**POC**: Tom Haynie; waddy.t.haynie@nasa.gov]

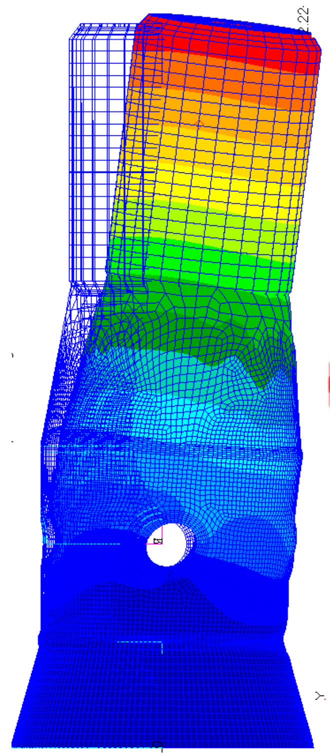
Thermal and Structural Analysis Capabilities

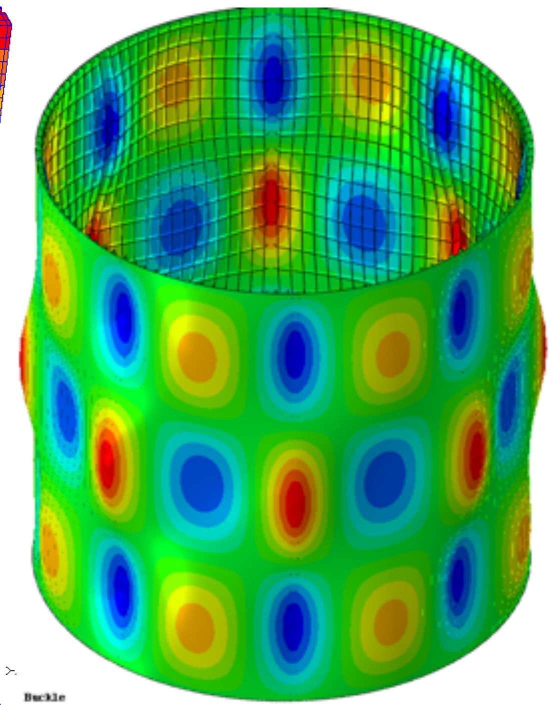
In-house machines:

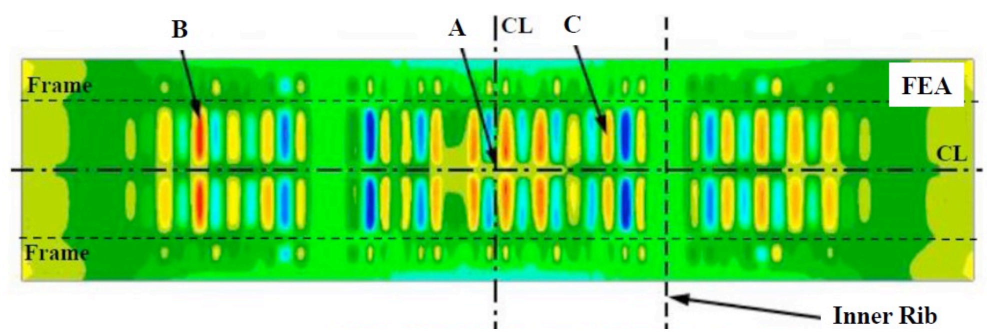
- Personal desktop/laptop computing
- Six symmetric multiprocessing (SMP) machines with multiple processor capability
  - Up to 96 Cores and 3 TB RAM

Commercial Analysis tools

- Finite Element Analysis
  - CAE / ABAQUS
  - MSC PATRAN / NASTRAN / Marc
  - STAGS
  - COMSOL
- BOSOR / PANDA2
- Hypersizer
- Mathematica
- Tecplot
- MATLAB
- Sierra Mechanics
- R
- CREO
- Fortran
- C++
- Python
- FIAT
- Octave



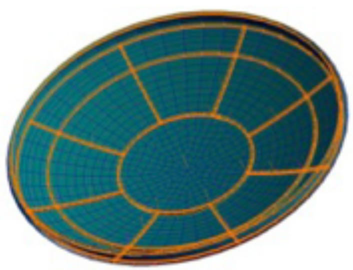


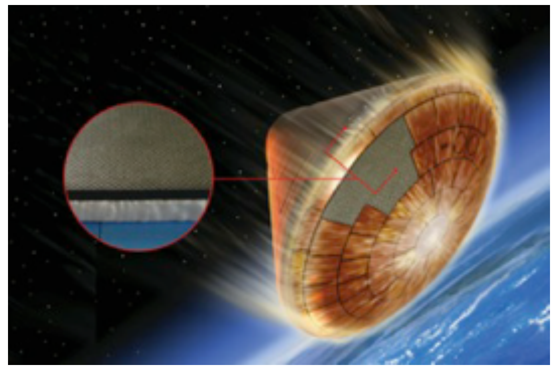


RECENT WORK

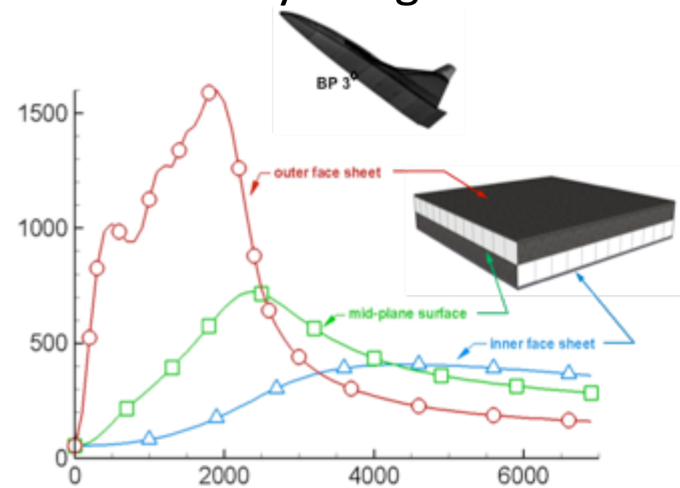
Hot Structure/Multi-Functional Concepts

Developing hot structure heatshields for planetary entry

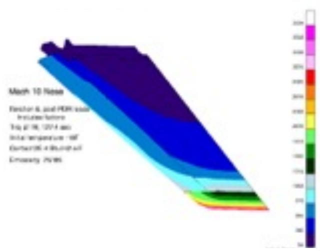


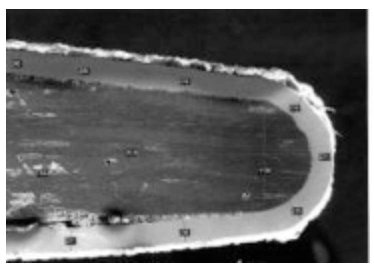


Structurally Integrated TPS



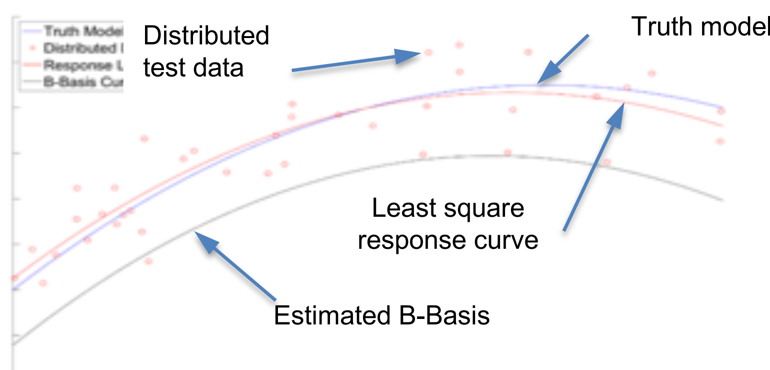
Sharp leading edges





Material Characterization

– Thermal and mechanical properties
– Impact damage
– Damage progression
– Coating degradation, etc.

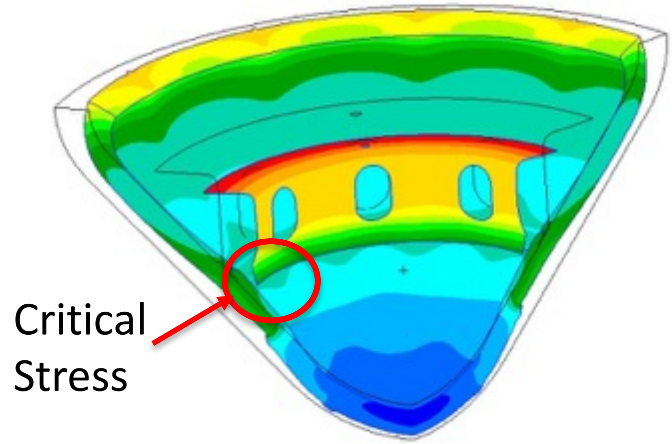


[**POC**: Sandra Walker; sandra.p.walker@nasa.gov]

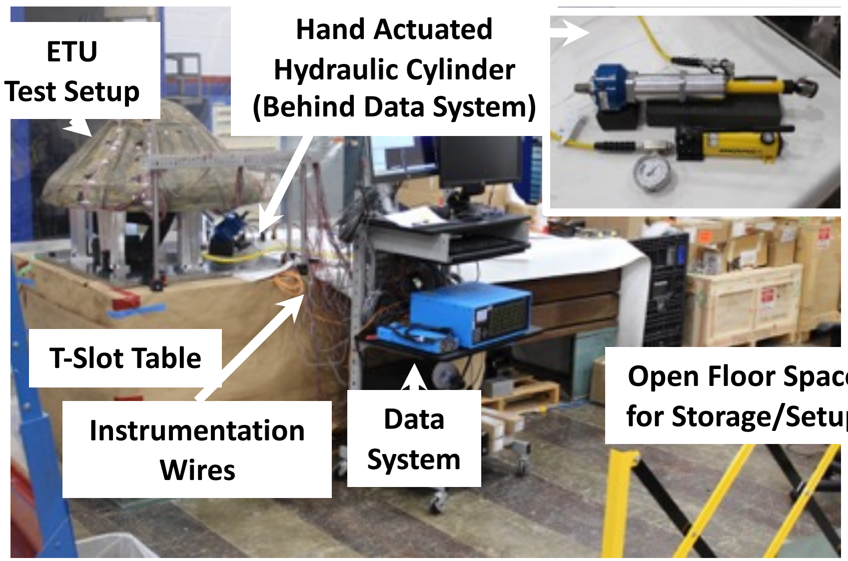
Heatshield Concept Development

Heatshield for Extreme Entry Environment Technology (HEEET)

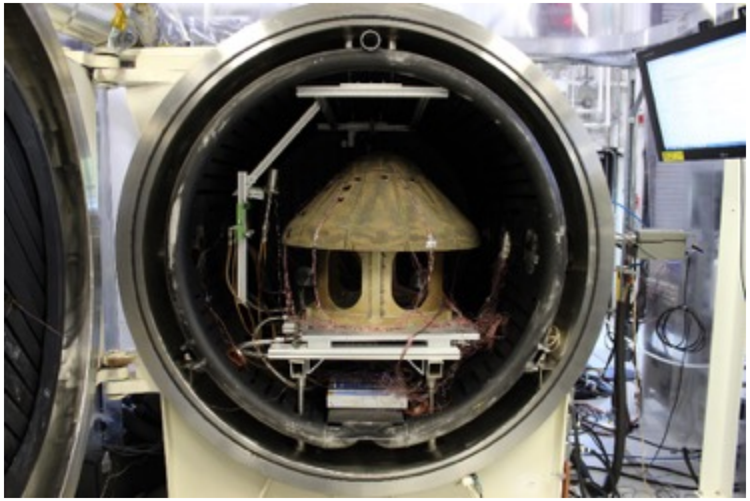
- Developed progressive damage analysis methodology
- Conducted tests to evaluate performance of 1-m diameter Engineering Test Unit (ETU)
- Applied both mechanical and thermal loads expected on-orbit and during planetary entry



Static Point Load Tests



Static Pressure and Thermal Vacuum Tests

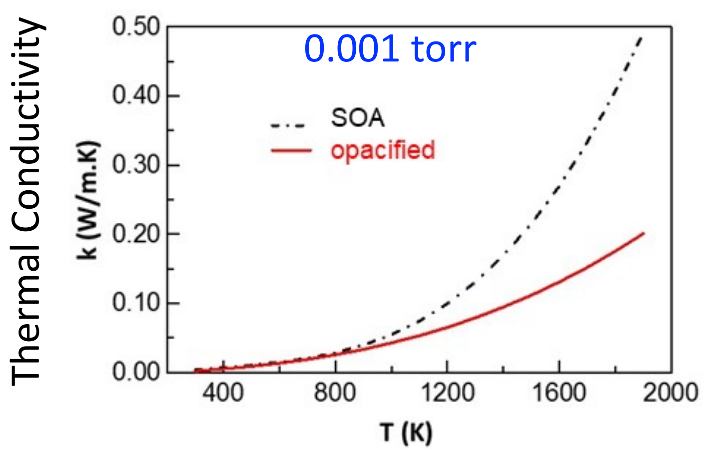


High Temperature Flexible Insulation Development

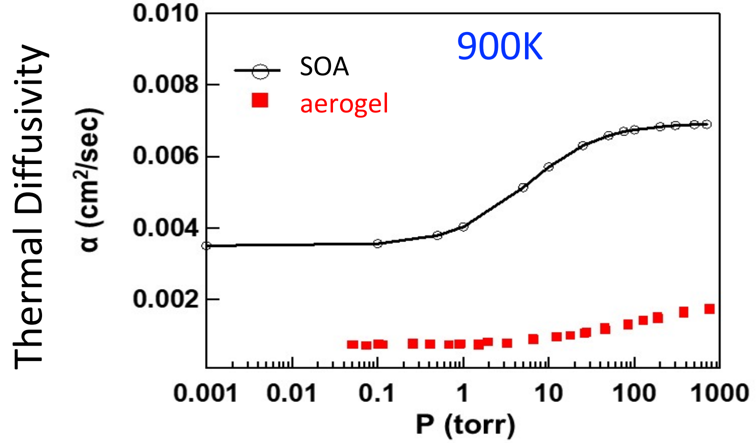
- Utilize physics-based heat transfer modeling to design and optimize high-temperature insulations with efficient embedded additives to suppress various modes of heat transfer

Additive	Heat Transfer Suppression
opacifier	radiation
aerogel	gas conduction

Radiation Attenuation



Gas Conduction Attenuation

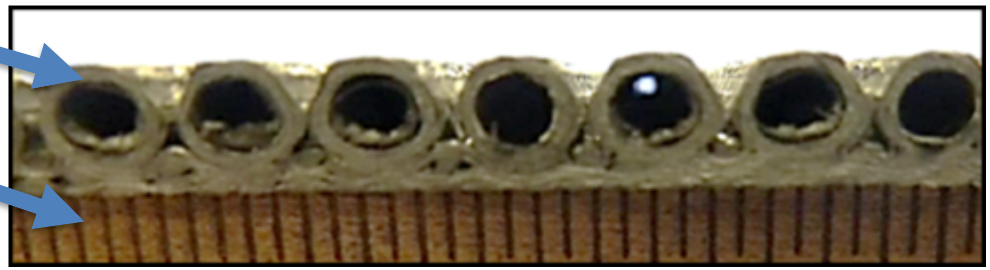


[**POC**: Kamran Daryabeigi; kamran.Daryabeigi-1@nasa.gov]

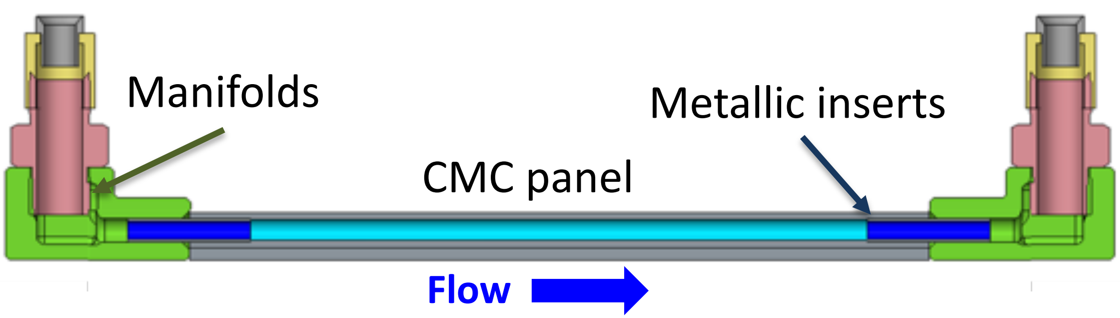
Carbon Matrix Composites (CMC) Heat Exchanger (HEX) Project Overview

- Application: CMC HEX for scramjet combustor wall
- Study indicated a performance benefit of CMC in scramjet flowpath

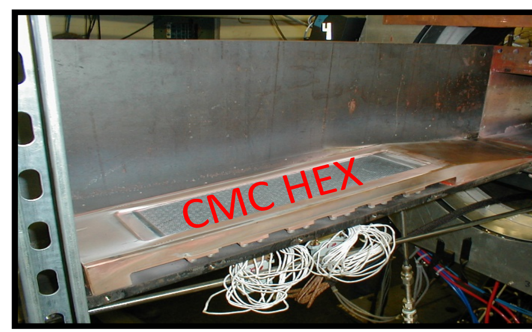
CMC HEX panel concept
(End view in flow direction)



Example CMC HEX panel components
(Side view cross section)



Durable Combustor Rig (DCR)

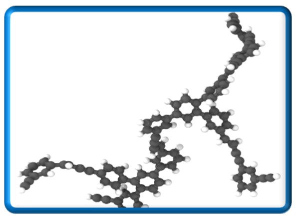


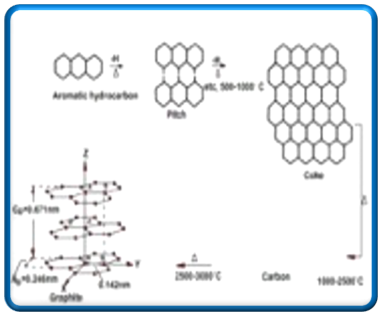
[**POC**: David Glass; david.e.glass@nasa.gov]

Affordable Reusable Extreme Temperature Structural Materials

Goal:

- Explore alternative approaches to the fabrication of reliable Carbon/Carbon (C/C) composites to overcome acknowledged challenges with this material class





Computationally Guided Design & Synthesis of C-C Matrix

Composite Process Development – Stitched Preform towards Net Shape Fabrication

Composite Component Testing

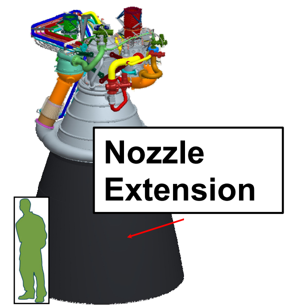
Technical Approach:

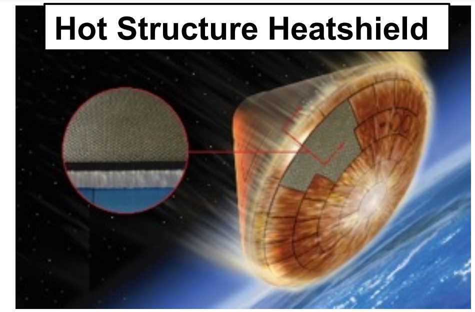
- Explored approaches for reducing processing time and improving the reliability of part dimensions
  - Developed new chemistry compositions as appropriate to improve processability
  - Prototyped composite component for testing in use environment for feedback on composite performance

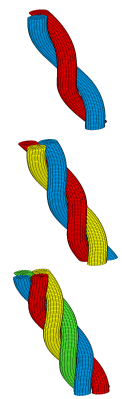
[**POC**: Emilie J. Siochi; emilie.j.siochi@nasa.gov]

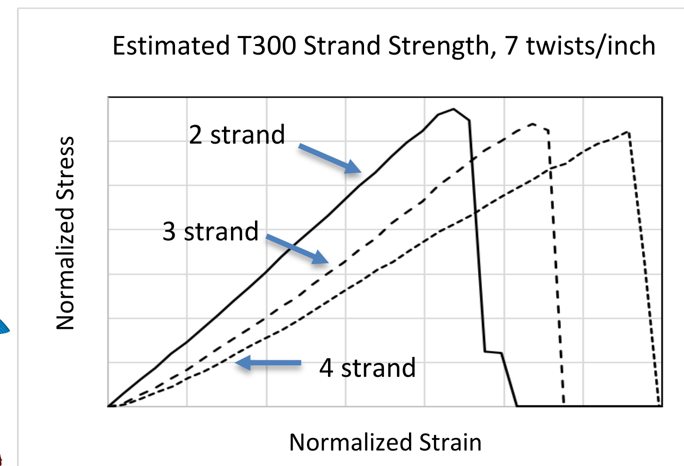
Hot Structure Concepts and Materials for Space Exploration

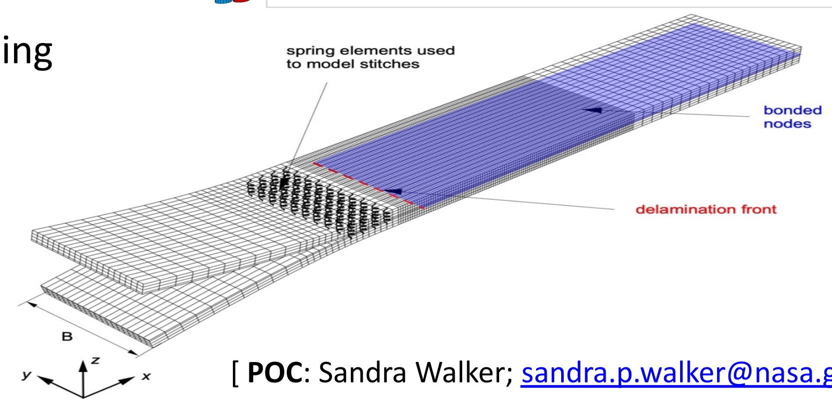
- **Office of Chief Engineer (OCE) Engineering Research & Analysis Project**
- **6-month project: April to September 2020**
- **<u>Goal:</u>** Develop hot structure concepts, integrated with thermal protection system (TPS), that are reliable, lightweight, reusable, and dimensionally stable; for aerocapture, precision landing and nozzle extensions
- **<u>Accomplishments:</u>**
  - Initiated development of computational tools for modeling the material fabrication process using an atomistic approach; extended the tool to allow modeling of the char conversion process
  - Trade study on generic toroidal section geometries revealed critical interlaminar stress load cases
  - Developed micro-mechanical modeling of stitching thread to predict behavior and mechanical properties of stitches
  - Preliminary fracture-based analysis revealed benefits of stitching on carbon-carbon laminate performance
  - Procured test specimen materials for V & V











[**POC**: Sandra Walker; sandra.p.walker@nasa.gov]

Summary

- NASA Langley Research Center (LaRC) has substantial capability in developing advanced hot structures and materials technology for high-temperature applications

- LaRC facilities provide a suite of capability to test advanced concepts under simulated environments/loads experienced during hypersonic flight/high-temperature applications

- Current research at LaRC is focused on developing affordable and durable multi-functional materials, insulation systems and advanced integrated concepts