Flexible Thermal Protection System Development for Hypersonic Inflatable Aerodynamic Decelerators

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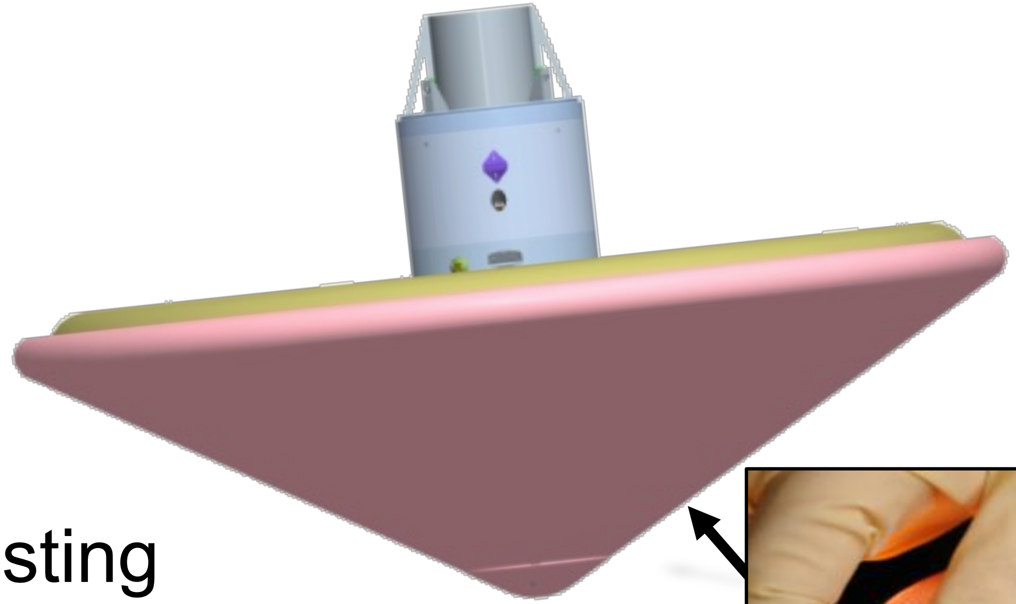
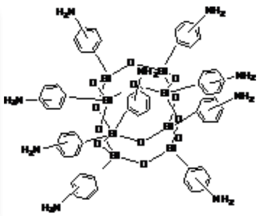
Outline

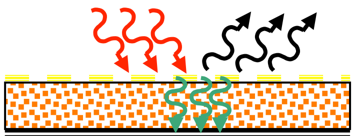
- Flexible Thermal Protection Systems (FTPS) Overview
- Ground Testing
- Thermal Modeling
- Margins Policy
- Material Catalysis
- Material Lifecycle Testing
- Advanced TPS Development
- Conclusions and Acknowledgments



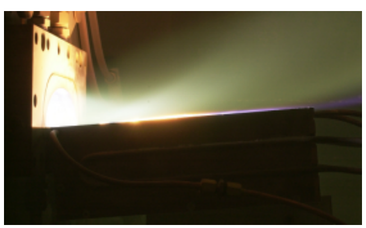
HIAD-FTPS Integration Overview

Flexible TPS Development and Qualification





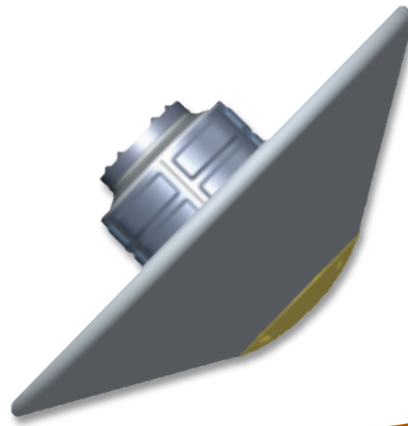
$$\rho C_p \frac{\partial T}{\partial t} - \frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x}\right) = 0$$



Sub-Orbital Flight Testing

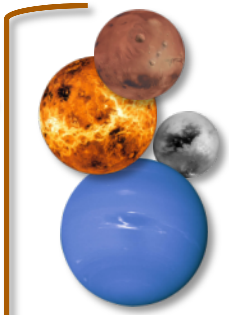
Inflatable Re-entry Vehicle Experiments

System Demonstration



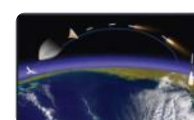
High-Energy Atmospheric Re-entry Test (HEART)

Future Missions

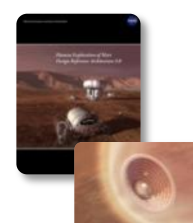


Robotic Missions

Crewed Earth Return



DoD Applications



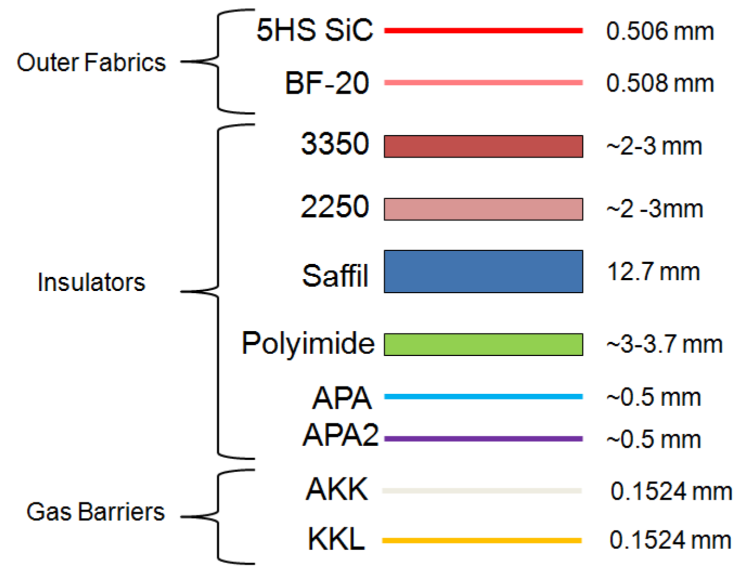
Technology Development & Risk Reduction

2012 ***2013*** ***2015***

FTPS advances technologies supporting flight project needs

FTPS Overview

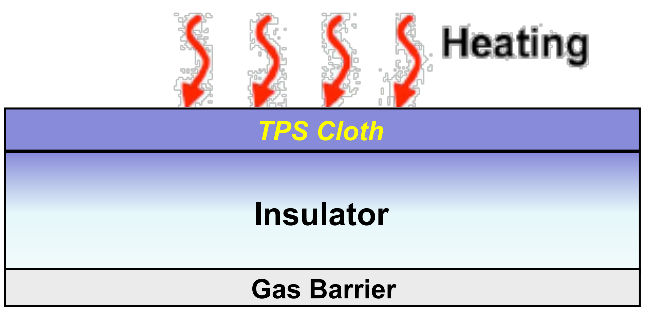
- **Development of FTPS for inflatable re-entry vehicles**
  - Multi-center NASA effort with industry and academia partnerships
  - Developing, characterizing, and testing emerging concepts and building analysis tools for new flexible TPS layups
- **FTPS are designed to maintain structural component interface temperatures and survive reentry aerothermal loads**
  - FTPS are designed to carry the entry mechanical and thermal loads



Flexible Thermal Protection Function

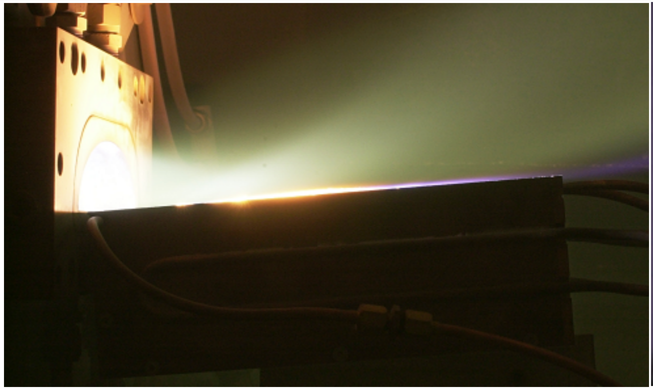
Heat Rate	Refractory Cloth
Heat Load	Insulator
Permeability	Gas Barrier

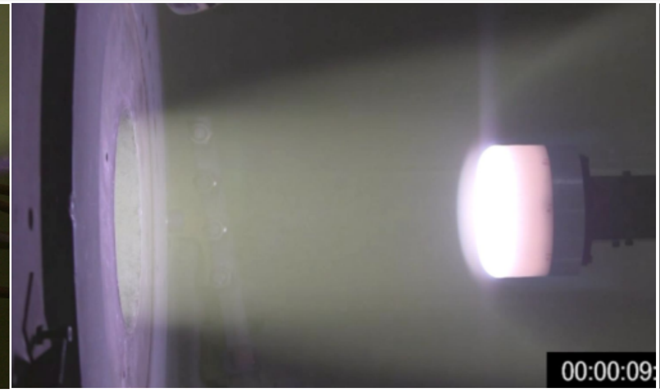
Modular design using functional layers

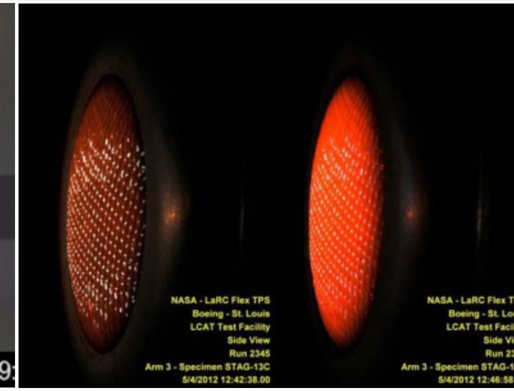


Ground Testing at Large-Core Arc Tunnel

The Boeing Company

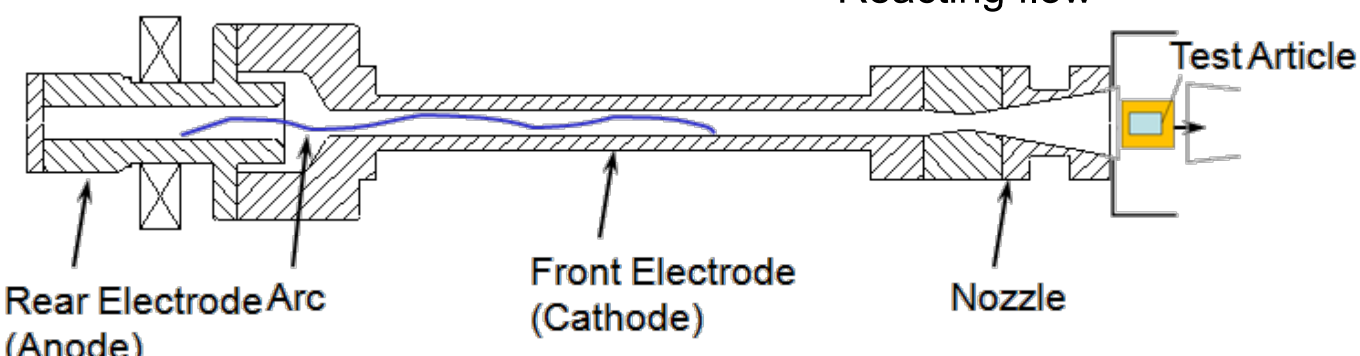






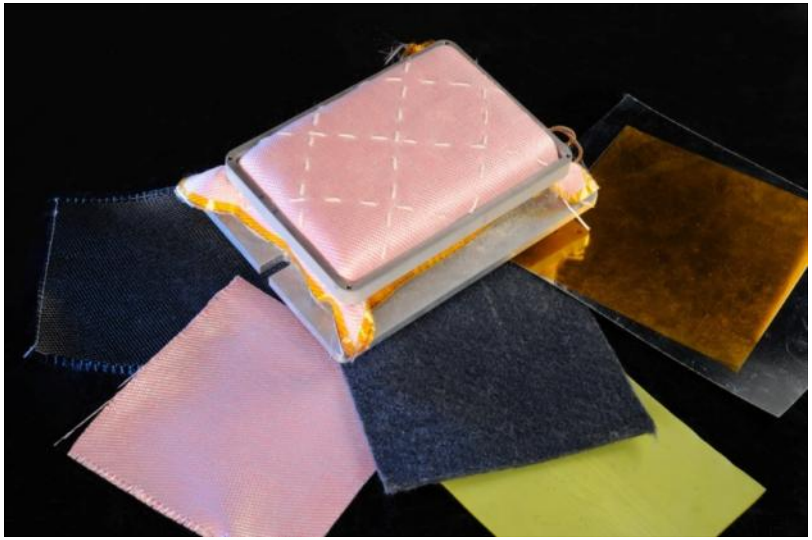
- Ground Test Objectives
  - Develop test techniques for evaluation of FTPS samples
  - Test coupon samples at stagnation and shearing conditions
  - Test at relevant mission heat flux and pressure

- LCAT – Huels arc heater
  - 18” and 27” cathodes with secondary air and12” mixing section
  - Heat flux range 5-150 W/cm^2
  - Surface pressure range 1-9 kPa
  - Shear range 30-270 Pa
  - Reacting flow



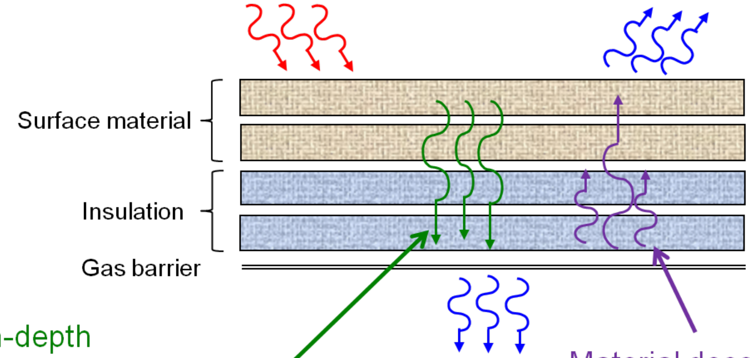
Thermal Modeling

- **Thermal Modeling Objectives**
  - Develop high fidelity COMSOL thermal model for candidate material layups
  - Validate COMSOL model against ground test data
  - Characterize to thermophysical properties to high fidelity



Convective heating

Radiative heat transfer to the surroundings



In-depth
•Solid conduction
•Gas conduction
•Internal radiative transport

•Material decomposition
•Pyrolysis gas flow
•Pyrolysis gas convective heat transfer

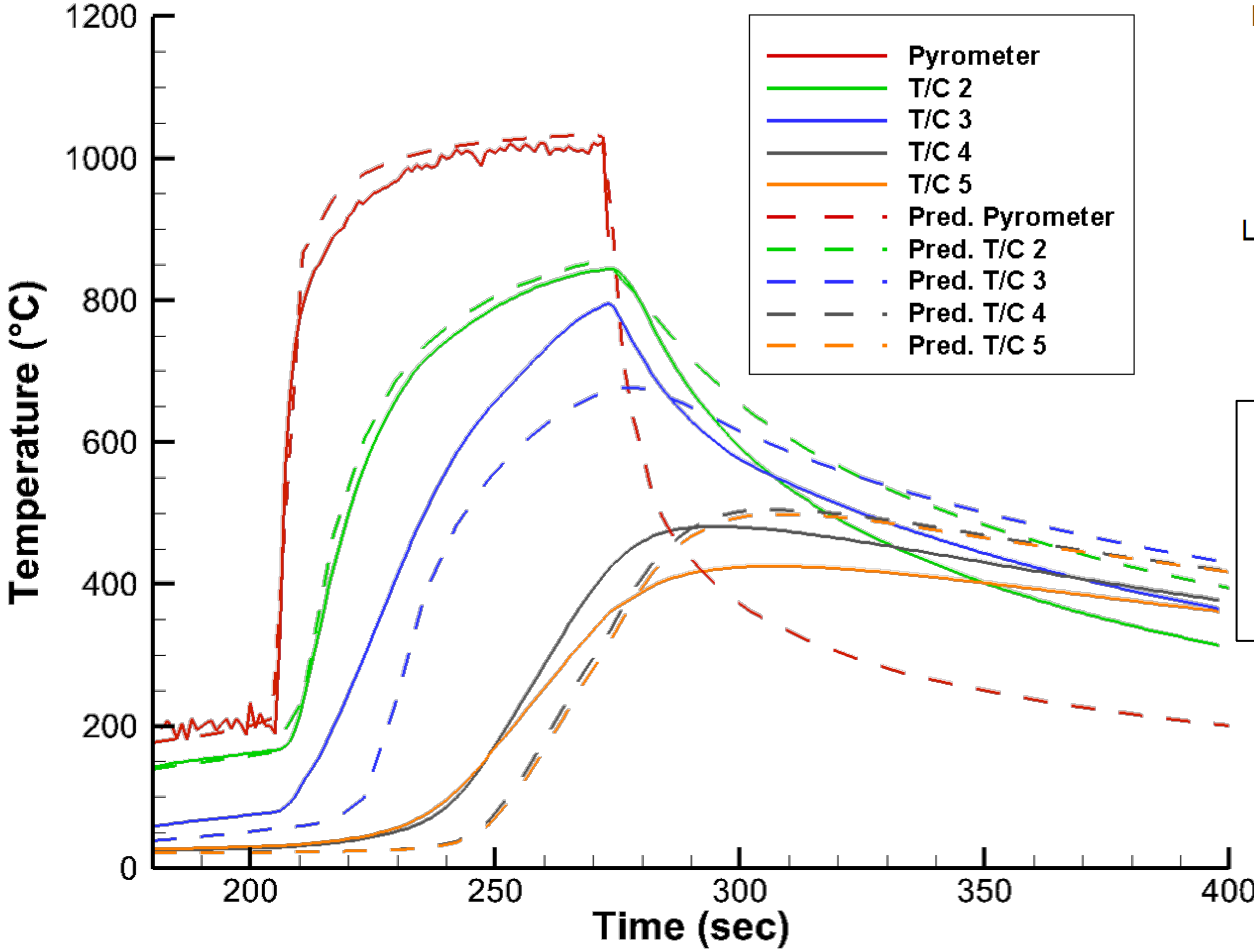
Pressure and temperature dependant

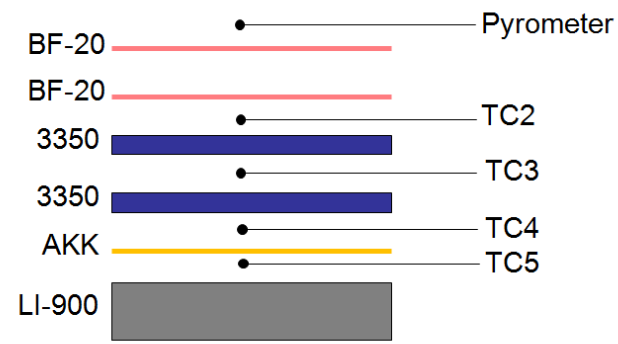
- **Flexible TPS Thermal Model v0.0d**
  - Gas advection*
  - Material decomposition*
  - Radiative transport
  - No requirement for contact conductance
  - Diffusion based

* Framework in place, not yet active in model

Test vs Analysis Comparison

LCAT Results vs COMSOL V0.0d Model (20 W/cm² TPS)

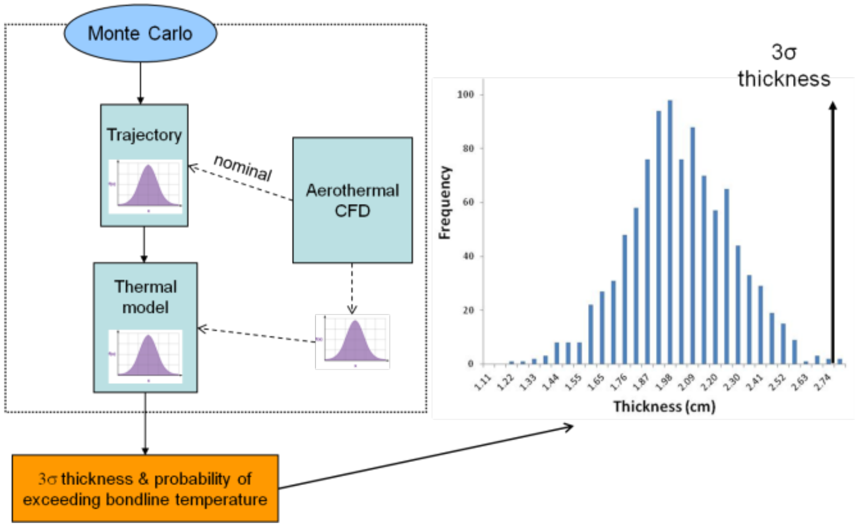


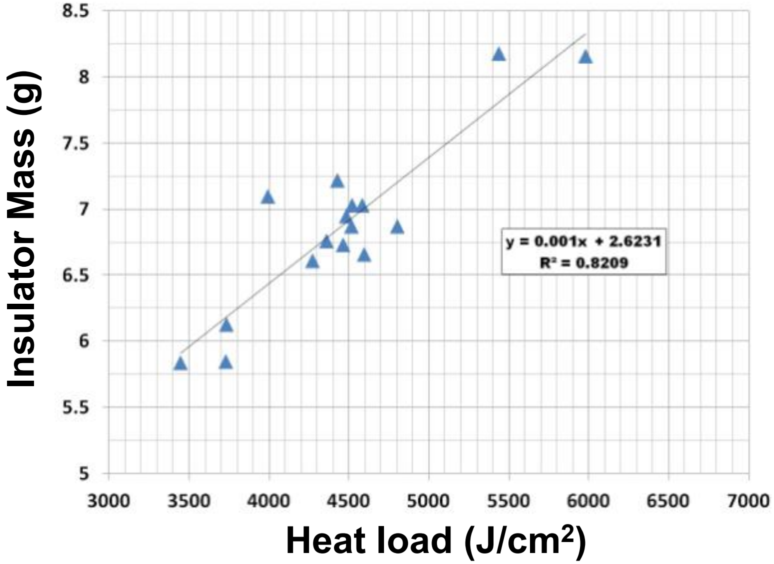


Spatial Distribution of Temperatures at Discrete Times

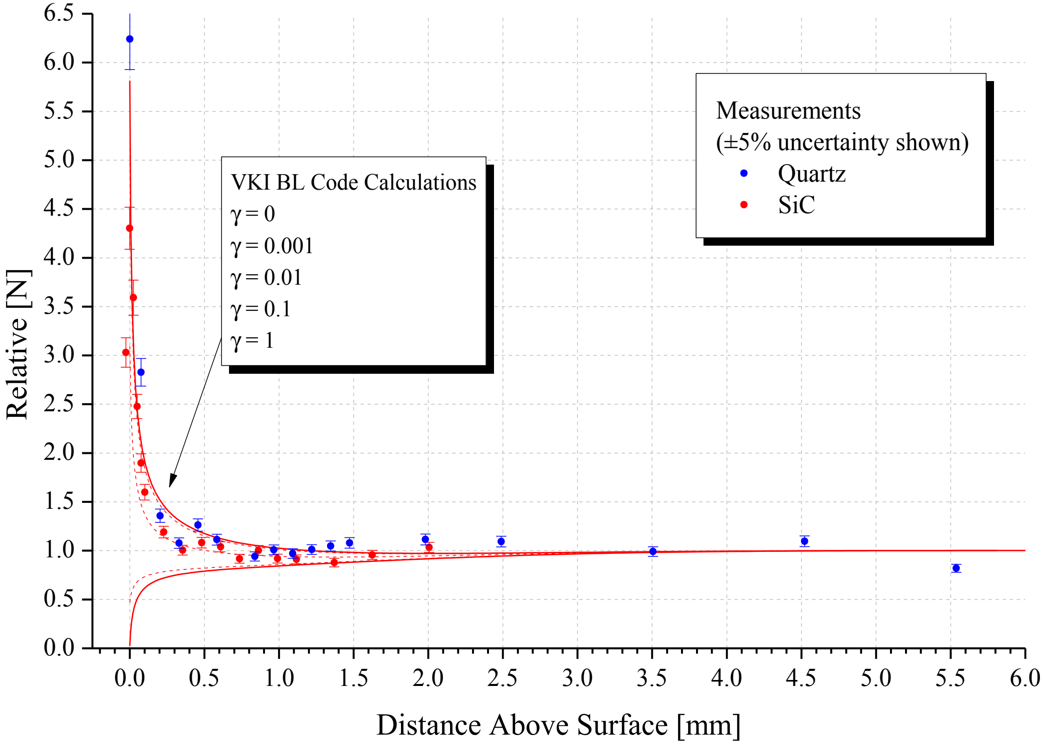
Thermal Margins Policy

- **Margins Policy Objectives**
  - Establish a rational design margins policy for FTPS that directly addresses modeling and material response uncertainty using a Monte Carlo simulation capability
  - Link FTPS sizing operation to trajectory dispersion and aerothermal Monte Carlo analysis routines
  - Predict time-resolved bondline temperature distributions that can be used to establish performance reliability intervals





Surface Catalysis
(Monolithic SiC Plugs & Fabrics)

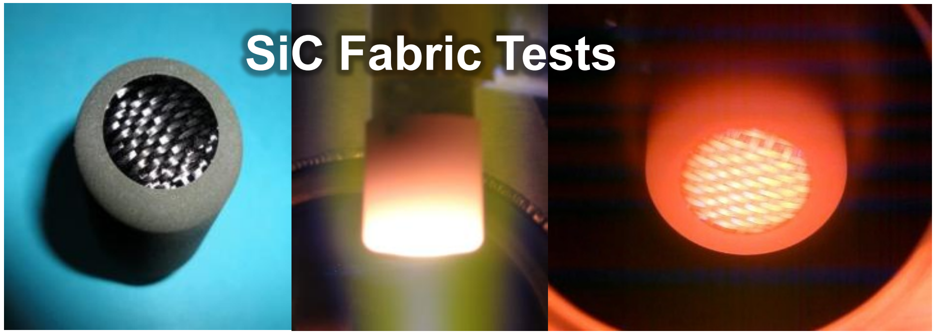


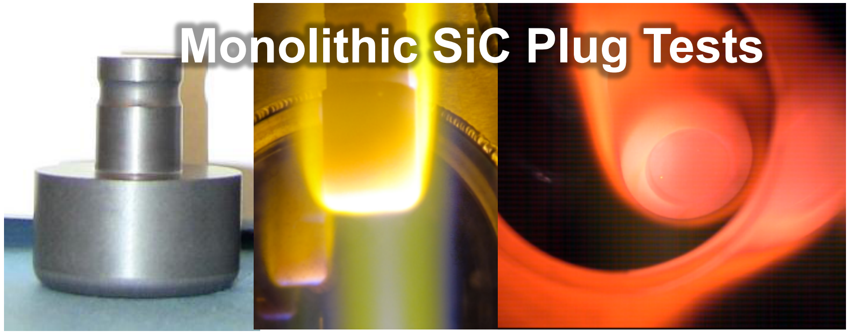
Catalysis Objective

- Characterize monolithic plug materials versus fabrics in N_2, O_2, and NO environments

Results

- Relative N atom concentration measurements for quartz and monolithic SiC (α)
- Increasing concentration toward wall indicates low surface reaction rate
- SiC (α) is slightly more catalytic than quartz for Tw = 1460 K



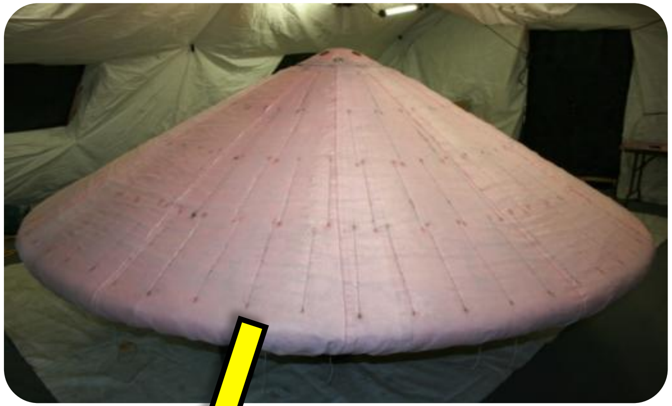


Material Lifecycle Testing

- Evaluate general and local degradation of FTPS as a function of packing, storage on orbit, and deployment

- Lifecycle Objectives
  - Develop techniques to characterize effects of pack, long duration stowage at pressure and temperature, & deployment
  - Identify FTPS tolerance limits for key environments
  - Establish predictive relationships in order to estimate system performance of aged FTPS
- Areas of interest
  - General acreage
  - Seams / joints
  - Manufacturing anomalies

Deployed 3-m FTPS



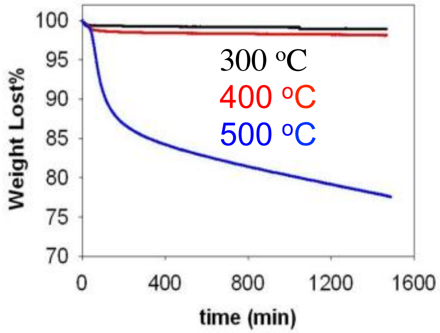
Packed 3-m FTPS

Polyimide Aerogel Development

- **Why develop polyimide aerogels?**
  - Baseline material (commercial aerogel composite) particulates in use
- **Polyimide Development Objectives**
  - Develop flexible, foldable insulation for inflatable decelerators
- **Solution**
  - Cross-linked PI aerogels have similar low thermal conductivity
  - Fabricated as flexible, thin films
  - 2-5 times stronger than polymer reinforced silica aerogels at comparable density, higher temperature stability
  - Collaboration with University of Akron for scale up

3-foot long film made at University of Akron

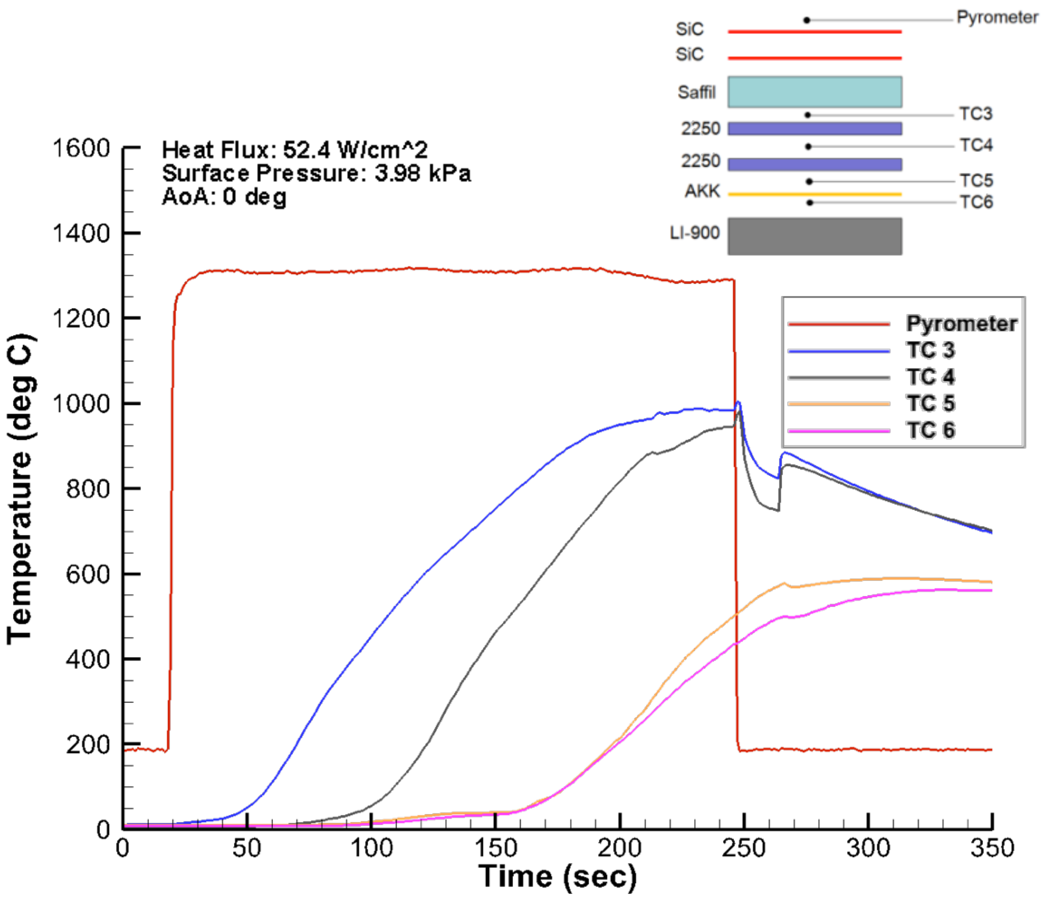
Flexible polymer aerogel film

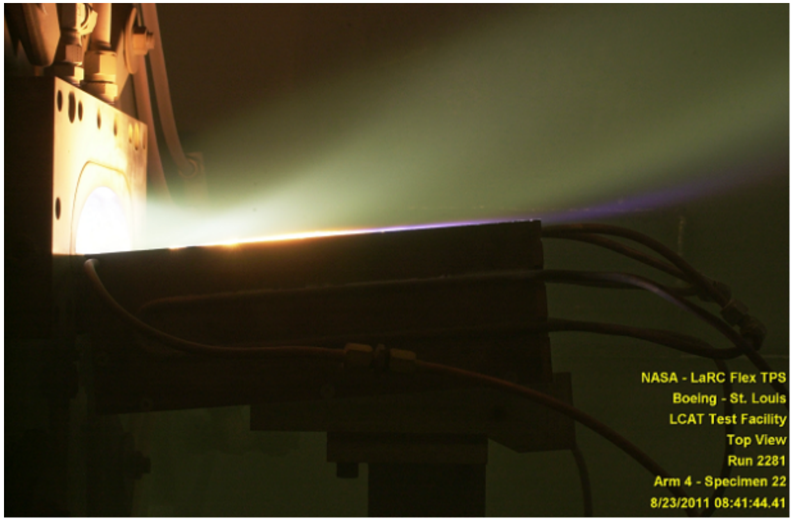


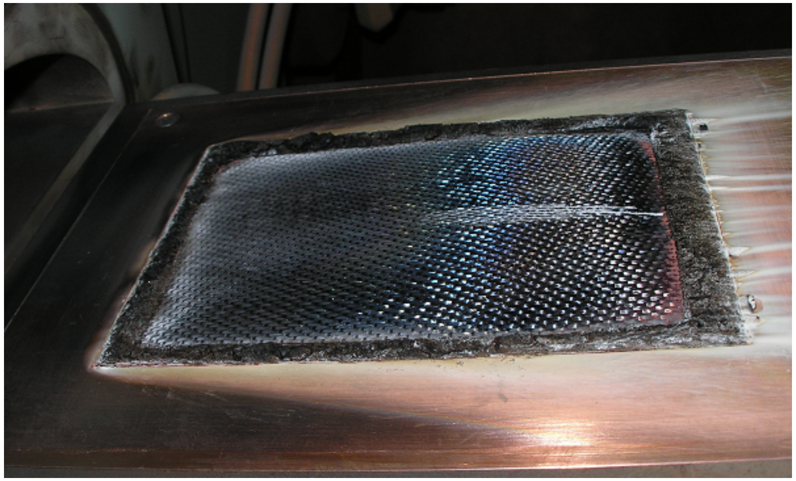
Very little weight loss up to 400C

Advanced TPS Development

- 50 W/cm^2 TPS Test of SiC Fabric







Conclusions

- Stagnation and shear testing techniques have been developed for the LCAT facility to support code development and FTPS development.
- Thermal modeling of physics-based processes have been coded in COMSOL and validated against ground test data for IRVE-3 TPS.
- Design margin policy for FTPS that incorporates load and material response uncertainty has been established using Monte Carlo simulation techniques.
- Material catalysis measurements of outer fabric materials for N_2 reactions have been completed.
- TPS Lifecycle techniques have been established to age materials to evaluate material degradation when packed and stowed for long durations.
- Advanced TPS development efforts have identified an optimized aerogel insulator which is flexible, strong, and can withstand temperatures up to 400-500°C.

Acknowledgements

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