Flexible Thermal Protection System Development for Hypersonic Inflatable Aerodynamic Decelerators

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Outline

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• 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

Sub-Orbital Flight Testing

System Demonstration

Future Missions

FTPS advances technologies supporting flight project needs

Flexible TPS Development and Qualification

Sub-Orbital Flight Testing

System Demonstration

Future Missions

IRVE-II

IRVE-3

Inflatable Re-entry Vehicle Experiments

High-Energy Atmospheric Re-entry Test (HEART)

Robotic Missions

Crewed Earth Return

DoD Applications

Technology Development & Risk Reduction

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
- Heat Load
- Permeability

Modular design using functional layers
• 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 and 12” mixing section
  – Heat flux range 5-150 W/cm²
  – Surface pressure range 1-9 kPa
  – Shear range 30-270 Pa
  – Reacting flow
• **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

• **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 ($\alpha$)
- Increasing concentration toward wall indicates low surface reaction rate
- SiC ($\alpha$) is slightly more catalytic than quartz for $T_w = 1460$ 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
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 400°C
• 50 W/cm² TPS Test of SiC Fabric

Heat Flux: 52.4 W/cm²
Surface Pressure: 3.98 kPa
AoA: 0 deg
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.
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