Outline

• Project Background, Goals, Approach

• Accomplishments
  – Testing Approach
  – Sensor / System Testing & Development
  – Thermal Analysis

• Conclusions / Current Efforts
Background

- Space vehicles utilize TPS to mitigate severity of re-entry heating
- TPS health monitoring is a necessary advancement for safety of flight
- New Approach – embed lightweight, sensitive, fiber optic strain and temperature sensors within the TPS
  - Temp / strain monitoring
  - Damage detection
Background

- Fiber Bragg Grating (FBG) sensors can be highly multiplexed using with LaRC demodulation architecture
- Hundreds of FBG sensors can be placed at variable intervals along the length of fiber
- FBG sensors max service temperature approximately 600°F
- FBG system currently limited to 4-5 sps (≈ 10 sps by summer 2006)
  - Acceptable for temperature / strain monitoring
  - Real-time damage detection (long term goal)
Goals

- Develop and demonstrate prototype TPS health monitoring system
- Develop a thermal-based damage detection algorithm
- Characterize limits of sensor / system performance
  - Determine fiber sensitivity and accuracy beneath tiles
  - Characterize the transient thermal response differences between damaged and undamaged TPS
  - Determine optimal fiber placement
  - Determine required sensor density
- Develop a methodology transferable to new designs of TPS health monitoring systems
Project Approach

Perform Setup / System Tests
- Discern significant physics present in test setup
- Validate model
- Determine sensor / system limits (response, accuracy, etc.)

Validate Tests with Thermal Analysis
- Utilize MSC’s Patran Thermal and generate computational model
- Determine physics
- Potential algorithm development application

Generate transient thermal response characteristics database for algorithm development and implementation

Develop algorithm for use with system
## Testing Approach

<table>
<thead>
<tr>
<th>System Component</th>
<th>Feature(s) Tested</th>
<th>Physics / Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Article</td>
<td>Test article material</td>
<td>Material property data uncertainty</td>
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<tr>
<td></td>
<td>Test article design</td>
<td>Uniformity/direction of heat transfer modes</td>
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<tr>
<td></td>
<td>Exterior insulation</td>
<td>Uniformity/direction of heat transfer modes</td>
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<tr>
<td></td>
<td>Interior insulation</td>
<td>Uniformity/direction of heat transfer modes</td>
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<td></td>
<td>Emissivity/Transmissivity coatings</td>
<td>Uniformity/direction of heat transfer modes</td>
</tr>
<tr>
<td>Test Setup</td>
<td>Supports</td>
<td>Undesired conduction</td>
</tr>
<tr>
<td></td>
<td>Profile input method</td>
<td>Surface temperature/rate precision</td>
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<tr>
<td></td>
<td>Thermal control</td>
<td>Control authority and precision across different test articles</td>
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<tr>
<td></td>
<td>Data acquisition system</td>
<td>TC data veracity</td>
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<tr>
<td></td>
<td>Heating element</td>
<td>Uniformity &amp; spectral properties of lamp/test article</td>
</tr>
<tr>
<td>FBG Sensor System</td>
<td>FBG Sensor System</td>
<td>Verify optimal placement of FBG in bondline</td>
</tr>
</tbody>
</table>
Setup/System Testing

- Setup/System Testing
- Fused Silica
- Type-K TC
- RTV
- F.O.
Setup / System Testing

- Experimented with setup for improved model comparison (48 tests)
  - Test article insulation
  - Gap insulation, seam covers
  - Conduction paths (supports, wires, etc.)
  - Profile input, repeatability
  - Data acquisition system
  - Monolith vs. Compartmentalized articles
  - Titanium vs. Ceramic
  - Test article cover
  - Test article coatings
  - IR Camera, & Quartz vs. GRHT
  - Alumina Oxide & Shuttle Tile

[Titanium Test and Model Data Graph]

Temperature (deg F)

Time (sec)
Setup / System Testing

- Validated FBG for use as TC when bonded with RTV to bottom surface of ceramic
- Validated FBG for use as TC when bonded with RTV between ceramic and Al substrate
  - Successful compensation of strain transfer from Al substrate through RTV layer
Thermal Analysis

- Videos → Tutorials → Textbook Solution Comparison
- Validated by LTA & SPAR codes
- Model system, refine
  - Simplify to monolith, add materials
  - Try simple, known materials
  - Perform mat. prop. perturbation study
  - Investigate mat. prop. thermal variation effects
  - Examine B.C. effects
  - Create performance envelope (10K, 0.1Cp, etc.)
  - Study solution convergence/quality
    - mesh refinement
    - FD vs. FEM
    - 1D/2D/3D models
  - Simulate possible additional physics

Patran vs. Textbook Solution

Comparison between Analytical and Computational Results
Thermal Analysis

Outcomes of Patran modeling effort:

- 65 Patran models
- Identified underlying physics in test materials and established confidence in test setup
- Successfully calibrated computational and experimental results
- Revealed bugs in Patran Thermal
  - FD does not work for transient (probably others)
  - Inability to run a 1D analysis with an LBC on the end of a bar element
Thermal Analysis Results

Comparison of Best Test/Model Results and Simulated Transmissivity Models

Temperature (deg F) vs. Time (sec)

- Monolith Test
- Patran (orig)
- Sim Trans (1.0)
- Sim Trans (0.5)
- Sim Trans (0.1)
- GC+&T&BB+

Best Test

Dryden Flight Research Center
NASA Non-Destructive Evaluation Working Group
Conclusions & Current Efforts

• Established confidence in understanding of both test setup and model
• Validated system / sensor performance in simple TPS structure
• Completed initial system testing, ready to begin algorithm development effort to complete prototype
• Generating damaged thermal response characteristics database from tests with varying levels of fidelity
• Developing test plan for integration testing of proven FBG sensors in simple TPS structure with proven AE sensors on NASA / CSIRO’s Concept Demonstrator
• Developing partnerships to apply technology
Questions?