TPS: From Arc-jet to Flight

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March 1, 2004
Background

- All space vehicles that reenter Earth's atmosphere from either LEO or from Lunar/Mars missions require thermal protection system (TPS) materials.
- TPS material development and verification require ground test facilities that simulate reentry aerothermodynamic environments.
Reentry Trajectory Drives TPS Material Requirements

- Shuttle Orbiter
- Apollo IV

**LEO Return Velocity**
25,000 fps (7 km/sec)

**Lunar Return Velocity**
35,000 fps (11 km/sec)
Lunar/Mars Return
Aerothermodynamic Environments

- High Enthalpy Gas
  - Lunar/Mars Return: Air @ 20,000+ Btu/lb\textsubscript{m} (46 MJ/kg)

- High Convective Heating
  - Lunar/Mars Return: 200+ Btu/ft\textsuperscript{2}-sec (227+ W/cm\textsuperscript{2})

- High Gas Cap Radiation Heating
  - Lunar/Mars Return: 200+ Btu/ft\textsuperscript{2}-sec (227+ W/cm\textsuperscript{2})

- High Stagnation Pressures
  - 0.5 atmospheres

- Aerodynamic Shear Stress
Convective and Radiation Heat Flux

Gas Cap Radiation Heating
Comparable Level as Convective

Increasing Radius increases Radiation and decreases Convection.
Scaling from Ground Test to Flight
Total Enthalpy and Stagnation Pressure

TPS material and Ground Test Facility needs Significantly Different.
Ground Test Facility Needs

• High Enthalpy Gas Facilities
  – Both air and CO₂
  – Large range of stagnation pressures
• Combined Convective and Radiative Heating
NASA Ames Arc-jet Facility
60MegaWatt Interaction Heating Facility

Test Gases: Air and Nitrogen

High Convective Heating and High Stagnation Pressures can be achieved on small test specimens.
NASA JSC Arc-jet Facilities
Orbiter TPS Certified Facility

Test Gases: Simulated Air; Nitrogen

Stagnation Heat Fluxes:
Stagnation Pressures:
Concluding Remarks

• Future Lunar/Mars missions require ground test facilities for TPS material development and flight certification.

• Existing arc-jet facility capabilities need to be updated and expanded.
  – Combined convective and radiation heating.
  – CO$_2$ test capability for Mars entry.
TRANSFORMATIONAL SYSTEMS CONCEPTS & TECHNOLOGIES
FOR FUTURE SPACE MISSIONS

A Technical Workshop

Sponsored by the Development Programs Division, NASA Office of Exploration Systems
&
Hosted Jointly by
The Lyndon B. Johnson Space Center
The Langley Research Center

March 1\textsuperscript{st} thru 3\textsuperscript{rd}, 2004

Hilton Hotel and Conference Center
The University of Houston
4800 Calhoun Rd.
Houston, Texas 77204

OVERVIEW

\textit{Monday, 1 March 2004, in the Plaza Room}

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<tr>
<th>TIME</th>
<th>EVENT</th>
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<tr>
<td>7:45 – 8:30 AM</td>
<td>Registration and Refreshments</td>
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<tr>
<td>8:30 – 8:45 AM</td>
<td>Welcome</td>
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<tr>
<td>8:45 – 9:30 AM</td>
<td>\textbf{Overview of NASA Vision for Exploration (TSI)}</td>
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<td>\textit{John Mankins, NASA HQ}</td>
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<td>9:30 – 10:30 AM</td>
<td>\textbf{Materials Needs for Exploration}</td>
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<td>\textit{Mr. John Connell, NASA Langley Research Ctr}</td>
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<td>Break</td>
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<tr>
<td>10:30 – 10:45 AM</td>
<td>\textbf{Revolutionary Materials}</td>
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<td>\textit{Dr. Richard Smalley, Nobel Laureate, Rice}</td>
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<td></td>
<td>University: Carbon Nanotubes and Space Applications</td>
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<td>Presentation and Discussion</td>
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<td>Lunch</td>
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<td>11:45 – 12:45 PM</td>
<td>\textbf{Carbon Nanotube Woven Garment}</td>
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<td>\textit{Mr. Ray H. Baughman}</td>
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<td>\textit{Robert A. Welsh Professor of Chemistry and NanoTechnology, University of Texas-Dallas}</td>
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<tr>
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<td>Catalytic Presentations &amp; Discussions</td>
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<td>Break</td>
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<td>3:45 – 4:00 PM</td>
<td>Catalytic Sub Session Reports and Discussion</td>
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