NASA ESR&T
INTEGRATED THERMAL PROTECTION SYSTEMS
AND HEAT RESISTANT STRUCTURES
Contract N° : NND04AA85C

30th Annual Conference on Composites, Materials, and Structures
Cocoa Beach, FL
23-26 January 2006

Thierry Pichon and Marc Lacoste, Snecma Propulsion Solide - SAFRAN Group
David E. Glass, NASA Langley Research Center
Agenda

- Overview

- Trajectory and Loads

- CAS
  - Design
  - Thermal Insulation

- Sepcore
  - Design
  - Ablators

- Structural Health Monitoring

- Concluding Remarks
### Overview - Modularity

3 DIFFERENT DESIGNS DERIVED FROM THE SAME TECHNOLOGY, ADAPTED TO 3 MISSIONS SCENARIOS

<table>
<thead>
<tr>
<th></th>
<th>CAS</th>
<th>I-TPS Seepcore®</th>
<th>Decelarator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat flux $\leq 1 \text{ MW/m}^2$</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Heat flux $\geq 1 \text{ MW/m}^2$</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Reusability</td>
<td>+</td>
<td>Partial / multi phase</td>
<td>NA</td>
</tr>
<tr>
<td>Aero -braking</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Aero -capture</td>
<td>+</td>
<td>+</td>
<td>NA</td>
</tr>
<tr>
<td>Aero -assist</td>
<td>+</td>
<td>+</td>
<td>NA</td>
</tr>
<tr>
<td>Lifting body</td>
<td>TPS</td>
<td>TPS</td>
<td>Hot Structure</td>
</tr>
<tr>
<td>Winged vehicle</td>
<td>TPS</td>
<td>TPS</td>
<td>Hot Structure</td>
</tr>
</tbody>
</table>
Overview - Concept Description – CAS

- Aero-dynamic shape and surface is maintained,
- No pollution by ablative residuals,
- Unit construction system design facilitates manufacturing, inspection and maintenance,
- Redundancy for thermal protection functions is provided,
- Reduced mass (compared to ablators),
- MMOD resistance,
- Reduced costs.
SEPCORE = CAS + ABLATOR

- Adapted to high heat fluxes (over 1 MW/m²)
- Significant mass savings compared to ablator only
- High mechanical strength at room temperature,
- Mechanical strength maintained at high temperature
- Increased robustness
- Partial reusability

<table>
<thead>
<tr>
<th>CAPSULE CONCEPT</th>
<th>ABLATOR</th>
<th>SEPCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamic structure</td>
<td>22</td>
<td>40</td>
</tr>
<tr>
<td>External heat shield</td>
<td>168</td>
<td>70</td>
</tr>
<tr>
<td>Internal insulation</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Total mass</td>
<td>190</td>
<td>120</td>
</tr>
</tbody>
</table>

Mass of ablator - Mass of Sepcore
\[ \approx 30\% \]
Overview - Concept Description – Decelerator

DECELERATOR = CAS + DEPLOYMENT

- Increase of aerodynamic surface to increase deceleration,
- Compact (when stowed),
- Robustness of thermal protection function,
- Minimum mass increase
- MMOD resistance,
- Reduced costs.
Agenda

- Overview

- Trajectory and Loads

- CAS
  - Design
  - Thermal Insulation

- Sepcore
  - Design
  - Ablators

- Structural Health Monitoring

- Concluding Remarks
 Loads Development Process

POST2
Trajectory Simulation

Miniver
Aerothermal Analysis

LAURA
High Fidelity CFD

Time history of accelerations, position, attitude
Time history of stagnation & corner heating rates
3-D map of heating rates & pressures at select conditions

Altitude, velocity, attitude time history
Flight conditions corresponding to max heating
Baseline Vehicle Geometry and Characteristics

- Command module center of gravity is offset providing aerodynamic trim at non-zero angle of attack
- This provides trajectory shaping through bank angle modulation

<table>
<thead>
<tr>
<th>Mach</th>
<th>Angle of Attack (deg)</th>
<th>C_L</th>
<th>C_D</th>
<th>Lift/Drag</th>
<th>Ballistic Coefficient (lb/ft^2)</th>
<th>Ballistic Coefficient (kg/m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>167.14</td>
<td>0.24465</td>
<td>0.85300</td>
<td>0.28682</td>
<td>110.12</td>
<td>537.39</td>
</tr>
<tr>
<td>0.7</td>
<td>164.38</td>
<td>0.26325</td>
<td>0.98542</td>
<td>0.26714</td>
<td>95.32</td>
<td>465.16</td>
</tr>
<tr>
<td>0.9</td>
<td>161.70</td>
<td>0.32074</td>
<td>1.10652</td>
<td>0.30110</td>
<td>84.89</td>
<td>414.26</td>
</tr>
<tr>
<td>1.1</td>
<td>154.87</td>
<td>0.49373</td>
<td>1.16970</td>
<td>0.42208</td>
<td>80.30</td>
<td>391.86</td>
</tr>
<tr>
<td>1.2</td>
<td>155.13</td>
<td>0.47853</td>
<td>1.15600</td>
<td>0.41395</td>
<td>81.25</td>
<td>396.50</td>
</tr>
<tr>
<td>1.35</td>
<td>154.01</td>
<td>0.56282</td>
<td>1.27880</td>
<td>0.44013</td>
<td>73.45</td>
<td>358.44</td>
</tr>
<tr>
<td>1.65</td>
<td>153.22</td>
<td>0.55002</td>
<td>1.26570</td>
<td>0.43455</td>
<td>74.21</td>
<td>362.14</td>
</tr>
<tr>
<td>2.0</td>
<td>153.14</td>
<td>0.53247</td>
<td>1.27210</td>
<td>0.41858</td>
<td>73.84</td>
<td>360.34</td>
</tr>
<tr>
<td>2.4</td>
<td>153.62</td>
<td>0.50740</td>
<td>1.24120</td>
<td>0.40881</td>
<td>75.68</td>
<td>369.32</td>
</tr>
<tr>
<td>3.0</td>
<td>154.14</td>
<td>0.47883</td>
<td>1.21670</td>
<td>0.39353</td>
<td>77.20</td>
<td>376.74</td>
</tr>
<tr>
<td>4.0</td>
<td>156.12</td>
<td>0.44147</td>
<td>1.21480</td>
<td>0.36340</td>
<td>77.32</td>
<td>377.32</td>
</tr>
<tr>
<td>10.0</td>
<td>156.79</td>
<td>0.42856</td>
<td>1.22460</td>
<td>0.34996</td>
<td>76.70</td>
<td>374.30</td>
</tr>
<tr>
<td>&gt; 29.5</td>
<td>160.06</td>
<td>0.38773</td>
<td>1.28910</td>
<td>0.30076</td>
<td>72.87</td>
<td>355.61</td>
</tr>
</tbody>
</table>

Ballistic Coefficient

- Command module center of gravity is offset providing aerodynamic trim at non-zero angle of attack
- This provides trajectory shaping through bank angle modulation
## Mission Definition Design Space

<table>
<thead>
<tr>
<th>Departure Planet</th>
<th>Arrival Planet (Atmosphere)</th>
<th>Entry Mode</th>
<th>Aerodynamic Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon</td>
<td>Earth (air)</td>
<td>Direct</td>
<td>Ballistic</td>
</tr>
<tr>
<td>Mars</td>
<td>Mars (CO₂)</td>
<td>Aerocapture</td>
<td>Lifting</td>
</tr>
<tr>
<td>Earth</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Baseline Mission

![Baseline Mission Diagram](image)

### Mission Nomenclature

- **LDR** - Direct Entry from Lunar Return Conditions
- **LAC** - Aerocapture into Earth Orbit from Lunar Return Conditions
- **MDR** - Direct Entry from Mars Return Conditions
- **MAC** - Aerocapture from Mars Return Conditions
- **LEO** - Entry from Low Earth Orbit

Entry into Mars (CO₂) Atmosphere not considered in trade space
### Direct Earth Entry from Luna: Trade Matrix

<table>
<thead>
<tr>
<th>case #</th>
<th>initial velocity (ft/s)</th>
<th>initial flight path angle (deg)</th>
<th>ballistic coefficient (~M30) (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>36334</td>
<td>-5.80</td>
<td>73</td>
</tr>
<tr>
<td>1</td>
<td>32038</td>
<td>-3.99</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>32038</td>
<td>-5.21</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>32038</td>
<td>-6.65</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>32038</td>
<td>-7.11</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>40031</td>
<td>-5.09</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>40031</td>
<td>-5.61</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>40030</td>
<td>-6.63</td>
<td>25</td>
</tr>
<tr>
<td>8</td>
<td>40031</td>
<td>-7.40</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>36334</td>
<td>-4.63</td>
<td>25</td>
</tr>
<tr>
<td>10</td>
<td>36334</td>
<td>-6.73</td>
<td>25</td>
</tr>
<tr>
<td>11</td>
<td>36334</td>
<td>-5.13</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>36334</td>
<td>-7.29</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>case #</th>
<th>initial velocity (m/s)</th>
<th>initial flight path angle (deg)</th>
<th>ballistic coefficient (~M30) (kg/m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11075</td>
<td>-5.80</td>
<td>356</td>
</tr>
<tr>
<td>1</td>
<td>9765</td>
<td>-3.99</td>
<td>122</td>
</tr>
<tr>
<td>2</td>
<td>9765</td>
<td>-5.21</td>
<td>488</td>
</tr>
<tr>
<td>3</td>
<td>9765</td>
<td>-6.65</td>
<td>122</td>
</tr>
<tr>
<td>4</td>
<td>9765</td>
<td>-7.11</td>
<td>488</td>
</tr>
<tr>
<td>5</td>
<td>12201</td>
<td>-5.09</td>
<td>122</td>
</tr>
<tr>
<td>6</td>
<td>12201</td>
<td>-5.61</td>
<td>488</td>
</tr>
<tr>
<td>7</td>
<td>12201</td>
<td>-6.63</td>
<td>122</td>
</tr>
<tr>
<td>8</td>
<td>12201</td>
<td>-7.40</td>
<td>488</td>
</tr>
<tr>
<td>9</td>
<td>11075</td>
<td>-4.63</td>
<td>122</td>
</tr>
<tr>
<td>10</td>
<td>11074</td>
<td>-6.73</td>
<td>122</td>
</tr>
<tr>
<td>11</td>
<td>11075</td>
<td>-5.13</td>
<td>488</td>
</tr>
<tr>
<td>12</td>
<td>11075</td>
<td>-7.29</td>
<td>488</td>
</tr>
</tbody>
</table>
Direct Earth Entry from Luna: Trajectory Data

Total Acceleration vs Earth Relative Velocity

Altitude vs Earth Relative Velocity
Reference Trajectory for CAS

- Initially selected LD-9
  - 11 km/s, 122 kg/m^2 ballistic coefficient, shallow entry angle
  - eventually determined to be too hot
- Selected LEO-2 as baseline
  - 8 km/s, 356 kg/m^2 ballistic coefficient
Reference Trajectory for Sepcore

Selected LD-12
- 11 km/s entry velocity
- 488 kg/m² ballistic coefficient
- Steep entry angle
Radiation Equilibrium Temperature, K
Lunar Direct Entry - Phase I Sepcore Evaluation

Case 12

“Hot” Corner vs Stagnation Pt Radiation Eq. Temperature Comparison Case 12

Relative Heating Rate Component Contribution Case 12
Agenda

- Overview
- Trajectory and Loads
- CAS
  - Design
  - Thermal Insulation
- Sepcore
  - Design
  - Ablators
- Structural Health Monitoring
- Concluding Remarks
The CAS represents the blunt aft body of an Apollo-shaped re-entry vehicle. It is mainly composed of:

- an annular array of equipped leading-edge elements
- a circular array of equipped panels
- the underlying cold structure of the blunt aft body

Preliminary panel distribution derived from past experience.
Concept trade-off performed on previous designs:

- Hermès
- Generic Shingle
- CHA
- X-38 chin panel
- FESTIP

Trade-off criteria:
- External assembly capability
- State-of-the-art material
- Manufacturability
- Maintainability
- Technical performance
CMC Panels Design

Central panel

Intermediate row panel

Inner row panel

Outer row panel

CMC panel

Attachment
CMC Panels Analysis

- Thermo-mechanical analysis to verify:
  - Geometrical definition
  - Maximum displacements
  - Allowable strains
  - Mass optimization

<table>
<thead>
<tr>
<th>Elements</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central CMC panel</td>
<td>0.5</td>
</tr>
<tr>
<td>Inner row CMC panels</td>
<td>10.1</td>
</tr>
<tr>
<td>Intermediate row CMC panels</td>
<td>26.5</td>
</tr>
<tr>
<td>Outer row CMC panels</td>
<td>20.5</td>
</tr>
<tr>
<td>Attachments</td>
<td>22.9</td>
</tr>
<tr>
<td>Seals and internal insulation</td>
<td>88.3</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>168.8</strong></td>
</tr>
</tbody>
</table>

Total heatshield mass budget (w/o leading edges)

Areal mass: 16.45 kg/m²
CMC Leading-Edge Design

Keraman® CMC Material

- Reference: X38-V201 NASA-CRV Prototype Vehicle
- Material: Keraman® C/SiC, 2D-Carbon fiber fabric with SiC matrix
- Process: Gradient-CVI infiltration process
- Qualification: Body Flap, Leading Edges & Chin Panel

- Material TRL: 8 (acc. to X-38 specification up to 12x life-cycles)
CMC Leading-Edge Design

CMC panels directly attached to CMC stand-offs (i.e. X-38 Leading Edge)

- Only with CMC fasteners directly bonded to hot surface → no risk of thermal mismatch
- C/SiC omega-shaped standoffs
- Direct access from outside (→ accessibility & maintainability in space)
- Simple panel design
- High TRL for applications up to 1600°C

Ceramic fasteners  TRL = 8
Attachment concept  TRL = 5
Several concepts investigated
Pros and cons assessed in terms of:
- TRL level
- Maintainability
- Simplicity
- Manufacturability
CMC Leading-Edge Design

CMC panels with metallic stand-offs (similar to X-38 Nose Assembly)
- Ceramic and metallic standoffs
- Metallic fasteners and ceramic plugs
- Fixation at “medium” temperatures
- Attachment concept TRL = 8

Temperature [K]
Time [s]

\[ T_{\text{max}} = 1820 \text{ K} \]
(CMC-Panel)

\[ T_{\text{max}} = 932 \text{ K} \]
(Stand-Off)

\[ T = 383 \text{ K at Touch Down} \]

Cold Structure
CMC Leading-Edge Design

CMC panels directly attached to cold structure

- Integral ceramic standoffs
- Metallic fasteners (off-the-shelf) and ceramic plugs
  attachment concept TRL = 5
- Fixation at “cold” temperatures
  (direct fixation on cold structure)

**Diagram:**

- Hot external side
- Cold rear side

**Materials:**

- SAFFIL, \( \rho = 96 \text{ kg/m}^3 \), \( d = 35 \text{ mm} \)
- SAFFIL, \( \rho = 48 \text{ kg/m}^3 \), \( d = 40 \text{ mm} \)
- PYROGEL, \( \rho = 115 \text{ kg/m}^3 \), \( d = 5 \text{ mm} \)

**Graph:**

- Temperature vs. Time
- Key temperatures:
  - \( T_{\text{max}} = 1820 \text{ K} \) (CMC Panel)
  - \( T = 449 \text{ K} (4\text{mm}) \)
  - \( T = 424 \text{ K} (3\text{mm}) \)
  - \( T = 400 \text{ K} (2\text{mm}) \)

**Touch Down Times:**

- \( t = 1070 \text{ s} \)
**Cold Structure Design**

- **Main characteristics:**
  - Made from aluminum alloys
  - Shape of cold structure underneath panel array identical to OML (reduced by panel height)
  - Cold structure shape adapted to Leading Edge thermal & mechanical design needs
  - Design will match with internal insulation lay-out and attachment concept
  - Mechanical attachment to the vehicle pressurized compartment realized by means of hinge rods

*Courtesy MT Aerospace*
Agenda

- Overview
- Trajectory and Loads
- CAS Design
  - Design
  - Thermal Insulation
- Sepcore
  - Design
  - Ablators
- Structural Health Monitoring
- Concluding Remarks
The temperature range of thermal conductivity apparatus was extended to 1250°C (replaced ceramic radiant heater with quartz lamp array heater):

- Cold side temperature: 20°C (water cooled)
- Hot side temperature: 100 – 1250°C
- Pressure: 0.0001 – 760 torr
- Specimen size: 30 x 30 x 2.5 cm (12 x 12 x 1 in.)
- Measure: \( T_{\text{hot}}, T_{\text{cold}}, q'' \) (thin film heat flux gage), L
- Calculate: apparent thermal conductivity, \( k_a \)
Thermal Insulation

- Performed steady-state thermal tests on selected fibrous insulation samples $350K \leq T \leq 1350K$, $0.0001 \leq P \leq 760$ torr
- Used thermal modeling in conjunction with measurements to determine pertinent parameters for gas/solid conduction and radiation heat transfer

<table>
<thead>
<tr>
<th>Insulation</th>
<th>Density (kg/m$^3$)</th>
<th>Temperature limit (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zirconia felt</td>
<td>240 (15 pcf)</td>
<td>2310 (4200°F)</td>
</tr>
<tr>
<td>Alumina blanket</td>
<td>96 (6 pcf)</td>
<td>1650 (3000°F)</td>
</tr>
<tr>
<td>Cerachem</td>
<td>96 (6 pcf)</td>
<td>1430 (2600°F)</td>
</tr>
<tr>
<td>Q-fiber felt</td>
<td>48, 96 (3, 6 pcf)</td>
<td>1000 (1800°F)</td>
</tr>
</tbody>
</table>

Setup in 5 x 5 ft vacuum chamber at LaRC
Agenda

- Overview
- Trajectory and Loads
- CAS Design
  - Design
  - Thermal Insulation
- Sepcore
  - Design
  - Ablators
- Structural Health Monitoring
- Concluding Remarks
Objective is to minimize thickness of ablator required on a TPS element by:

- Attaching it to a hot CMC structure instead of a cold metallic structure
- Sizing the layer of ablator so that the temperature at the CMC/ablator interface remains within CMC allowable
- Introducing lightweight insulation at the rear side of the CMC structure

Significant heatshield mass saving compared to classical ablators

Adapted to high I
Concept A:
- Ablative tiles are attached to CMC panels, fixed on a cold structure
- Minor modifications of CAS panels to attach an ablative layer
Sepcore® Architectures

Concept B:
- Ablative tiles are attached to hot structure made of CMC
- Same type of CMC material than for CAS panels, but very different architecture (skin attached by screws or rivets to a web of stiffeners)
- Full potential of Sepcore® can be used, leading to lower mass
Cold structure sizing (concept A)
- Sizing criterion: max. displacement of structure = 3 mm
- Boundary conditions:
  - Structure clamped at R=1,3 m
  - Pressure on front face = 88 000 Pa (difference between wall pressure and atmospheric pressure)
- 2D axi-symmetric model of sandwich structure (aluminum honeycomb and C/epoxy skins)

Approximate weight 280 kg

<table>
<thead>
<tr>
<th>#</th>
<th>Honeycomb thickness</th>
<th>Skins thickness</th>
<th>Honeycomb density</th>
<th>Displacement</th>
<th>Mass of structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>120 mm</td>
<td>0.5 mm</td>
<td>50 kg/m³</td>
<td>10.0 mm</td>
<td>148 kg</td>
</tr>
<tr>
<td>#2</td>
<td>120 mm</td>
<td>0.5 mm</td>
<td>130 kg/m³</td>
<td>6.2 mm</td>
<td>332 kg</td>
</tr>
<tr>
<td>#3</td>
<td>120 mm</td>
<td>1.5 mm</td>
<td>50 kg/m³</td>
<td>4.5 mm</td>
<td>213 kg</td>
</tr>
<tr>
<td>#4</td>
<td>120 mm</td>
<td>1.5 mm</td>
<td>130 kg/m³</td>
<td>2.7 mm</td>
<td>397 kg</td>
</tr>
<tr>
<td>#5</td>
<td>120 mm</td>
<td>2.0 mm</td>
<td>50 kg/m³</td>
<td>3.5 mm</td>
<td>246 kg</td>
</tr>
<tr>
<td>#6</td>
<td>120 mm</td>
<td>2.0 mm</td>
<td>130 kg/m³</td>
<td>2.0 mm</td>
<td>430 kg</td>
</tr>
<tr>
<td>#7</td>
<td>80 mm</td>
<td>2.0 mm</td>
<td>50 kg/m³</td>
<td>4.5 mm</td>
<td>207 kg</td>
</tr>
<tr>
<td>#8</td>
<td>80 mm</td>
<td>2.0 mm</td>
<td>130 kg/m³</td>
<td>2.9 mm</td>
<td>330 kg</td>
</tr>
</tbody>
</table>
Sepcore® Preliminary Sizing

Hot structure sizing (concept B)

- 4 configurations analyzed:
  - I. 16 radial stiffeners + 3 circum. stiffeners
  - II. 32 radial stiffeners + 6 circum. stiffeners
  - III. id + inner skin
  - IV. 64 radial stiffeners + 6 circum stiffeners + inner skin

- CMC Thickness = 3 mm
- Stiffener height 60 mm for I, II, III, 80 mm for IV
- Estimated mass: 250 x 1.3 = 325 kg

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Displacement</th>
<th>Mass of structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>13.7 mm</td>
<td>123 kg</td>
</tr>
<tr>
<td>II</td>
<td>9.2 mm</td>
<td>137 kg</td>
</tr>
<tr>
<td>III</td>
<td>5.6 mm</td>
<td>203 kg</td>
</tr>
<tr>
<td>IV</td>
<td>3.9 mm</td>
<td>221 kg</td>
</tr>
</tbody>
</table>
### Apollo size heatshield, 10 MW/m²

<table>
<thead>
<tr>
<th>MASS (kg)</th>
<th>Reference : Ablator on cold structure</th>
<th>Sepcore concept A</th>
<th>Sepcore concept B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C / phenol*</td>
<td>PICA</td>
<td>C / phenol</td>
</tr>
<tr>
<td>Ablator</td>
<td>1,360</td>
<td>66</td>
<td>390</td>
</tr>
<tr>
<td>CMC parts</td>
<td>-</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>Insulation</td>
<td>-</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Cold structure</td>
<td>280</td>
<td>280</td>
<td>280</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,640</td>
<td>611</td>
<td>935</td>
</tr>
</tbody>
</table>

* sizing made by SPS on material similar with NASA but not identical: comparison with ablator sizing of Sepcore with C/phenolic ablator
Agenda

- Overview
- Trajectory and Loads
- CAS Design
  - Design
  - Thermal Insulation
- Sepcore
  - Design
  - Ablators
- Structural Health Monitoring
- Concluding Remarks
Aerothermal Environments Used for Ablator Sizing

- Lunar Direct Entry, case No.12
- Aerothermal environments are based on those predicted by LaRC’s engineering code, not LAURA CFD
As specified in SEPCORE Preliminary Specification developed by Snecma:

- **Vehicle Internal Structure**: Aluminum Alloy
- **Insulator**: CMC
- **Ablator**
- **Bond-line Temp Limit = 1500 °K**

Convection + Radiation

Material

Convection + Radiation

Thickness

Variable

Ablator

CMC

Insulator

Vehicle Internal Structure

Aluminum Alloy
Ablative TPS Materials

- Generic fully dense carbon phenolic composite

- PICA (Phenolic Impregnated Carbon Ablator)
  - Developed by NASA ARC
  - Used on Stardust Sample Return Capsule, will re-enter the Earth atmosphere in 2006
  - Manufactured by Fiber Materials, Inc.
Agenda

- Overview
- Trajectory and Loads
- CAS Design
  - Design
  - Thermal Insulation
- Sepcore
  - Design
  - Ablators
- Structural Health Monitoring
- Concluding Remarks
• Established notional approach for a health monitoring system to support large-scale heat-shield testing

• Identified potential high-temperature acoustic emission (AE) sensors and potential heat shield locations

• Continued development of AE sensor multiplexing technology

• Miniaturized and increased channel count and data rate of existing Fiber-Bragg Grating (FBG) system for strain and temperature monitoring

• Initiated sensor attachment technique development on customer supplied C/SiC specimen
Agenda

- Overview
- Trajectory and Loads
- CAS Design
  - Design
  - Thermal Insulation
- Sepcore
  - Design
  - Ablators
- Structural Health Monitoring
- Concluding Remarks
Concluding Remarks

- The Snecma-led TPS task for NASA’s Exploration Initiative began the development of three complementary TPS approaches
  - CAS
  - Sepcore
  - Deployable Decelerator

- Significant work was performed on the trajectory and loads definition, and on the CAS design

- The task was cancelled by NASA as part of a major restructuring of the Exploration Initiative