TPS for Outer Planets

Ethiraj Venkatapathy,
D. Ellerby, P. Gage, M. Gasch, H. Hwang,
D. Prabhu, M. Stackpoole, and Paul Wercinski

Entry Systems and Technology Division, NASA ARC

OPAG – Technology Forum
February 23, 2018  Hampton, VA
Objective and Outline

To provide insight into TPS needs and the current state of readiness to enable future Outer Planet Missions

• Mission Science Drivers for TPS
  • Modest environments for Titan
  • Severe to extreme environments for Icy/Gas Giants

• Current state of readiness
  • PICA
  • HEEET

• Sustainability
  • Challenges and solutions
Science, Mission Design and Entry Environment Considerations for TPS Selection

• Destinations
  • Jupiter, Saturn, Titan, Uranus and Neptune
• In Situ Science
  • Probes at Ice/gas Giants,
  • (Aerial Platforms, Landers, Boats, and Submarines) at Titan
• Mission Architecture and Vehicle
  • Ballistic, Direct Entry
  • Lift Guided Entry (Direct or Aerocapture followed by Entry)
  • Rigid Aeroshell (for both ballistic and lift guided)
    • Deployable may be applicable to Titan
      • ADEPT and HIAD are at Low TRL – out of scope in this talk
• TPS must not fail during entry
  • Must be manufacturable at relevant scale including thicknesses to withstand heat-load
Past Outer Planet Missions and Entry Environment

Huygens (62 W/cm², 0.1 atm.)
Galileo (30,000 W/cm², 8.0 atm)

Heat-flux, W/cm²

Heat-flux, W/cm²

Pressure, atm.

0.1
1
10
100
1000
10000
100000

Galileo

Huygens
Future Outer Planet Missions and Entry Environment Considered for TPS Development

Huygens (62 W/cm², 0.1 atm.)
Galileo (30,000 W/cm², 8.0 atm)

Heat-flux, W/cm²

Pressure, atm.

Titan & Backshell TPS (OP Probes)

Outer Planet Probe Missions (Saturn)

Galileo

OPAG, Feb 23, Technology Forum, Hampton, VA
Ethiraj.Venkatapathy-1@nasa.gov
Current TPS Capability to Support Outer Planet Missions

- *Huygens* (62 W/cm², 0.1 atm.)
- *Galileo* (30,000 W/cm², 8.0 atm)
- *Carbon Phenolic* (Atrophied)
- *HEEET* (In Development)
- *PICA* Avcoat
- *SLA* Acusil
- *SIRCA*

Heat-flux, W/cm² vs. Pressure, atm.
Outer Planet Missions and Current TPS

Huygens (62 W/cm², 0.1 atm.)
Galileo (30,000 W/cm², 8.0 atm)

Heat-flux, W/cm²
Pressure, atm.
PICA Readiness
(More details can be found in the PICA Poster presented earlier)

• In 2016 NASA ARC learned that the heritage rayon utilized in PICA was stopping production, leading to a flight-qualified PICA sustainability challenge

<table>
<thead>
<tr>
<th>Heatshield Peak Conditions</th>
<th>Pressure atm</th>
<th>Heat Flux W/cm²</th>
<th>Heat Load kJ/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titan</td>
<td>Titan 1</td>
<td>0.17</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Huygens</td>
<td>0.1</td>
<td>62</td>
</tr>
<tr>
<td>Mars</td>
<td>MSL</td>
<td>0.33</td>
<td>225</td>
</tr>
</tbody>
</table>

• In FY16/17, NASA ARC was funded by SMD/PSD to address PICA rayon sustainability
  • Lyocell Based PICA (PICA-D) was manufactured and limited testing performed
    • Limited data and comparison indicated PICA-D to be good candidate for potential drop-in replacement for heritage PICA
  • SMD-PSD has initiated two tasks (CY18 and CY19) to:
    • Establish PICA-D as a Drop-in replacement for Heritage PICA
    • Establish the Expanded Capability (Extensibility) of PICA-D
• Successful completion of the above tasks are targeted towards:
  • Titan (& Mars) heatshield TPS and backshell for Outer Planet (& Venus) probes
  • Enable higher speed sample return missions from Comets and Asteroids
HEEET Readiness
(More details can be found in the HEEET Poster presented earlier)

- Thermal and thermo-mechanical performance of acreage and seam have been established; Material property database developed; Thermal response model completed
  - > 5000 W/cm² and > 5 atm. capable
  - Efficient and Enabling
    - All NF-4 proposals able to target < 50g entry
  - Flight design tools validation on going

- All basic manufacturing steps have been developed and transferred to industry to establish supply chain for future missions

- All manufacturing and integration operations have been demonstrated.
  - 1m scale MDU/ETU can be scaled to larger dia.
  - Loom capable of thicker weaving (current MDU/ETU has 0.5” recession layer and 1.1” insulating layer)

- Current plans are to complete MDU/ETU testing, AEDC and LHEML testing, design tool validation and documentation in CY’18
Assessment of HEEET Development for Outer Planet Probe Missions

- Current HEEET Capability is Scalable
  - In areal dimension (funding limitations required us to focus on areal scalability)
  - HEEET system demonstrated at 0.5” thick recession layer (RL) and 1.1” insulating layer (IL) on the 1m diameter MDU/ETU

- Recent Outer Planet mission studies show more severe entry environments
  - Ice-Giants may require seam performance assessment (pressure > 10 atm.)
  - Outer Planet (Neptune and Saturn) missions may require thicker recession layer (~2 X to 3X)
  - Current loom is capable of ~0.7” RL & 0.8” IL (or 0.6” RL & 1.2” IL)
  - For thicker than 0.5” RL, manufacturing and integration need to be demonstrated at the system level.
    - The loom capability can be expanded to weave much thicker recession layer, (1.5” – 2.5”) recession layer.

- Common Probe study is reassessing and may provide a better bounding thickness
  - Integrated system needs to be demonstrated at bounding thickness levels

<table>
<thead>
<tr>
<th></th>
<th>Pressure atm</th>
<th>Heat Flux W/cm²</th>
<th>Heat Load kJ/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter</td>
<td>7.31</td>
<td>32000</td>
<td>200</td>
</tr>
<tr>
<td>Saturn</td>
<td>2</td>
<td>2000</td>
<td>250</td>
</tr>
<tr>
<td>Saturn</td>
<td>8</td>
<td>8000</td>
<td>75</td>
</tr>
<tr>
<td>Uranus</td>
<td>12</td>
<td>3500</td>
<td>44</td>
</tr>
<tr>
<td>Uranus</td>
<td>9</td>
<td>2500</td>
<td>41</td>
</tr>
<tr>
<td>Neptune</td>
<td>25</td>
<td>9600</td>
<td>82</td>
</tr>
<tr>
<td>Neptune</td>
<td>11.5</td>
<td>5500</td>
<td>109</td>
</tr>
<tr>
<td>Neptune</td>
<td>6.8</td>
<td>4400</td>
<td>134</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Stag Point (Recession Lyaer, in)</th>
<th>Flank (Shoulder) (Recession Lyaer, in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturn</td>
<td>1.03</td>
<td>0.91</td>
</tr>
<tr>
<td>Uranus</td>
<td>0.33</td>
<td>0.877</td>
</tr>
<tr>
<td>Neptune</td>
<td>0.69</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Aerocapture: Configurations and TPS

- **Entry Environment and Configurations**

<table>
<thead>
<tr>
<th></th>
<th>Neptune</th>
<th>Titan</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry Velocity</td>
<td>29</td>
<td>6.5</td>
<td>5.7</td>
</tr>
<tr>
<td>km/sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atm. Scale Height</td>
<td>49</td>
<td>40</td>
<td>10.5</td>
</tr>
<tr>
<td>L/D</td>
<td>0.8</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>M/CdA</td>
<td>895</td>
<td>90</td>
<td>148</td>
</tr>
<tr>
<td>Convective Heating</td>
<td>8000</td>
<td>46</td>
<td>30</td>
</tr>
<tr>
<td>W/cm²</td>
<td>(4000-8000)</td>
<td>(93-280)</td>
<td>~0</td>
</tr>
<tr>
<td>Radiative Heating</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W/cm²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time of Flight (min)</td>
<td>10</td>
<td>42</td>
<td>10</td>
</tr>
</tbody>
</table>

Ref: Neptune Aerocapture Systems Analysis, Mary Kae Lockwood, AIAA 2004-4951

- **Neptune:**
  - Multiple TPS needed for optimizing payload mass fraction
  - HEEET, PICA and (SIRCA/SLA/ACUSIL/Tile)

- **Titan: Benign**
  - TPS: Within the current TPS SOA (e.g. PICA/SLA/SIRCA/ACUSIL)

Addressing TPS for ballistic, direct entry will address aerocapture needs
Common Probe Study

- Could a common atmospheric probe design be used for missions to Venus, Jupiter, Saturn, Uranus, and Neptune? Could we build multiple units and address sustainability concern?
  - Study funded by SMD-PSD
  - Typical designs have been 45deg sphere cones with high density TPS
  - Study will address inefficiencies or limitations that a common design cause for missions to these destinations
  - 4 NASA Centers involved (ARC, LaRC, GSFC, and JPL)

- Approach:
  - Strawman instrumentation payloads defined for each target based on science community input
    - Shallow and steep entry g-loads defined for each destination based on instrument sensitivity
  - TPS and carrier structure analysis and trades being conducted, including long term storage issues
  - Rough costing for design(s)

- Findings and recommendations to be presented at OPAG, VEXAG, and IPPW
- Final report to be delivered to PSD and published by summer 2018
Sustainability of TPS for OP Missions

• Why worry?
  • Missions are few and far between
  • TPS capability is critical and NASA unique

• PICA and HEEET
  • Simple compositional systems and manufacturing is automated
    • Both are essentially carbon and phenolic composition
      • PICA uses rayon. HEEET does not (by choice)
  • Technology capability has been transferred to industry
    • Raw material and processing – off the shelf – need to keep an eye
    • Multiple vendors and processing involved
      • Raw material to processing/manufacturing to assembly and integration
    • NASA has to assess the risk of atrophy periodically

• Approaches to addressing capability availability in the future
  • Periodically assess and take risk mitigation action for sustaining the capability
    • HEEET and PICA are NASA IP and NASA can transfer the technology at any time
  • Build and store a common aeroshell design capable of missions at multiple destinations
Concluding Remarks & Recommendations

• TPS needs for Outer Planet Missions falls into two distinct groups
  • Moderate to low heat-flux missions (Titan) – PICA
    • Drop-in replacement for heritage PICA is funded and in progress (Completion by CY’20)
  • Extreme Entry Environment – HEEET
    • HEEET is more efficient, robust and capable

• PICA Replacement and Extensibility development in progress

• HEEET development for Saturn, Uranus or Neptune missions
  • Require thicker recession layer
  • Continued development will meet the future OP mission needs

• Sustainability is critical for extreme entry environment missions
  • Periodic assessment necessary
  • Common Probe – build and store multiple copies – may be a solution