TPS for Outer Planets

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Objective and Outline

To provide insight into what TPS is needed 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

<table>
<thead>
<tr>
<th></th>
<th>Pressure, atm.</th>
<th>Heat-flux, W/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huygens</td>
<td>0.1</td>
<td>62</td>
</tr>
<tr>
<td>Galileo</td>
<td>8.0</td>
<td>30,000</td>
</tr>
</tbody>
</table>

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

Galileo

Titan & Backshell TPS (OP Probes)

Outer Planet Probe Missions (Saturn)

Titan Backshell
Current TPS Capability to Support Outer Planet Missions

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

TPS Materials:
- PICA
- Avcoat
- SLA
- Acusil
- SIRCA
- HEEET (In Development)
- Carbon Phenolic (Atrophied)
- Galileo

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 vs. 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

- Recent NF-4 Mission study (Dragonfly) compared to Huygens and MSL
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>Heat-shield Environment from Recent Mission Studies</th>
<th>Pressure atm</th>
<th>Heat Flux W/cm²</th>
<th>Heat Load kJ/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter Galileo</td>
<td>7.31</td>
<td>32000</td>
<td>200</td>
</tr>
<tr>
<td>Saturn 1</td>
<td>2</td>
<td>2000</td>
<td>250</td>
</tr>
<tr>
<td>Saturn 2</td>
<td>8</td>
<td>8000</td>
<td>75</td>
</tr>
<tr>
<td>Uranus 1</td>
<td>12</td>
<td>3500</td>
<td>44</td>
</tr>
<tr>
<td>Uranus 2</td>
<td>9</td>
<td>2500</td>
<td>41</td>
</tr>
<tr>
<td>Neptune 1</td>
<td>25</td>
<td>9600</td>
<td>82</td>
</tr>
<tr>
<td>Neptune 2</td>
<td>11.5</td>
<td>5500</td>
<td>109</td>
</tr>
<tr>
<td>Neptune 3</td>
<td>6.8</td>
<td>4400</td>
<td>134</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stag Point</th>
<th>Flank (Shoulder)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recession Lyaer, in</td>
<td>Insulation Layer, in</td>
</tr>
<tr>
<td>Saturn</td>
<td>1.03</td>
</tr>
<tr>
<td>Uranus</td>
<td>0.33</td>
</tr>
<tr>
<td>Neptune</td>
<td>0.69</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, km/sec</td>
<td>29</td>
<td>6.5</td>
<td>5.7</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, W/cm²</td>
<td>8000</td>
<td>46</td>
<td>30</td>
</tr>
<tr>
<td>Radiative Heating, W/cm²</td>
<td>(4000-8000)</td>
<td>(93-280)</td>
<td>~0</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)

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**Addressing TPS for ballistic, direct entry will address aerocapture needs**
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
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**
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