Hybrid Propulsion In-Situ Resource Utilization Test Facility Development

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Outline

• Introduction to the Mars Sample Return and the Mars Ascent Vehicle
• Motivation
• Driving Requirements
• System Design and Capabilities
• Future Work
• Conclusions
Introduction

• Hybrid propulsion allows for an incremental approach to *In Situ* Resource Utilization (ISRU)

• A hybrid test facility has been developed at JPL
  – Enables testing of Mars relevant propellant combinations to determine the performance parameters
    • Paraffin fuel with gaseous oxygen and an *in situ* simulating oxidizer (oxygen with varying concentrations of CO and CO₂)
  – Flexibility to test the L/D’s of the combustion chamber for packaging constraints.

• Development of an ISRU process to provide the oxidizer is occurring in tandem to this research.
Motivation

- Hybrid ISRU allows for approximately a 2/3 reduction in propellant mass.
- Desire to determine performance parameters for ISRU oxidizer

<table>
<thead>
<tr>
<th></th>
<th>Paraffin/GO₂ Hybrid</th>
<th>Conventional Propulsion Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Solid</td>
</tr>
<tr>
<td>Isp (performance)</td>
<td>~330 s</td>
<td>285 s</td>
</tr>
<tr>
<td>Restart capability</td>
<td>Yes, multiple</td>
<td>N/A</td>
</tr>
<tr>
<td>Throttling</td>
<td>Simple, 10:1</td>
<td>None</td>
</tr>
<tr>
<td>Low temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage &amp; operation</td>
<td>&lt; -100 C*</td>
<td>- 40 C</td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toxicty</td>
<td>Nontoxic</td>
<td>Toxic</td>
</tr>
<tr>
<td>System Complexity</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Recurring Cost</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

*Predicted value, requires empirical confirmation.
Driving Requirements

- Geometric constraints
  - L/D

- Thermal cycling
  - Average annual temperature of about -60 C
  - Daily variations of up to 100 C.
System Design (3/3)

- Fuel grain outer diameter: 2 in [5 cm]
- Maximum operating pressure: 1.72 MPa [250 psi]
- Thrust: 222 N [50 lbf]
Capabilities

• First open air rocket test at JPL in more than 15 years
• Oxidizer mass flux can be varied by swapping out the injector or changing the upstream oxidizer pressure.
• Oxidizers include any combination of O₂, CO₂ and CO.
• Combustion chamber tubes may be swapped out to vary L/D
Future Work

• Up to four hot fire tests this fiscal year (through September). Additional tests may be completed next year allowing for
  – Determination of efficiency based on L/D
  – Determination of regression rate law parameters for ISRU simulant oxidizer

\[ \dot{r} = a \, G^n \]
Conclusions

- Hybrid propulsion presents many benefits specifically for Mars based propulsion, especially as an incremental step towards ISRU.
- Main challenges include packaging and the Mars environment.
- Flexibility has been built into the system:
  - Multiple geometries
  - Multiple oxidizers to determine optimal performance
- Testing is a necessary step toward the adoption of hybrid propulsion systems to clarify some of the performance parameters.
Acknowledgements

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Questions?

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