Summary

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• Potential Mars Sample Return Campaign
• Assumptions
• Motor Sizing
• Propellant Selection
• Nozzle and Controls
• Development and Qualification Testing
• Future Work
Mars Ascent Vehicle Study

Potential Mars Sample Return Campaign

- Mars 2020 rover
  - Collect and cache samples

- Earth Return Orbiter (ERO)
  - Enter Mars orbit ready to receive samples and transport back to earth

- Sample Retrieval Lander
  - Places Mars Ascent Vehicle (MAV) on Mars for sample stow and launch to ERO

For More Information, Contact: andrew.s.prince@nasa.gov
Currently MAV is trading between hybrid and solid propulsion with a selection to be made in September 2019

This presentation is about the methodologies and progress toward developing the solid propulsion vehicle
**Ground Rules and Assumptions**

- Mass, length and diameter are driven by the lander
  - Length is shared with payload, avionics and Reaction Control System (RCS)
- Landing site selection will affect low temperature requirements
- Maximum shock will be parachute snap

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum GLOM (kg)</td>
<td>400.0</td>
</tr>
<tr>
<td>Maximum Vehicle Length (m)</td>
<td>3.0</td>
</tr>
<tr>
<td>Vehicle Diameter (m)</td>
<td>0.57</td>
</tr>
<tr>
<td>Payload Length Length (m)</td>
<td>0.5</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>343,000.0</td>
</tr>
<tr>
<td>Maximum Angle of Attack (degrees)</td>
<td>4.0</td>
</tr>
<tr>
<td>Launch PBMT (°C)</td>
<td>-20 (+/-2)</td>
</tr>
<tr>
<td>Storage Temperature Min/Max (°C)</td>
<td>-70/40</td>
</tr>
</tbody>
</table>

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**Design Methodology**

- **First Stage:** High initial thrust to overcome gravity losses; Burn time and throttling to minimize max Q (Boost-Sustain)
- **Second Stage:** Insensitive to burn time variation; Sensitive to $I_{sp}$ variation

![Mission Flight Profile](image1)

![First Stage Dynamic Pressure](image2)

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Propellant Mass Fraction Model

- A non-dimensional relationship was derived for propellant mass fraction (pmf)
  - Like sized motors were surveyed based on pmf and propellant mass
  - A subset of boost-sustain motors yields a slightly lower curve due to added insulation for the longer burn times
    
    \[ f_i = f_{i_{\text{min}}} + C_{\text{ref}} \left( \frac{m_{\text{pref}}}{m_p} \right)^{\frac{2}{3}} \]
    
    \[ \text{pmf} = \frac{1}{1 + f_i} \]

- Where,
  - \( f_{i_{\text{min}}} \) = minimum inert mass or the limit as propellant goes to infinity
  - \( C_{\text{ref}} \) = slope of data
  - \( m_{\text{pref}} \) = a reference propellant mass driving the location of inflection
**MAV Motor Model**

- Modification to the pmf model were made to account for MAV specifics
  - Additional interstage structures were accounted for by assuming 10% propellant offload
  - A 25% MGA assumed for the second stage
  - Additional inert mass added to the larger first stage for increased TVC
  - The first stage is similar to a commercially available system allowing a 15% MGA to be assumed

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Motor Sizing

- Modified COTS solution:
  - Minimize Gross Lift Off Mass (GLOM)
  - $I_{sp}$ assigned to each motor based on Commercial Off The Shelf (COTS) motors and 3 DOF analysis
  - Propellant mass allowed to vary to meet orbital assumptions while minimizing GLOM

- Optimum solution:
  - GLOM limited to 400 kg
  - $I_{sp}$ allowed to move along trend as required to meet orbital assumptions
**Thrust Traces for Both Solutions**

- The optimum solution requires challenging $I_{sp}$ values that are above the trend of other COTS products.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$I_{sp}$, sec</th>
<th>GLOM, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Stage 2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Modified COTS</td>
<td>288</td>
<td>291</td>
</tr>
<tr>
<td>Optimum</td>
<td>300</td>
<td>293</td>
</tr>
</tbody>
</table>
**Propellant Selection**

- A set of COTS propellants were surveyed based on a set of specific assumption
  - -70 °C/ +40 °C storage and -20 °C Operation
  - Ranked density-impulse
  - Effects of Planetary Protection procedures
    - Bio-reduction (heat or radiation)
    - Bio-barriers
    - End-of-mission procedures
  - TRL level – Similar mission histories
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Mars Ascent Vehicle Study

Nozzle and Controls

• With low operational temperature assumptions freezing slag is concern
  • Subsonic splitline vectorable nozzle could get entrained with slag and freeze up
  • Therefore a super sonic splitline was selected

• RCS sizing will rely on 6 DOF results when received
  • Cold gas vs hydrazine
  • Minimize mass
  • Favors minimal Q at first stage burnout
Development and Qualification Testing Planning

- Defining a development/qualification is important for planning purposes
- More motors can reduce risk and increase cost requiring these to be balanced
- A qualitative matrix of risk with varied numbers of motors was derived based on assumption parameters qualified
- A set of 3 development and 3 qualification motors were selected by the project
  - Flight test is considered a qualification motor in Dev/Qual Plan

<table>
<thead>
<tr>
<th>OPTION</th>
<th>SUB-SCALE TESTING</th>
<th>FULL-SCALE TESTING</th>
<th>LIKELIHOOD X CONSEQUENCE</th>
<th>FINAL RISK SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PLANETARY PROTECTION</td>
<td>THERMAL CYCLING</td>
<td>COLD-SOAK</td>
<td>PLANETARY PROTECTION</td>
</tr>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>3 DMs + 8 QMs</td>
</tr>
<tr>
<td>2</td>
<td>2X</td>
<td>2X</td>
<td>2X</td>
<td>3 DMs + 6 QMs</td>
</tr>
<tr>
<td>3</td>
<td>3X</td>
<td>3X</td>
<td>3X</td>
<td>3 DMs + 4 QMs</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>3 DMs + 4 QMs</td>
</tr>
<tr>
<td>5</td>
<td>2X</td>
<td>2X</td>
<td>2X</td>
<td>3 DMs + 3 QMs</td>
</tr>
<tr>
<td>6</td>
<td>3X</td>
<td>3X</td>
<td>3X</td>
<td>2 DMs + 2 QMs</td>
</tr>
</tbody>
</table>

Dev/Qual Risk Matrix

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**Future Work**

- Refine and iterate with other subsystems
  - Trade $I_{sp}$ (expansion ratio) with vehicle mass (interstage)
  - Trade aero stability with flow feature mass and location and design

- Refine design models (CAD) for minimum mass

Current MAV Solid Vehicle Concept