National Aeronautics and Space Administration

Mission and Design Sensitivities for Human Mars Landers Using Hypersonic Inflatable Aerodynamic Decelerators

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Introduction

- This paper explores the impact of human Mars mission architecture decisions on the design and performance of a lander using the HIAD entry system.
  - Earth departure options
  - Mars arrival options
  - Entry Descent and Landing options

Related papers at this conference

- “Human Mars EDL Pathfinder Study: Assessment of Technology Development Gaps and Mitigations” – Randy Lillard

- “Human Mars Mission Design Study Utilizing the Adaptive Deployable Entry and Placement Technology” – Alan Cassell

- “Impacts of Launch Vehicle Fairing Size on Human Exploration Architectures” – Sharon Jefferies
Entry Technologies

Inflatable
HIAD – Hypersonic Inflatable Aerodynamic Decelerator

Deployable
ADEPT – Adaptable Deployable Entry and Placement Technology

Mid L/D
Rigid Structure

Capsule Concept

NASA is studying 4 entry system technologies for human missions. This paper is focused on the HIAD option.
HIAD Lander

- **Cargo**
  - Ascent vehicle, habitats, etc.

- **Mars Descent Module (MDM)**

- **Entry System**
  - Hypersonic Inflatable Aerodynamic Decelerator (HIAD)
There are several in-space propulsion options for delivering cargo to Mars. Solar electric, chemical, and nuclear thermal have been studied.

Solar Electric Propulsion offers 2 unique opportunities

- Single launch of lander and propulsion to Mars
  - Uses SEP one-way to Mars.
  - Spiral escape from high Earth orbit

- Reusable Earth to Mars transportation
  - SEP + chemical hybrid vehicle
  - Cislunar aggregation
Earth Departure Options

Packaging in SLS 10m Fairing

Single Launch SEP + Lander

Lander only launch
Then rendezvous with reusable SEP hybrid for transit to Mars

Lander and SEP co-manifested results in greater lander structural mass due to challenge of meeting 5 Hz lat. stiffness goal
Earth Departure Options

- SLS launch fairing diameters of 10m and 8.4m have been studied.
- 3 of 4 entry system technologies are not likely to be feasible at 8.4m.
- 8.4m fairing challenges mitigated by increasing lander mass and overall architecture risk;
  - Structures,
  - landing gear design,
  - stability during entry,
  - aft body heating.
- More landers needed to deliver the same payload.
- See paper on this topic.
Mars Arrival Options

- Two options for Mars orbit capture were studied
  - Aerocapture into a 1 Sol orbit, loiter ≤ 1yr, deorbit duration ~12hrs
  - Propulsive Capture using SEP Hybrid into 5 Sol orbit, loiter ≤ 1yr, deorbit duration ~2.5 days

Deorbit from 5 Sol may increase risk of unfavorable landing weather
Aerocapture cases use a 2\textsuperscript{nd} HIAD system to mitigate risk of long exposure during Mars loiter prior to entry.
Entry Descent and Landing Options

• Sensitivity to payload mass
  – The greater the payload capability of each lander the fewer number of landers are needed.
    • 4 landers are required with 20mt capability, 3 with 27mt
  – Smaller payload capability results in lighter landers, easier payload packaging and minimum required SEP power levels
  – Payload capability is driven by MAV
    • Ascent to high Mars orbit (1Sol-5Sol) is desired for rendezvous with Earth return vehicle
    • Reliance on ISRU LOX production significantly reduces necessary MAV landed mass (MR > 3 for lox methane)

Total Lander Mass (t) = 1.51(payload) + 23.5  
Aerocapture = 1.43(payload) + 18  
Propulsive delivery to 5 Sol
Entry Descent and Landing Options

- **Propulsion Options: Lox/methane vs storable MMH/NTO (both assume pump fed main engines)**
  - Common propulsion technology is assumed for descent and ascent to minimize investments across the architecture
  - Lox/methane + ISRU allows for MAVs to reach high Mars orbits while minimizing landed mass to 20mt
  - A storable solution eliminates technology investment in long duration cryofluid management and offers greater packaging density for both descent and ascent stages
  - Storable option must deliver more payload because ISRU MAV propellant production is no longer an option
    - To minimize lander payload delivery requirement, the storable MAV is limited to ascent to a low Mars orbit and the cabin size is minimized to reflect 8-12hr habitation.
    - Requires a new vehicle, Mars orbit taxi, to complete ascent and rendezvous with Earth return vehicle.
### Results

<table>
<thead>
<tr>
<th>Component</th>
<th>Aerocapture to 1 sol Parking Orbit SEP/Chem Split Options</th>
<th>Propulsive delivery to 5 sol Parking Orbit SEP/Chem Hybrid Options</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>27 t LOX/Methane 20 t LOX/Methane NTO/MMH</td>
<td>27 t LOX/Methane 20 t LOX/Methane NTO/MMH</td>
</tr>
<tr>
<td>Structures</td>
<td>5442 4961 4961</td>
<td>4652 4253 4136</td>
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<tr>
<td>Propulsion</td>
<td>5310 4899 5206</td>
<td>5260 4842 5189</td>
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<td>Power</td>
<td>1437 1217 1575</td>
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<tr>
<td>C&amp;DH</td>
<td>136 136 136</td>
<td>136 136 136</td>
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<tr>
<td>C&amp;T</td>
<td>76 76 76</td>
<td>76 76 76</td>
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<tr>
<td>GNC</td>
<td>116 116 116</td>
<td>116 116 116</td>
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<tr>
<td>Thermal</td>
<td>357 328 573</td>
<td>357 328 573</td>
</tr>
<tr>
<td>Decelerator</td>
<td>9444 9444 9444</td>
<td>4185 4185 4185</td>
</tr>
<tr>
<td><strong>Dry Mass</strong></td>
<td>22,318 21,177 22,087</td>
<td>16,219 15,373 15,986</td>
</tr>
<tr>
<td><strong>Cargo</strong></td>
<td>27,000 20,000 23,881</td>
<td>27,000 20,000 24,187</td>
</tr>
<tr>
<td>Non-prop Fluids</td>
<td>851 848 951</td>
<td>850 843 920</td>
</tr>
<tr>
<td><strong>Inert Mass</strong></td>
<td>50,168 42,025 46,919</td>
<td>44,068 36,216 41,093</td>
</tr>
<tr>
<td><strong>Used Propellant</strong></td>
<td>14,093 11,668 12,289</td>
<td>12,519 10,367 11,497</td>
</tr>
<tr>
<td><strong>Total Wet Mass</strong></td>
<td>64,261 53,693 59,208</td>
<td>56,587 46,583 52,590</td>
</tr>
</tbody>
</table>
Parametric mass models are in development for all four entry system technologies considered. Models are anchored by point designs generated by multidisciplinary team.
Conclusions

• Landers can be launched alone or co-manifested with SEP stages. However in either case a 10m fairing diameter is desired.

• Dual HIADs are assumed for aerocapture options. A single dual use HIAD may be possible but further testing is required.

• Lox/methane propulsion + ISRU allows for direct ascent to high Mars orbit, while keeping lander payload delivery requirement small.

• Storable propulsion options are heavier, require another vehicle to complete ascent, but eliminate need for CFM technology investments.

• The HIAD-based Mars lander can accommodate a variety of architecture options.