IAC-08-D2.3.6
Analysis and Design of Cargo Transport Architectures for Manned Mars Missions Using Electric Propulsion

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Introduction

What are we intending to do?
• Cargo delivery for manned Mars missions

What cargo modules are required?
• Habitat (Complex)
• Nuclear Reactors
• Mars Ascent Vehicle (MAV)
• Earth Return Vehicle (ERV)

How to send the cargo modules to Mars?
Reference Mission

NRM Data:
- Nuclear Thermal Propulsion, $I_{sp} = 900s$
- Two 80t launches to LEO, Cargo + Propulsion
- Payload to surface fraction of 33%

Reference Scenario Hohmann-Transfer:
- Chemical Propulsion, $I_{sp} = 450s$
- TMI by Ariane 5 SH
- Direct re-entry
- Surface payload 27.6t (or 27.6%)

Scenario Design

The Idea:
- Use of Solar Electric Propulsion

Parameter variations:
- Different thruster types
- Initial acceleration 0.2-1.0 mm/s²
- TMI 400km & 6000km LEO
- Target relative velocity 3-5km/s

<table>
<thead>
<tr>
<th>Parameter variations</th>
<th>$I_{sp}$ [s]</th>
<th>$P_{max}$ [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arcjet</td>
<td>480</td>
<td>750</td>
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<tr>
<td>Hall</td>
<td>1650</td>
<td>1500</td>
</tr>
<tr>
<td>RIT-22-Lo</td>
<td>3714</td>
<td>4020</td>
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<tr>
<td>RIT-22-Me</td>
<td>4762</td>
<td>6209</td>
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<tr>
<td>RIT-22-Hi</td>
<td>6605</td>
<td>11100</td>
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</table>

Two Scenarios:
- Dispensable
- Reusable
Trajectory Optimization:
• DLR tool InTrance
• Evolutionary algorithm
• Neurocontrol
• Superior by combination

EDL Subsystem Optimization:
• DLR software developed by co-author

Dispensable Scenario:
• Launch
• Earth escape
• Interplanetary transfer
• Direct entry

Launch:
• Ariane 5 Super-Heavy (A5SH)
• 100t payload to 400km circular LEO
Dispensable Scenario – 2/2

Payload at re-entry:

- Hi: 57t, Me: 55t, Lo: 50t, Hall: 28t → discarded
- Low acc. → high $I_{sp}$, high acc. → low $I_{sp}$

Reusable Scenario – 1/2

Reusable Scenario:
- Two Ariane 5SH launches to 400 km LEO
- Hohmann Transfer to 6000 km HEO
- Assembly in HEO
- Earth Escape from HEO, $m_0 = 100t$
- Outbound flight
- Payload detachment
- Gravity assist
- Return flight
- Capture at Earth to HEO
Payload Reusable Scenario:

- Higher payload with high $I_{sp}$ engines
- Payload capability of 43 to 52t

Reusable Scenario – 2/2

Dispensable vs Reusable Entry Payload:

- Dispensable also better for the fast transfer
- Reusable better at 2300t launched → 15 flights

Comparison
Entry: L/D=0.18
• Inflatable Heatshield → SP Heat Flux 25W/cm²
• 7.5m is chosen → bc = 66.3kg/m²
• Entry angle: 13.4° → a = -6.8gₑ, Q = 1625J/cm²

Descent:
• 30m supersonic parachute (700m²)
• 80m subsonic parachute (5000m²) → unavailable today
→ Four 42m subsonic parachute cluster, 90% efficiency

Landing:
• 500kN LOX/CH₄ thruster chosen
• Thrust as burn time – propellant consumption trade off

<table>
<thead>
<tr>
<th>Entry mass</th>
<th>25000 kg</th>
<th>35000 kg</th>
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<tr>
<td>Total EDL mass</td>
<td>3880 kg</td>
<td>5210 kg</td>
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Entry, Descent, Landing – 3/3

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Thruster</th>
<th>a</th>
<th>Payloa</th>
<th>T [a]</th>
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</thead>
<tbody>
<tr>
<td>Disp. LEO</td>
<td>RIT-22-Me</td>
<td>0.4</td>
<td>28.4%</td>
<td>1.14</td>
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<tr>
<td>Disp. LEO</td>
<td>RIT-22-Hi</td>
<td>0.2</td>
<td>47.4%</td>
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<td>Disp. HEO</td>
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<td>Reusab. 1st</td>
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<tr>
<td>NRM</td>
<td>NTP</td>
<td>-</td>
<td>33.0%</td>
<td>-</td>
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<tr>
<td>Reference</td>
<td>Chem.</td>
<td>-</td>
<td>27.6%</td>
<td>-</td>
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</tbody>
</table>

Summary
Conclusion

Final Facts:
• Better results than reference mission
• Dispensable always superior to Reusable
• Reusable feasible if Hohmann is skipped

Weakness:
• Large inflatable heat shields
• Undeveloped propulsion system
• Huge solar generators (MW)