Human Mars Entry, Descent & Landing Architecture Study (EDLAS)

Rigid Decelerators

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Study Objectives

- Develop two evolutionary rigid vehicle concepts to deliver human scale payloads (20 metric ton) to the surface of Mars
  - Capsule
  - Lifting body, mid-range lift-to-drag ratio (Mid L/D)
- Determine vehicle configurations for various mission flight phases
- Determine vehicle performance:
  - Integrated system mass
  - Ability to meet landing constraints
  - Payload packaging and surface access
- Provide technology investment recommendations to NASA’s Space Technology Mission Directorate
Cargo Elements for Long Duration Surface Stay

10 m diameter SLS fairing; 300 day stay; Crew of 4; Four 20 t payloads

**Lander 1**
- Surface Power Units
- Unpressurized Rovers
- Cargo Off-loading
- Logistics Module
- Science Payloads

**Lander 2**
- Mars Ascent Vehicle
- Atmosphere ISRU
- Crew Access Tunnel

**Lander 3**
- Pressurized Rover
- Logistics module
  - Crew consumables
  - Fixed system spares
  - Mobile system spares
  - EVA spares
- Surface Mobility

**Lander 4**
- Habitation
Vehicle Summaries: Capsule

Vehicle Configuration

Sizing Assumptions:
• Soyuz Shape
• 3G limit during AC & EDL
• 10 m diameter heatshield - *Fairing interference, but potential to fly without a fairing*
• No Jettison events during EDL
• Ballistic coefficient = 500 kg/m²

Launch to Mars Landing Vehicle Configurations

EDL Concept of Operations

Entry
AOA = -20 deg
Velocity = 4.7 km/s
FPA = -10.6deg

Deorbit
Aft RCS Thrusters

Powered Descent Initiation (PDI)
Mach = 4.7 Alt = 9.8 km
Pitch up to 0 deg AOA

Approach
8x125kN engines
80% throttle

Touchdown
## Capsule Mass

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Component</th>
<th>Quantity</th>
<th>Unit Mass (kg)</th>
<th>CBE (kg)</th>
<th>MGA %</th>
<th>MGA (kg)</th>
<th>MEV (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeroshell</td>
<td>Heatshield Structure + TPS</td>
<td>1</td>
<td>1,893</td>
<td>1,893</td>
<td>35%</td>
<td>663</td>
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<td>Backshell Structure + TPS</td>
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<td>3,310</td>
<td>3,310</td>
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<td>1,158</td>
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<td><strong>TOTAL</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>7,025</td>
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</table>

CBE = Current Best Estimate  
MGA = Mass Growth Allowance  
MEV = Maximum Expected Value
Capsule Vehicle Configurations

Apollo Class (AIAA-2016-0219)

GE D-2 Apollo Concept
3.9 m (Arthur, 1963) diameter

Soyuz Class
2.7 m diameter

Recent studies considered heritage shapes with storable propellants (10 m diameter)

Earth human flight heritage; Shape has not flown at Mars

0.75 m ground clearance

10 m
Capsule Payload Packaging

Lander 1
- OK

Lander 2
- rework
  - LMO MAV (requires taxi)
  - Repackaged radiators

Lander 3
- rework
  - Logistics Module separate launch to fit

Lander 4
- rework
  - Habitat volume divided into 2 HABs

Design impacts of adding landers
- More launches (est. 5)
- Larger landing zone
- Modular Habitat; need way to connect them on surface
- Different payload masses per mission
- Additional architecture element (taxi)
- Extended delivery schedule
Capsule Performance

• **Landing Constraints**
  – Within 50 m of a target
  – At 0 km above reference areoid
  – 8-100 kN engines

• **Guidance Approach:**
  – Heritage Bank Angle with Pure Gravity Turn, thrust factor 1.875 (BNKPGT1875)
  – Direct Force Control with Augmented Gravity Turn, thrust factor 1.5 and 1.2 (DCFAGT15 and DCFAGT12)

• **Results**
Vehicle Summaries: Mid L/D

Vehicle Configuration

EDL Concept of Operations

Sizing Assumptions:
- 5 G axial, 2 G lateral load at launch on all concepts
- **Payload element structures need to be redesigned for horizontal launch orientation**
- 9.1 m max diameter in 10 m SLS fairing
- No Jettison events during EDL
- Ballistic coefficient = 380 kg/m²

Launch to Mars Landing Vehicle Configurations

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 4</th>
<th>Phase 5</th>
<th>Phase 5a</th>
<th>Phase 6</th>
<th>Phase 7</th>
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<tbody>
<tr>
<td>Launch</td>
<td>Earth Loiter &amp; Stack Chase</td>
<td>Earth-Mars Flight</td>
<td>Mars Arrival</td>
<td>Mars Orbit Loiter</td>
<td>Crew Transfer</td>
<td>Entry, Descent &amp; Landing</td>
<td>Surface</td>
</tr>
</tbody>
</table>

- **Deorbit**
  - Aft RCS Thrusters

- **Entry**
  - AOA = 55 deg
  - Velocity = 4.7 km/s
  - FPA = -10.8 deg

- **Powered Descent Initiation**
  - Mach = 1.98, Alt = 3.2 km
  - Pitch up to 90 deg AOA

- **Approach**
  - T/W = 1.25 Earth g
  - 8x125kN engines
  - 80% throttle
  - 10 deg outward cant

- **Touchdown**

Ground Operations
## Mid L/D Mass

<table>
<thead>
<tr>
<th>ID</th>
<th>System</th>
<th>Without cargo bay door</th>
<th></th>
<th>With CBD</th>
<th></th>
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<tr>
<td></td>
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<td>Basic (kg)</td>
<td>MGA (%)</td>
<td>Predicted (kg)</td>
<td>Basic (kg)</td>
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<td>20%</td>
<td>1943.6</td>
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<td>24.1%</td>
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<tr>
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<td>Power</td>
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<td>27.7%</td>
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<td>953</td>
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<td>675</td>
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<td>475</td>
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<td>Cargo</td>
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<td>8.0</td>
<td>Non-Propellant</td>
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<td>6.0%</td>
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<td>911</td>
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<td>58872</td>
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</table>

CBD = Cargo Bay Doors
MGA = Mass Growth Allowance
Mid L/D Vehicle Configurations

49% scale version in the Delta IV Heavy long and short fairings precursor payloads up to 10t
Design impacts

• Habitability of horizontal habitat orientation has not yet been assessed. May require more or less volume.
• Launch and landing loads on payloads are in different directions

Lander 4
Habitat volume reconfigured to horizontal orientation
Mid L/D Performance

- **Landing Constraints**
  - Within 50 m of a target
  - At 0 km above reference areoid
  - 8-100 kN engines

- **Guidance Approach:**
  - Bank angle Control with Alpha Modulation (BCAM)
  - With thrust factor 1.2 (BCAMTHR12)

- **Results**

![Histograms](image)
Launch Vehicle Integration

- **SLS Launch Fairing Options**
  - 10m diameter x 19 m or 27 m

- **Impacts of Flying Without a Fairing**
  - Launch vehicle aerodynamics & loads
  - Fairing subsystems carried all the way to Mars

<table>
<thead>
<tr>
<th>ID</th>
<th>Subsystem</th>
<th>No CBDs Predicted Mass (kg)</th>
<th>No SLS PLF Predicted Mass (kg)</th>
<th>No CBD with SLS PLF Predicted Mass (kg)</th>
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<td>3.0</td>
<td>Power</td>
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<td>4.0</td>
<td>Avionics</td>
<td>333</td>
<td>333</td>
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<td>5.0</td>
<td>Thermal</td>
<td>844</td>
<td>844</td>
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<td>6.0</td>
<td>Aero decelerator</td>
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<td>TPS</td>
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<td>6.3</td>
<td>Mechanisms</td>
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<td>962</td>
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<tr>
<td>6.4</td>
<td>Landing Gear</td>
<td>985</td>
<td>985</td>
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<td>6.5</td>
<td>SLS PLF-Specific Components</td>
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<td>7.0</td>
<td>Cargo</td>
<td>20,000</td>
<td>20,000</td>
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<td>8.0</td>
<td>Non-Propelled Fluids</td>
<td>966</td>
<td>966</td>
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<td>Used Propellant</td>
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<td>227</td>
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<td></td>
<td>Total Stage Gross Launch Mass</td>
<td>67,276</td>
<td>63,922</td>
<td>3.3 t heavier without fairing</td>
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## Integrated Vehicle Mass

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<tr>
<th>ID</th>
<th>Subsystem</th>
<th>Capsule</th>
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<td>333</td>
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<td></td>
<td><strong>Dry Mass</strong></td>
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<td>20,000</td>
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<td>Non-Propelled Fluids</td>
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<td>1,523</td>
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<td><strong>Total Stage Gross Launch Mass</strong></td>
<td><strong>68,277</strong></td>
<td><strong>66,192</strong></td>
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Recommendations

• Down select to one rigid vehicle design: Mid L/D
  – Payload Packaging

• Determine the effects of different launch and landing load paths on payload structural design

• Perform extensive CFD analysis on SRP initiation and surface interaction phase

• Define *EDL GN&C sensor requirements* matrix (performance and software requirements and vehicle accommodation)
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