# EDL Vehicle Designs: 20 t Payload Capability

<table>
<thead>
<tr>
<th>Name</th>
<th>Shape</th>
<th>Vehicle Dimensions</th>
<th>Launch Mass</th>
<th>Entry Mass</th>
<th>Ballistic Number</th>
<th>L/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capsule</td>
<td></td>
<td>10 m (h) x 10 m (w)</td>
<td>68t</td>
<td>63t</td>
<td>500 kg/m²</td>
<td>0.3</td>
</tr>
<tr>
<td>Mid L/D</td>
<td></td>
<td>22m (l) x 7.3m (h) x 8.8m (w)</td>
<td>66t</td>
<td>62t</td>
<td>380 kg/m²</td>
<td>0.55</td>
</tr>
<tr>
<td>ADEPT</td>
<td></td>
<td>4.3m (h) x 18m diameter</td>
<td>60t</td>
<td>55t</td>
<td>155 kg/m²</td>
<td>0.2</td>
</tr>
<tr>
<td>HIAD</td>
<td></td>
<td>4.3m (h) x 16m diameter</td>
<td>57t</td>
<td>49t</td>
<td>155 kg/m²</td>
<td>0.2</td>
</tr>
</tbody>
</table>

ADEPT = Adaptable Deployable Entry Placement Technology
HIAD = Hypersonic Inflatable Aerodynamic Decelerator

Study down select
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
## EDLAS Requirements and Assumptions

### Informal Requirements

1. Launch on Block 2B SLS, 10m fairing
2. Interface with Mars transit systems
3. Enable docking and crew transfer from deep space habitat
4. Aerocapture at Mars & Deorbit from 1 Sol parking orbit
   - Loiter in Mars orbit up to 1 year
4. Aerocapture at Mars & Deorbit from 1 Sol parking orbit
5. Crewed and cargo landers are of the same design and fly the same trajectories
   - Human Systems Integration Requirements (HSIR) compliant trajectory (< 4 Earth g)
6. Deliver 20mt crewed payload to Mars surface
   - Allow for payload access on Mars surface
7. Land within 50m of target, 0 km above the reference areoid
8. Limit hazardous landing debris to <700m radius

### Assumptions

1. No separation events during EDL
2. No parachutes as primary drag devices
3. Navigation errors not considered at this time
4. Common MAV and EDL main engines (LOX/CH4 ISRU compatible)
5. No MAV assembly on Mars surface
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

EDL Concept of Operations

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

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

Launch to Mars Landing Vehicle Configurations
Vehicle Summaries: Mid L/D

Vehicle Configuration

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

EDL Concept of Operations

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

Ground Operations

Launch to Mars Landing Vehicle Configurations

<table>
<thead>
<tr>
<th>Phase 1 Launch</th>
<th>Phase 2 Earth Loiter &amp; Stack Chase</th>
<th>Phase 3 Earth-Mars Flight</th>
<th>Phase 4 Mars Arrival</th>
<th>Phase 5 Mars Orbit Loiter</th>
<th>Phase 5a Crew Transfer</th>
<th>Phase 6 Entry, Descent &amp; Landing</th>
<th>Phase 7 Surface</th>
</tr>
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<tbody>
<tr>
<td><img src="image1" alt="Launch" /></td>
<td><img src="image2" alt="Earth Loiter &amp; Stack Chase" /></td>
<td><img src="image3" alt="Earth-Mars Flight" /></td>
<td><img src="image4" alt="Mars Arrival" /></td>
<td><img src="image5" alt="Mars Orbit Loiter" /></td>
<td><img src="image6" alt="Crew Transfer" /></td>
<td><img src="image7" alt="Entry, Descent &amp; Landing" /></td>
<td><img src="image8" alt="Surface" /></td>
</tr>
</tbody>
</table>
Vehicle Summaries: ADEPT

Vehicle Configuration

Sizing Assumptions:
- 9.1 m max diameter in 10 m SLS fairing
- Deployable decelerator stowed forward of the heatshield in launch configuration surrounding launch adapter
- Dual Heat Pulse Capable Deployable Decelerator & Rigid Heatshield
- Ballistic coefficient 155 kg/m²
- 30% Mass Growth Allowance (MGA) applied, higher MGA in less mature system areas.

EDL Concept of Operations

Deploy
In Earth orbit

Entry
AOA = -17 deg Velocity = 4.7 km/s FPA = -10.6 deg

Deorbit
Aft RCS Thrusters

PDI
Mach = 3.0 Alt = 8.3 km Pitch to 0 deg AOA

Approach
8x100kN engines 80% throttle

Touchdown

Ground Operations

Launch to Mars Landing Vehicle Configurations

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<td><img src="image7" alt="Phase 6" /></td>
<td><img src="image8" alt="Phase 7" /></td>
</tr>
</tbody>
</table>

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Vehicle Summaries: HIAD

Vehicle Configuration

Sizing Assumptions:
- 9.1 m maximum diameter in 10 m SLS fairing
- 2 HIAD systems carried for each Lander
  - Aerocapture HIAD = 17.2 m; 7 tori with 0.8m minor diameter
  - EDL HIAD = 16.2m; 5 tori with 0.8m minor diameter
- Deployable decelerator stowed around the perimeter of the rigid center body
- HIAD Ballistic coefficient =155 kg/m²

EDL Concept of Operations

Launch to Mars Landing Vehicle Configurations

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<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 4</th>
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<td>Launch</td>
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<td>Crew Transfer</td>
<td>Entry, Descent &amp; Landing</td>
<td>Surface</td>
</tr>
</tbody>
</table>

Entry
AOA= -10 deg
Velocity = 4.7 km/s
FPA = 10.6 deg

Powered Descent Initiation
Mach = 3.0,
Alt = 8.3 km
Pitch to 0 deg AOA

Approach
8x100kN engines
80% throttle

Deorbit & Deploy

Touchdown

Deorbit & Deploy
Vehicle Analysis: Packaging

Lander 1
Lander 2
Lander 3
Lander 4
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
<table>
<thead>
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<th>Figures of Merit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle Mass</strong></td>
</tr>
<tr>
<td>Mass of vehicle transported to Mars; Impacts in-space</td>
</tr>
<tr>
<td>transportation architecture; lower mass is better</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Transportation Interface</strong></td>
</tr>
<tr>
<td>Rendezvous and docking: Considerations for docking</td>
</tr>
<tr>
<td>with Earth-Mars transportation stage AND with transit</td>
</tr>
<tr>
<td>habitat to support crew transfer into the lander</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Cargo Packaging</strong></td>
</tr>
<tr>
<td>How well does the lander configuration package the</td>
</tr>
<tr>
<td>standard 1st mission surface manifest</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Cargo Support</strong></td>
</tr>
<tr>
<td>How well does the lander accommodate the various</td>
</tr>
<tr>
<td>payload needs: Obstruction-free access, leveling, etc.</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Cargo Protection</strong></td>
</tr>
<tr>
<td>How well does the concept protect the payload</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Control Scheme</strong></td>
</tr>
<tr>
<td>Complexity of EDL control system</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>MPS Engine Requirement</strong></td>
</tr>
<tr>
<td>How close is the desired descent engine thrust level</td>
</tr>
<tr>
<td>to the desired ascent engine thrust level</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Developments</strong></td>
</tr>
<tr>
<td>Number of Technology Developments required to field</td>
</tr>
<tr>
<td>the concept</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Concept Maturity</strong></td>
</tr>
<tr>
<td>Maturity of the design analysis; how well to we</td>
</tr>
<tr>
<td>believe we have estimated the mass and complexity of</td>
</tr>
<tr>
<td>the concept</td>
</tr>
</tbody>
</table>
In 2000 randomly generated weighting schemes:

- HIAD ranked 1st or 2nd in 99% of the cases
- Mid L/D ranked 1st or 2nd in 72% of the cases
- Capsule ranked 4th in 93% of the cases

HIAD and Mid L/D consistently scored 1st or 2nd despite reweighting.
Summary

- Developed four closed EDL vehicle designs within defined requirement and assumptions
- Prioritized and identified entry system technology investments
- Higher fidelity analysis needed in key areas to drive out additional technology requirements
  - Sensors
  - GN&C
  - Engine design parameters
  - Surface plume interactions
  - Landing gear
  - Mid L/D shape optimization
  - Multiple guidance and control algorithms for each vehicle
## Key Accomplishments

- Multi-Directorate, Multi-Center, Multi-Year year collaboration
- Common Mars architecture assumptions and requirements
- Core group that understands complex integrated Mars Architecture
- Appreciate that every assumption has significant design implications
- Payload definition allowed for integrated lander/EDL design
- Subsystem commonality allowed for consistent vehicle comparisons
- Identified Figures of Merit and down selected to two EDL designs
Recommendations

- **STMD: EDL Technology Investment Recommendations**
  - *Down select to two closed vehicle designs* that bound EDL problem
    - Mid L/D and Low L/D (HIAD)
  - Perform extensive *CFD analysis on SRP initiation* and surface interaction phase
    - FY18 EDLAS + Propulsive Descent Technologies follow on efforts
  - Determine if *Direct Force Control systems* can replace heritage bank angle guidance
    - FY18 Entry Systems Modeling GN&C effort
  - Define *EDL GN&C sensor requirements* matrix (performance and software requirements and vehicle accommodation)
    - FY18 Safe & Precise Landing Integrated Capabilities Evolution (SPLICE)

- **HEOMD: Mars Architecture Design and Optimization**
  - Integrate vehicle design updates following STMD investigations
  - Assess transportation impacts for delivering heavier landers to Mars

- **SMD: Facilitate Communication**
  - To maintain awareness to upcoming Mars Sample Return mission
  - Information about common landing sites of interest (i.e. Jezero Crater)
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