Overview of the Phoenix Entry, Descent and Landing System

Rob Grover
Jet Propulsion Lab
Phoenix Mission Goals

Rebirth of the Mars 2001 Lander

- Study the history of water in Mars’ arctic region.
- Search for habitable zones in Mars’ arctic.
- Develop a robotic system to explore Mars.
Phoenix Payload

Surface Stereo Imager (SSI)
University of Arizona

Robotic Arm (RA)
JPL

Robotic Arm Camera (RAC)
Max Plank Aeronomie

Microscopy, Electrochemistry & Conductivity Analyzer (MECA)
JPL

Thermal Evolved Gas Analyzer (TEGA)
University of Arizona

Mars Descent Imager (MARDI)
MSSS

Meteorological Package with scanning LIDAR
Canadian Space Agency
## Aeroshell/Entry Comparison

<table>
<thead>
<tr>
<th></th>
<th>Viking I, II</th>
<th>MSL</th>
<th>'01 Lander</th>
<th>MPF/MER</th>
<th>Phoenix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter, m</td>
<td>3.505</td>
<td>4.572</td>
<td>2.65</td>
<td>2.65</td>
<td>2.65</td>
</tr>
<tr>
<td>Rel. Entry Velocity, km/s</td>
<td>4.5, 4.42</td>
<td>5.2 to 6.8</td>
<td>6.5</td>
<td>7.6/5.5</td>
<td>5.7</td>
</tr>
<tr>
<td>Rel. Entry FPA, deg</td>
<td>-17.6</td>
<td>-15.63 to -13.68</td>
<td>-12</td>
<td>-13.8/-11.5</td>
<td>-12.5</td>
</tr>
<tr>
<td>Entry Mass, kg</td>
<td>930</td>
<td>2400</td>
<td>588</td>
<td>585/840</td>
<td>602</td>
</tr>
<tr>
<td>m/(C_dA), kg/m²</td>
<td>63.7</td>
<td>94</td>
<td>62.9</td>
<td>62.3/89.8</td>
<td>69.3</td>
</tr>
<tr>
<td>X&lt;sub&gt;CG&lt;/sub&gt;/D reference</td>
<td>0.221</td>
<td>0.27, TBD</td>
<td>0.25</td>
<td>0.27/0.26</td>
<td>0.25</td>
</tr>
<tr>
<td>Nominal α, deg</td>
<td>-11.1</td>
<td>-11</td>
<td>-3.5</td>
<td>0</td>
<td>-3.5</td>
</tr>
<tr>
<td>Nominal L/D</td>
<td>0.18</td>
<td>0.18</td>
<td>0.06</td>
<td>0</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Entry Trajectory Comparison
Phoenix EDL Timeline

- Entry Turn Starts: E-6.3 min. Turn completed by E-5 min.
- Cruise Stage Separation: E-5 min
  - Entry: E-0 s, L-470 s, 125 km*, 5.7 km/s, γ = -12.5°
  - Peak Heating: E+99 s, L-301 s, 45 km, Peak Deceleration: E+117 s, L-353 s, 7 g
  - Parachute Deployment: E+250 s, L-150 s, 10 km, < 350 m/s (Mach 1.45)
    - Heat Shield Jettison: E+260 s, L-140 s, 9 km
    - Radar Activated: E+263 s, L-137 s, 8 km
    - Leg Deployments: E+293 s, L-107 s, 6.5 km
- Lander Separation: E+371 s, L-29 s, 0.74 km
  - Throttle Up: E+374 s, L-26 s, 0.57 km
  - Constant Velocity Achieved: E+393 s, L-7 s, 0.012 km, 1.6 m/s
  - Radar cutoff: E+395 s, L-5 s, 0.010 km, 1.6 m/s
- Touchdown: E+400 s, L-0 s, 0 km, 1.6 m/s
  - Dust Settling: L+0 to L+15 min
  - Fire Pyros for Deployments: L+7 sec
  - Solar Array Deploy: L+25 min
  - Begin Gyro-Compassing: L+100 min

- Entry: E-0 s, L-470 s, 125 km*, 5.7 km/s, γ = -12.5°
- Leg Deployments: E+293 s, L-107 s, 6.5 km

* Altitude referenced to equatorial radius

Landing at -3.5 km elevation above MOLA

X-band DTE Closed / Open Loop
UHF-band to Orbiter

X-band DTE Open-Loop
UHF-band to Orbiter

X-band DTE
UHF-band to Orbiter
Hypersonic Phase

• Hypersonic Guidance will be Demonstrated by Using a Modified Version of the Apollo Earth-entry Guidance
  – Terminal Point Range Control with Gain Matrix From Trajectory Perturbations
  – Nominal Vehicle L/D = 0.06 (Alpha=3.5 deg)
  – Utilizes Bank Control to Steer to Target at Chute Deploy
  – Operates at 10 Hz

• Hypersonic Guidance will be Demonstrated by Using a Modified Version of the Apollo Earth-entry Guidance

• No Requirement on Guidance Accuracy
• Performance will be Characterized by End-to-End Monte Carlos
• “Break-it” Testing Will Help Define Capability Limits
• Full “Lift Up”/“Lift Down” Does Not Impact Landed Success, Just Accuracy
Hypersonic Phase

- Begins with Entry Interface at 125 km Reference Altitude
- Dominated by Entry Heating
- *All Key Parameters Within Mars 2001 Design Envelope*

<table>
<thead>
<tr>
<th></th>
<th>Phoenix</th>
<th>Mars ’01 Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry Velocity</td>
<td>5.76 kps</td>
<td>~6.5 kps</td>
</tr>
<tr>
<td>Entry Errors, Delivery</td>
<td>0.20 deg</td>
<td>0.27 deg</td>
</tr>
<tr>
<td>Entry Errors, Nav</td>
<td>0.15 deg</td>
<td>0.15 deg</td>
</tr>
<tr>
<td>Max Heating</td>
<td>62 W/cm²</td>
<td>72 W/cm²</td>
</tr>
<tr>
<td>Max Loads</td>
<td>9.5 g’s</td>
<td>16 g’s</td>
</tr>
<tr>
<td>Max Bondline Temp</td>
<td>150 C</td>
<td>250 C</td>
</tr>
</tbody>
</table>

- Exist Hardware: Heatshield / Backshell Structure & TPS
- New Hardware: EDL Antennas & Assoc. TPS
Parachute Phase

Phoenix Parachute

• Viking Design Disc Gap Band (DGB)

• Mars 2001 Parachute: 13.4m Viking disc gap band
• Phoenix Currently 12.4m Viking Disc Gap Band
•Phase Begins with Parachute Mortar Firing
• Mars-01 Deploy Pushed to Viking Limit for Site Performance
•Current Lander Loads Capability Requires a Deploy Below 500 Pa

<table>
<thead>
<tr>
<th>Phoenix</th>
<th>Mars ’01 Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Deploy Mach</td>
<td>1.7</td>
</tr>
<tr>
<td>Max Deploy Qbar</td>
<td>485 Pa</td>
</tr>
<tr>
<td></td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td>1100 Pa</td>
</tr>
</tbody>
</table>
Terminal Descent Phase

**Doppler Radar**

- **Altitude**
  - Op. Range: 40-2400 m
  - Error: ≤5%
- **Velocity**
  - Op. Range: 40-1400 m
  - Error: ≤4% (> 1 m/s)
  - Quantization: 0.82 m/s
- **Phoenix Upgrade**
  - Mitigates horizontal vel. error due to slopes
  - Extra set of antennas (8 total)
  - Alt. Range: 1-3700 m
  - Vel. Range: 10-2150 m
  - Quantization: 0.40 m/s
  - Same error specs

**Descent Engines**

- 12 descent engines, ~300N each.
- Pulse-width modulated at 10Hz.
- Current baseline 3 full on.
- In addition to descent breaking, provides 3-axis attitude control.
EDL Communications

Data Return

- **UHF Comm during all of EDL**
  - Direct link to Odyssey or MRO
  - 8 Kb/s Data Rate
  - Concern about Plasma blackout in Hypersonic
- **X-Band Semaphores during all of EDL**
  - Confirmation of Key Events
  - Capability to produce “fault” semaphores
  - Some level of performance data
- **Link analyses to be refined as Mission Design matures**
Phoenix is a rebirth of the 2001 Lander using the same hardware and many of the same team members.

Continuation of follow water strategy targeting subsurface ice in the northern polar region.

First use of hypersonic guidance at Mars.

Launching in 2007 and landing in 2008, it returns to propulsive soft landing with strong similarity to the Viking landings.