MSL EDL Landing Site Safety Assessment and Prelaunch Status

Adam Steltzner, Steve Sell
and the
MSL EDL Team
Jet Propulsion Laboratory
California Institute of Technology

8th International Planetary Probe Workshop
Portsmouth, Va.
June 6th, 2011
Introduction

• MSL EDL system is finishing its final V+V prior to launch in November 2011

• The system has passed it’s S/W-H/W run-for-record in April

• EDL risk assessment has been performed at all landing sites to support site selection
  – All sites have very low EDL risk (< 2%)

• Margins comfortable at all sites
  – Gale has highest margins
  – Eberswalde has lowest margins
  – Under worst case conditions, all margins at all sites still acceptable

• External review of EDL landing site risk assessment has been conducted
  – Board concurs with EDL team’s conclusions

• EDL design is nearing completion of V+V and the team is comfortable flying to any site
- **Density interactions**
  - Density profiles impact altitude capability
  - Dispersions may consume guidance control authority as system tries to “fly them out”

- **Wind interactions**
  - Dispersions in steady state winds impact landing precision capability
  - Wind spreads near Mach sensitive events impact altitude and landing precision capability
Atmosphere Characterization and Modeling Overview

• Atmosphere characterization approach unchanged
  – Updated and validated mesoscale models (OSU, SwRI) based on latest observations
  – Performed surface pressure normalization
  – Developed dust cases based on observed dust events
  – Updated model data integration approach and generated new nominal and dust case atmosphere tables

• Generated EDL performance results for all sites using updated atmosphere model results

• No further major atmosphere characterization activities planned prior to approach
  – Continuing nominal monitoring and model updates if necessary
  – Will execute additional local dust storm robustness work
Executed As Planned Updates

- Updated and validated mesoscale models based on MCS measurements and interannual comparisons
  - Observed multiple local times at landing site regions during L-1 Mars year campaign (Fall 2010)

- Updated and corrected any systematic surface pressure biases in Ames GCM and mesoscale model runs
  - Used UK MGCM with TES data assimilation as source
    - Tuned to VL1 record
    - Closely fits radio occultation and Phoenix measurements
  - Used MOLA topography and model thermal structure to compute pressure at precise site elevations
Dust Observations

- Observed thermal anomalies associated with dust events via MCS
  - Used observations to validate dust distributions in models

- Commissioned survey of dust events from orbital imagery near sites and arrival season
  - Cantor (MSSS) analyzed 6 Mars years of MOC and MARCI data
  - Assessed likelihood of encountering local and regional dust events
  - Provided information to mesoscale modelers to model dust events

- Regional storm risk interrogated
  - Eberswalde, Holden impacted in 2 of 7 observed Mars years
  - Gale peripherally impacted in 1 of 7 observed Mars years
  - Mawrth impacted in 0 of 7 observed Mars Years

- Modeled regional storm and haze to assess impact on EDL system
Dust Modeling

- Focused on regional events due to larger temporal and spatial likelihood of encounter

- Modeled MY29-like regional dust events in mesoscale models
  - Augmented nominal mesoscale runs with two types of higher dust cases
  - Dust “haze” mesoscale runs akin to MarsGRAM dusttau cases
  - Parameterized opacity variations in OSU model: “regional-scale dust bombs” designed to simulate observed regional storms

- Use regional dust event runs as part of landing site safety assessment process
  - Investigated sensitivity of zonal winds to dust loading
  - Evaluated an elevated well mixed dust case via mesoscale models
  - “Flew through” model results using same integration process used for nominal cases
System Impact of Regional Dust Events

- Modeling results revealed dust-related density and wind perturbations to be on par with nominal uncertainties
  - Nominal uncertainties set conservatively using variability bounds of both mesoscale models
  - No significant differences at altitudes of interest

- EDL performance simulations show no significant loss of performance associated with dust

- EDL system is robust to as-modeled regional dust events
EDL Terrain Interactions

Critical EDL terrain interactions occur via three distinct mechanisms

Radar Interaction
- Surface acquisition following heatshield separation
- Measures range to surface & relative velocity

Rover Interaction
- Rover mobility serves as landing gear during touchdown event

Plume Interaction
- Mars Lander Engine jets impinge on surface at low descent stage altitudes
- Ground over-pressures may result in surface alteration and/or dust excitation
# Terrain Interaction Assessment Matrix

## Interaction Category

<table>
<thead>
<tr>
<th>Interaction Category</th>
<th>Description</th>
<th>Primary Analysis Method</th>
<th>Confirming Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touchdown Loads</td>
<td>Rover/Mobility margins during touchdown</td>
<td>ADAMS</td>
<td>Test</td>
</tr>
<tr>
<td>Touchdown Stability</td>
<td>Rover dynamic stability (tip-over)</td>
<td>ADAMS</td>
<td>Test</td>
</tr>
<tr>
<td>Terrain Relief</td>
<td>Accordion not sized properly to account for terrain relief</td>
<td>Bounding Analysis</td>
<td>POST/Sulcata</td>
</tr>
<tr>
<td>RF (IDS Performance)</td>
<td>TDS range and velocimetry data inaccurate outside of the expected TDS performance</td>
<td>Simulations (POST/Sulcata)</td>
<td>Field Test</td>
</tr>
<tr>
<td>Touchdown Trigger Spooling</td>
<td>Prolonged Rover-DS interaction (retensioning of the bridle) could preclude timely detection of the post-touchdown state and cause the DS to approach too close to the surface</td>
<td>Bounding Analysis</td>
<td>ADAMS</td>
</tr>
<tr>
<td>Propellant Usage (during TD)</td>
<td>Extended touchdown event due to large slope</td>
<td>Bounding Analysis</td>
<td>ADAMS (time)</td>
</tr>
<tr>
<td>Loaded Bridle Contact</td>
<td>Tensioned bridles coming into contact with top deck hardware during the touchdown event</td>
<td>Bounding Analysis</td>
<td>ADAMS</td>
</tr>
<tr>
<td>Direct Plume Impingement</td>
<td>Thermal and physical damage caused by direct plume impingement on the rover during the touchdown event</td>
<td>Bounding Analysis – Through TD Offline Sim – Flyaway</td>
<td>ADAMS – Through TD POST – Flyaway</td>
</tr>
<tr>
<td>Indirect Plume Impingement</td>
<td>Sandblasting/cratering the rover with entrained surface particulates</td>
<td>Bounding Analysis</td>
<td>N/A</td>
</tr>
<tr>
<td>Telecom/Thermal</td>
<td>Rover left in a state such that basic surface operation functions can be carried out</td>
<td>Engineering Assessment</td>
<td>N/A</td>
</tr>
<tr>
<td>Trafficability</td>
<td>Rover is left in a state where traverse is possible</td>
<td>Engineering Assessment</td>
<td>N/A</td>
</tr>
</tbody>
</table>

## Biggest Drivers

- Radar
- Plume
- Direct
“Direct” Interaction
Critical Terrain Data Sets

Digital Elevation Maps

Surface Material Maps

Mawrth Vallis Hazards Map

Inescapable Hazard Maps

Rock Maps
Touchdown Hazard Maps

EBW

MAW

HOL

GAL
Ellipse Sensitivities

- Risk assessment at all sites is robust to variations in landing points distributions / ellipse size
- Risk assessment process and tools enable optimal ellipse placement to minimize EDL risk
  - Small motions relative to current targets (<5km)

Improved Landing Accuracy (~12km x ~20km)

- Ellipse Size / Targeting Study
Convolution of Landing Points/Hazards

EBW

GAL

HOL

MAW

<table>
<thead>
<tr>
<th>EDL Terrain Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eberswalde</td>
</tr>
<tr>
<td>Gale</td>
</tr>
<tr>
<td>Mawrth</td>
</tr>
<tr>
<td>Holden</td>
</tr>
</tbody>
</table>
Conclusions

- EDL risk assessment has been performed at all sites
  - Preliminary EDL tuning is complete

- External review of EDL landing site risk assessment has been conducted
  - Board concurs with EDL team’s conclusions

- All sites have low EDL risk
  - Sites have differing levels of risk, but differences are small

- Margins comfortable at all sites
  - Gale has highest margins
  - Eberswalde has lowest margins
  - Under worst-case conditions, all margins at all sites still acceptable

- EDL team is comfortable flying to any site