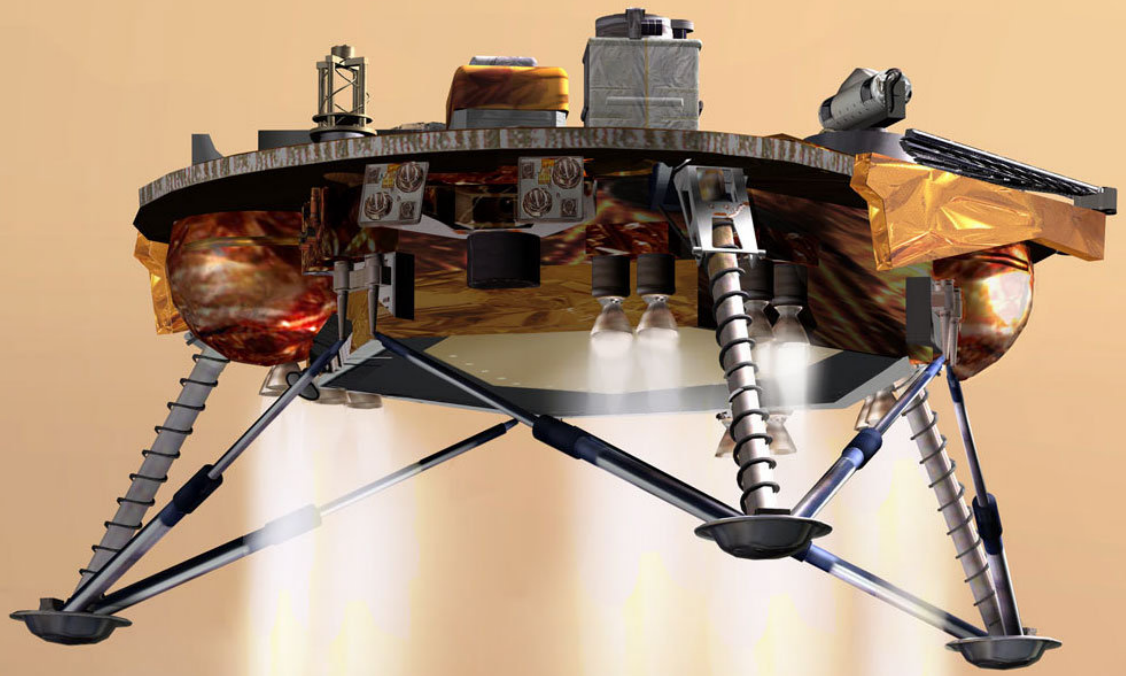
# The Phoenix Mars Landing
## An Initial Look




**Presented by M. R. Grover[1]**

**E. S. Bailey[1], J. P. Chase[1], B. D. Cichy[1], P. N. Desai[2], D. B. Eldred[1], P. E. Laufer[1], M. E. Lisano[1], J. L. Prince[2], E. M. Queen[2] and E. D. Skulsky[1]**

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]NASA Langley Research Center



**International Planetary Probe Workshop 6**
**25 June 2007**
**Atlanta, Georgia, USA**

National Aeronautics and Space Administration
Jet Propulsion Laboratory, California Institute of Technology

# Acknowledgements

**Special Acknowledgement: Lockheed Martin Phoenix Entry Descent & Landing Team**

**T. D. Gasparrini**
**B. R. Haack**
**M. A. Johnson**
**T. M. Linn**
**T. A. Priser**
**J. A. St. Pierre**

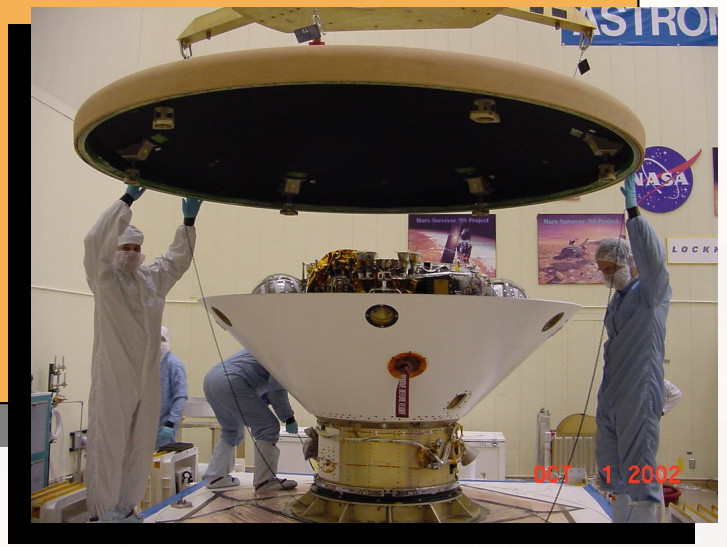
**And the entire Lockheed Martin Phoenix Team**

# Landing Analysis Maturity

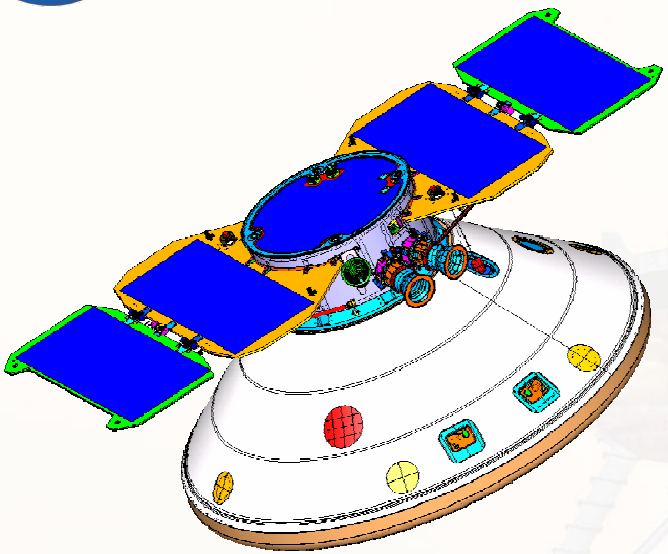
**The contents of this presentation represents present understanding of the Phoenix landing. A rigorous analysis of the Phoenix landing is currently underway and a more complete and thorough assessment will be available in coming months.**

# The Phoenix Story

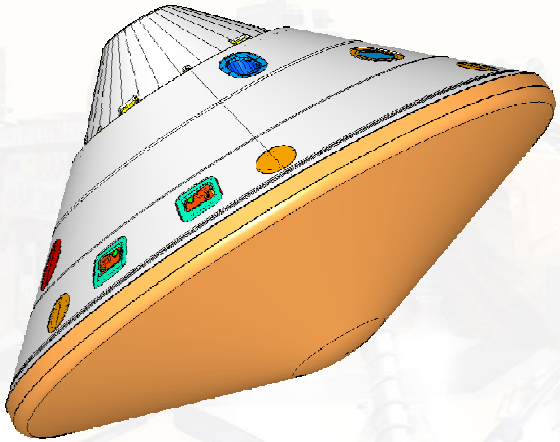
- **Started as Mars Surveyor 2001 Lander**
  - **Faster, better, cheaper spacecraft**
  - **Sister spacecraft of Mars Polar Lander**
  - **Cancelled after Mars Polar Lander failure in 1999**
    - **Not enough time to address findings of MPL failure review prior to 2001 launch window**
- **Reborn as Phoenix in 2003**
  - **Same spacecraft, modified science payloads**
  - **Enhanced radar**
  - **Addition of EDL communication system**
  - **Enhanced test program**
  - **Launched Aug 4th, 2007**



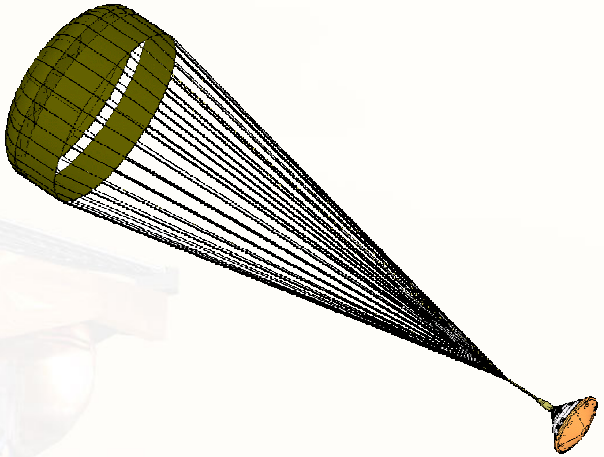
# Spacecraft Overview



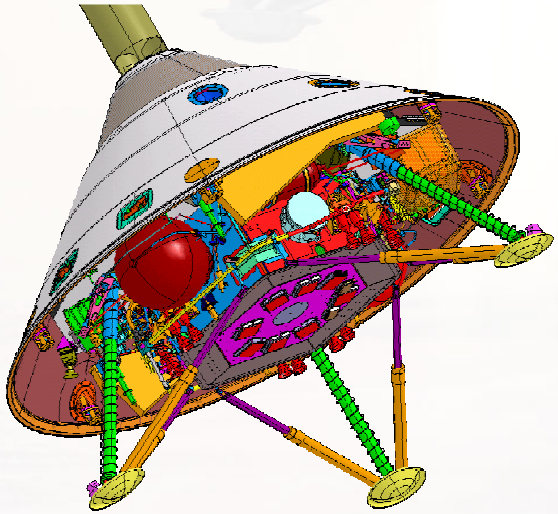
Pre-Entry Configuration



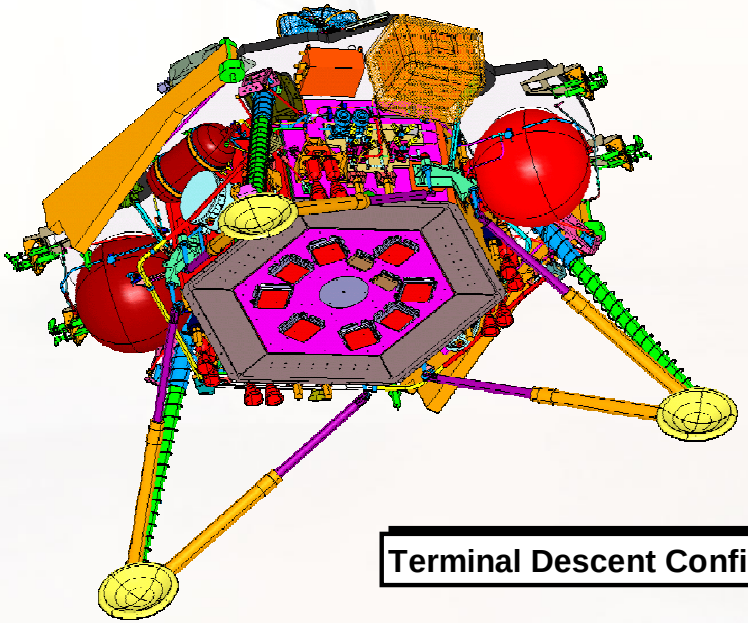
Entry Configuration



Parachute Configuration

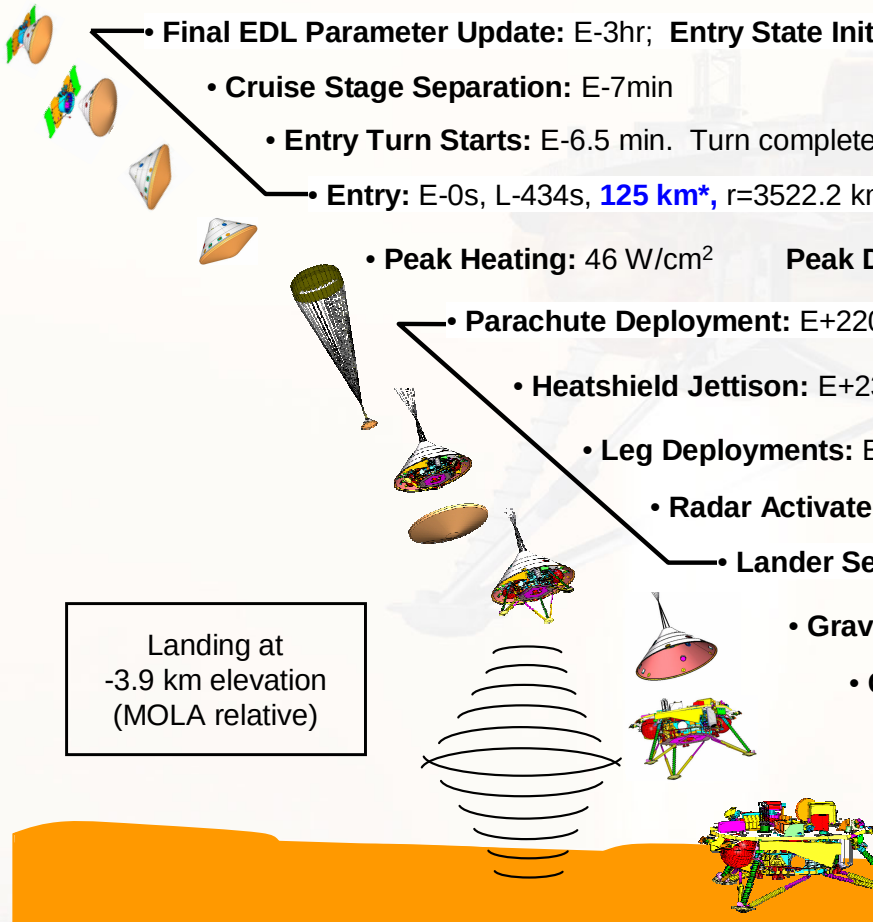


Post HS & Leg Deploy Configuration



Terminal Descent Configuration

# EDL Nominal Design



- **Final EDL Parameter Update:** E-3hr; **Entry State Initialization:** E-10min
- **Cruise Stage Separation:** E-7min
- **Entry Turn Starts:** E-6.5 min. Turn completed by E-5min.
- **Entry:** E-0s, L-434s, **125 km*,** r=3522.2 km, 5.6 km/s, $\gamma$ = -13.0 deg

**Entry Prep Phase**

- **Peak Heating:** 46 W/cm$^2$ **Peak Deceleration**: 9.2G

**Hypersonic Phase**

- **Parachute Deployment:** E+220s, L-213s, **12.6 km**, Mach 1.65
- **Heatshield Jettison:** E+235s, L-198s, **11.0 km,** 120 m/s
- **Leg Deployments:** E+245s, L-188s
- **Radar Activated:** E+295s, L- 138s
- **Lander Separation:** E+390s, L-43s, **0.98 km,** 56 m/s

**Parachute Phase**

- **Gravity Turn Start:** E+393s, L-40s, **0.80 km**
- **Constant Velocity Start:** E+414s, L-19s, **0.051 km**

**Terminal Descent Phase**

- **Touchdown:** E+434s, L-0s, **0 km**, Vv=2.4 ±1 m/s, Vh<1.4 m/s
- **Dust Settling:** L+0 to L+15min

Landing at
-3.9 km elevation
(MOLA relative)

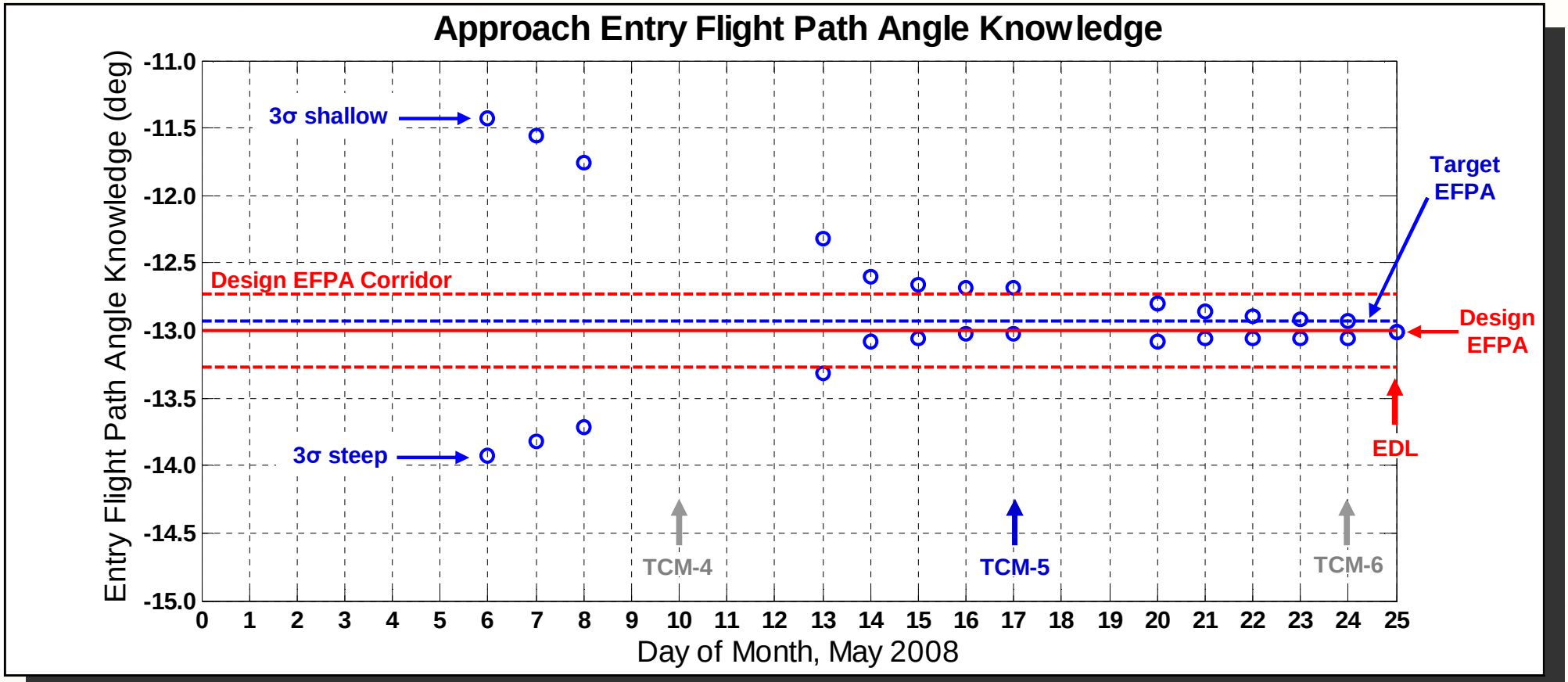
- **Begin Gyro-Compassing:** L+5min
- **Solar Array Deploy:** L+16min

* Entry altitude referenced to equatorial radius.
All other altitudes referenced to ground level

Note: Information in this graphic represents a nominal entry (C726-102). Dispersions exist around all values.

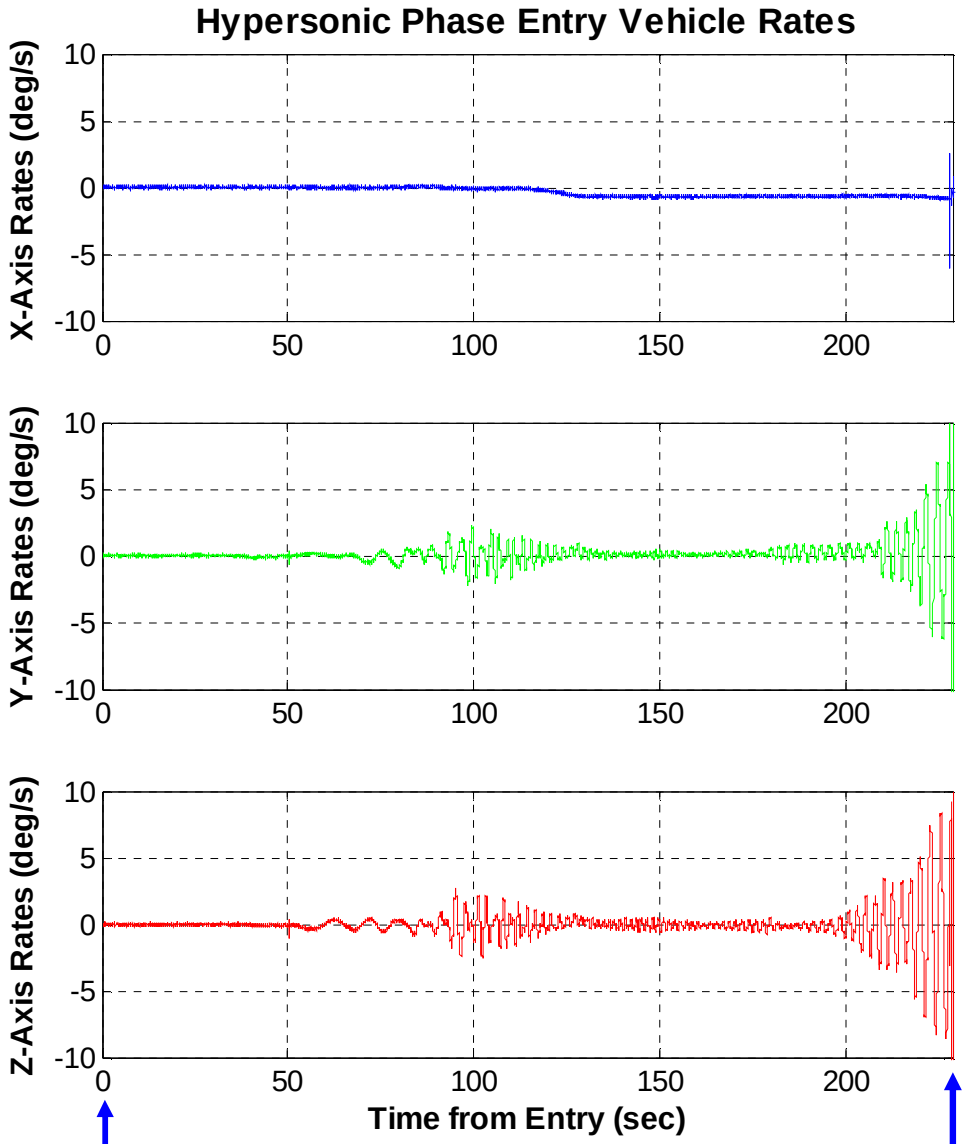
Feb 2008

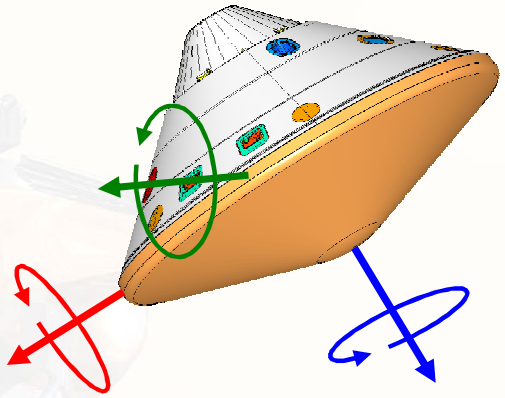
# Final Approach EFPA Knowledge




- **TCM-4 cancelled: If executed TCM-5 too small**
- **TCM-6 cancelled: Landing safety criteria all within desired limits**
- **Navigated final pre-entry EFPA determination: -13.007° ± 0.003°**

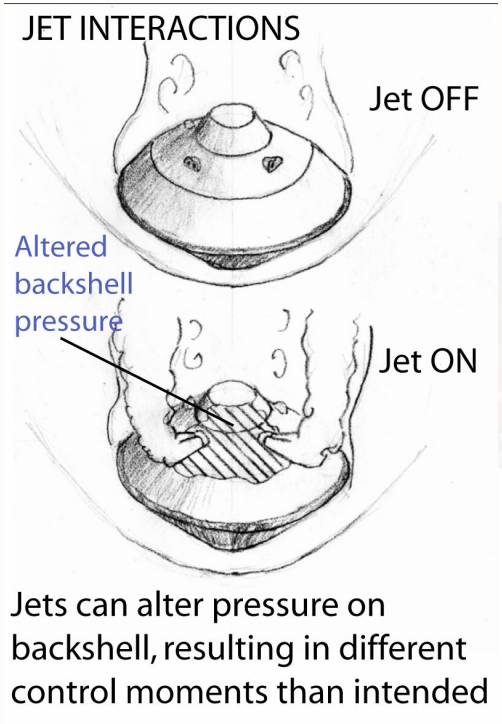
# Hypersonic Phase



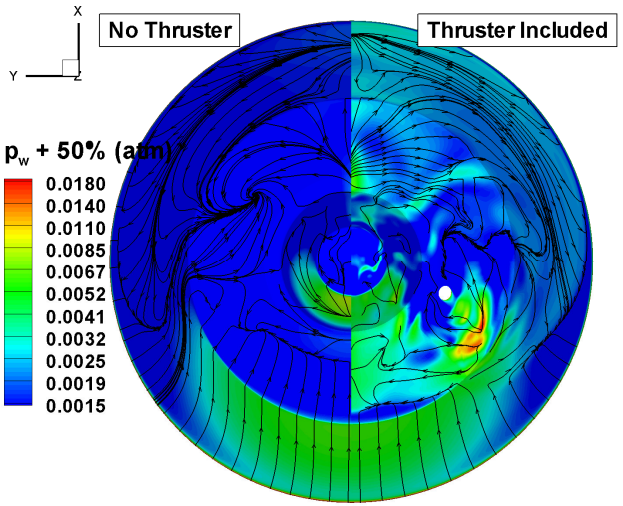
- **Rates during hypersonic and supersonic flight are within expected values**
- **Angle of attack reconstruction underway at LaRC**

# Aero/RCS Interaction Issue



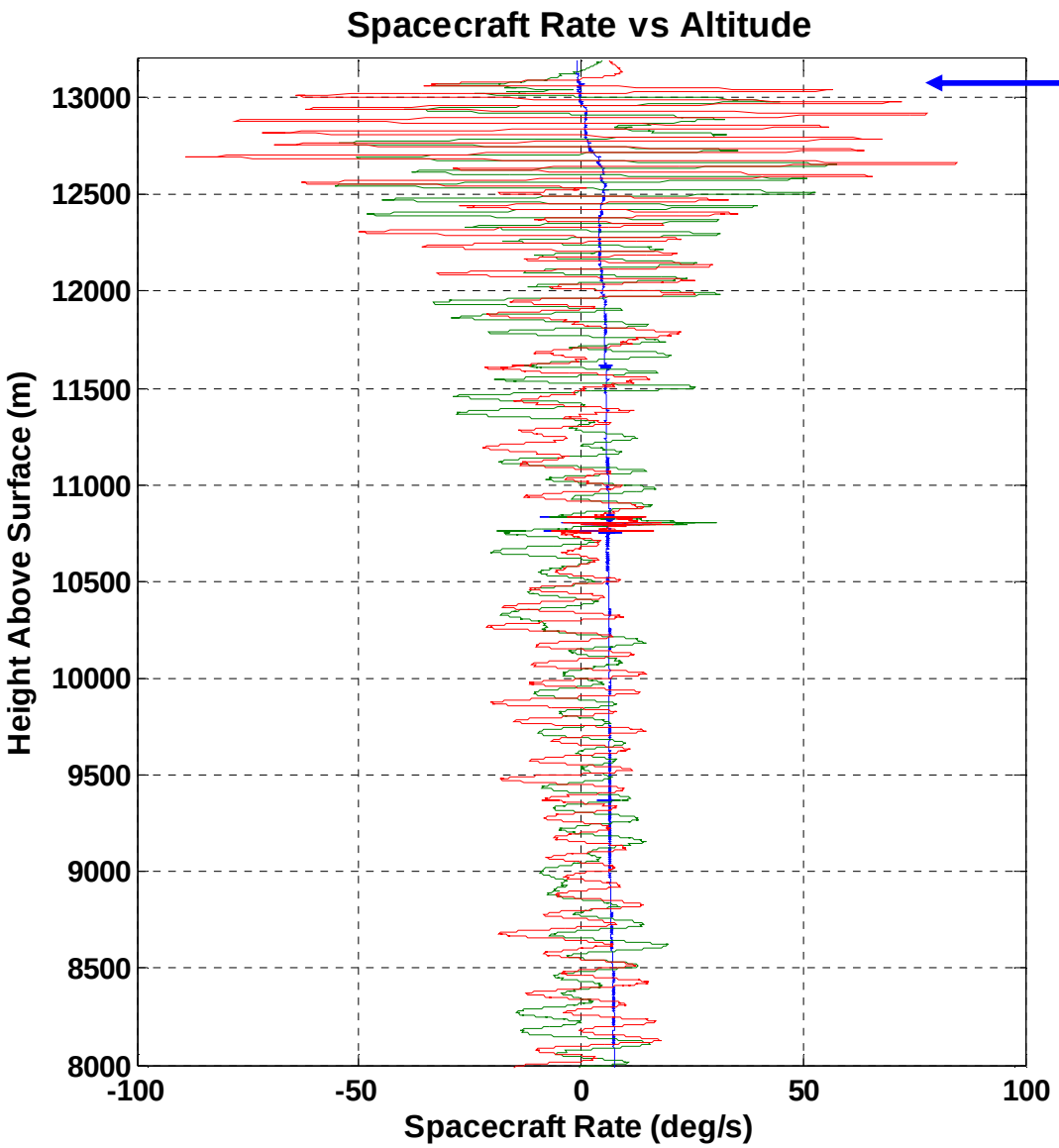

Jets can alter pressure on backshell, resulting in different control moments than intended

- CFD solutions of Aero/RCS flow field shows potential for strong interaction
  - RCS Pitch authority is degraded and Yaw authority is low to non-existent (potential for control reversal exists)
  - Potential of large attitude at parachute deployment leading to excessive wrist mode dynamics impacting radar performance

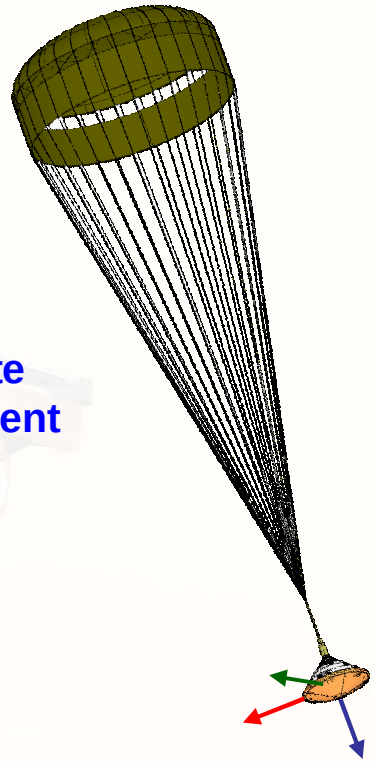



- Mitigation recommendation was to open up control system deadbands during entry from early-Hypersonic regime through Supersonic regime to minimize/ eliminate RCS firings
  - Relying on inherent capsule stability to traverse flight regimes
  - **There were no RCS firings from Hypersonic 2 through Lander separation**

# Parachute Phase

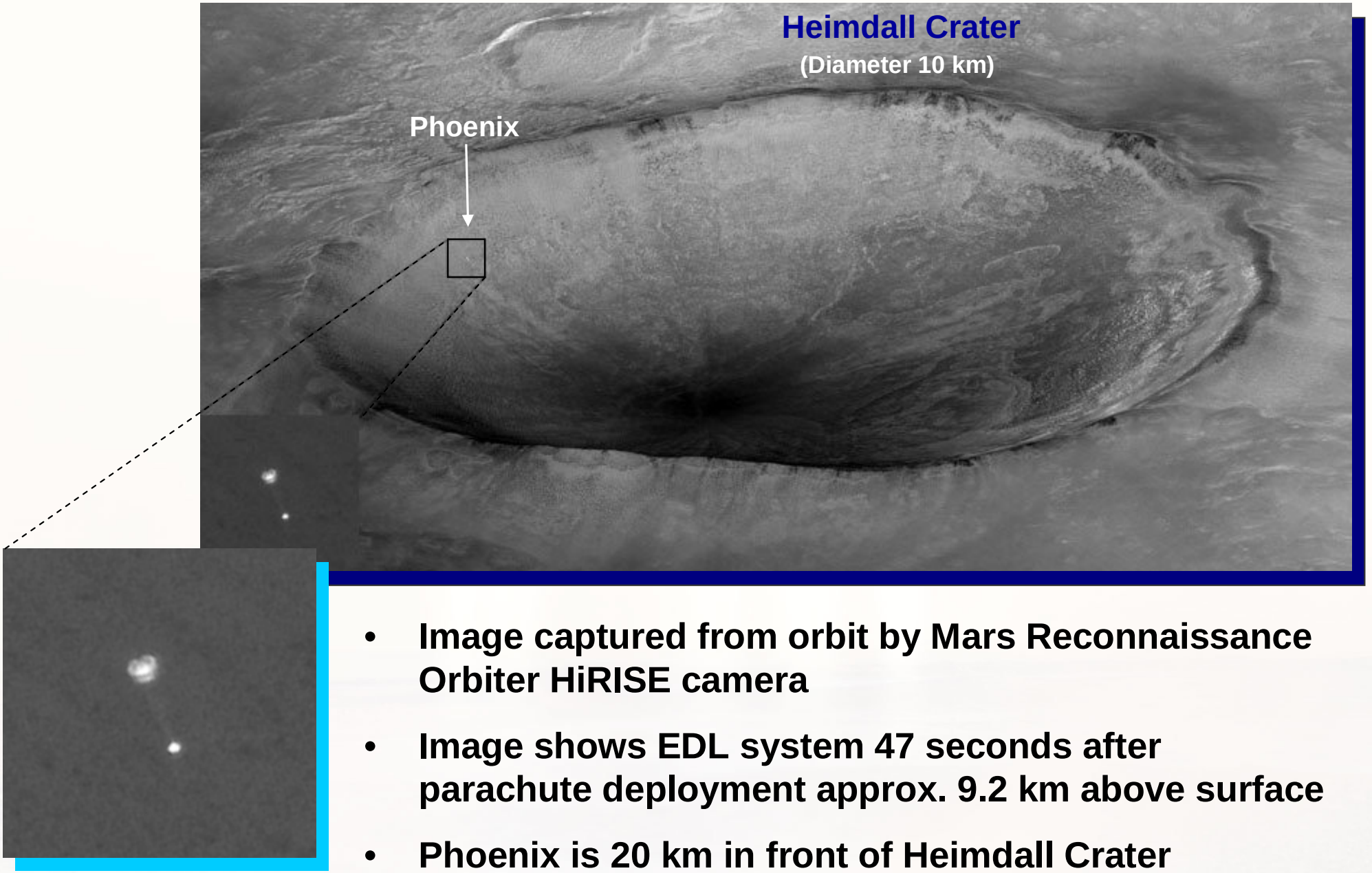



Parachute Deployment



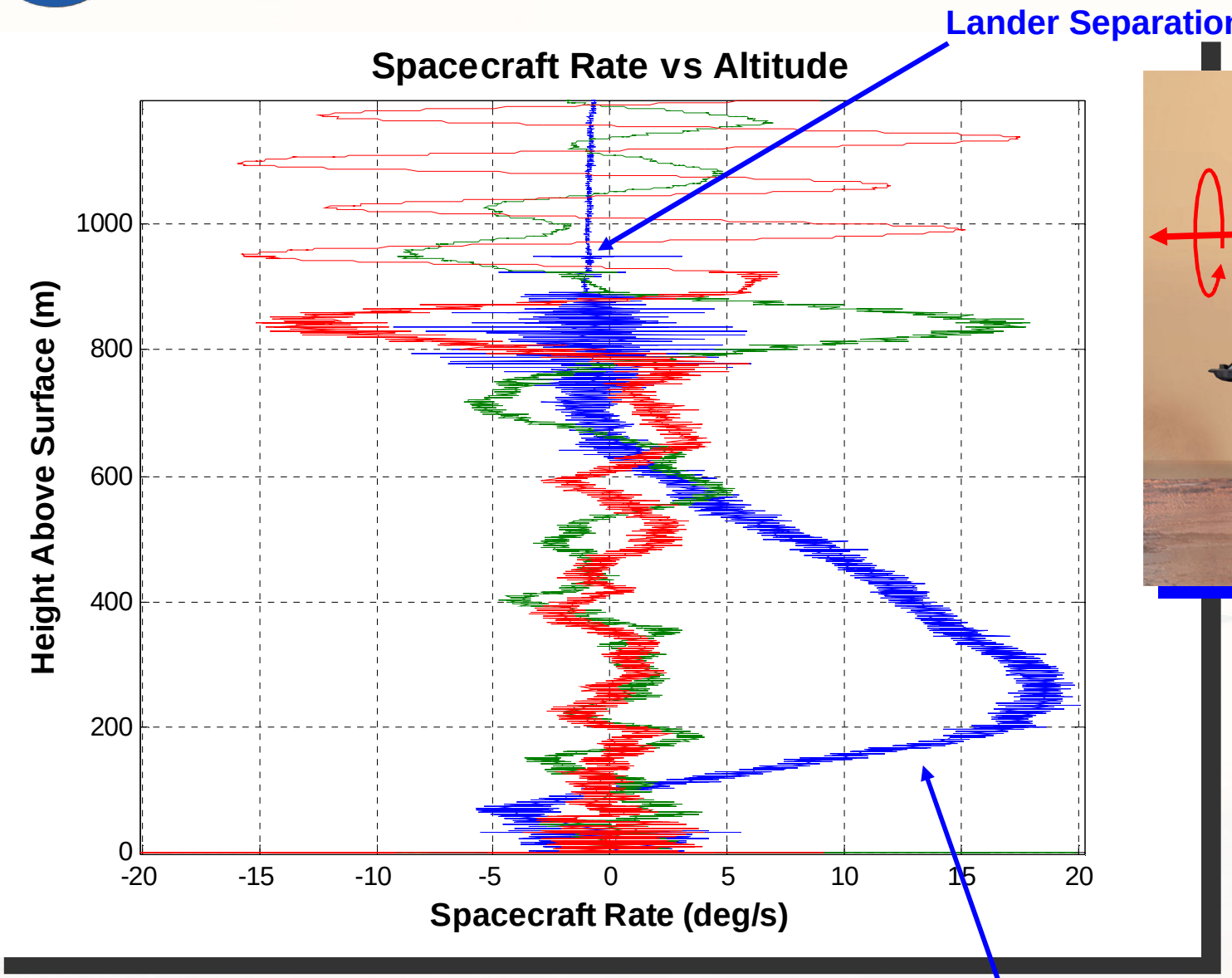
- **Parachute deployment conditions:**
  - **Dyn. Press.: 492 Pa**
  - **Mach: 1.68**
  - **Altitude: 13.26 km**
- **As expected, “wrist mode” rates were high immediately after parachute deployment, but damped quickly**

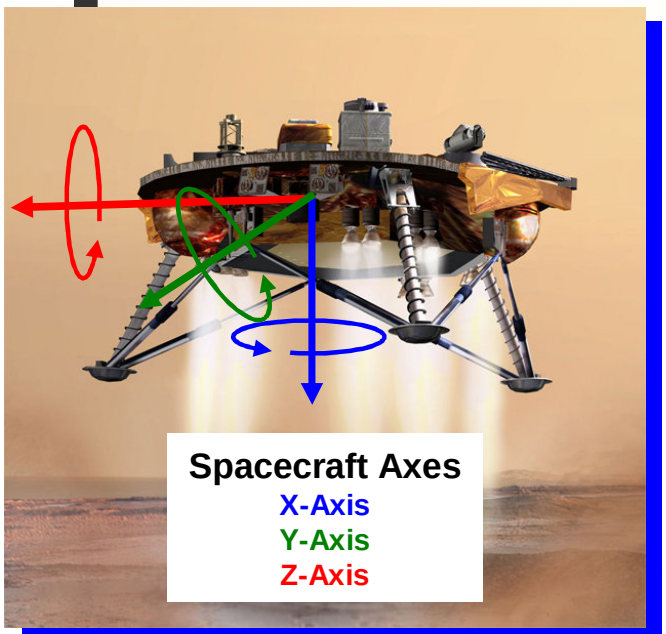
# Phoenix on the Parachute - Spectacular!




- Image captured from orbit by Mars Reconnaissance Orbiter HiRISE camera
- Image shows EDL system 47 seconds after parachute deployment approx. 9.2 km above surface
- Phoenix is 20 km in front of Heimdall Crater

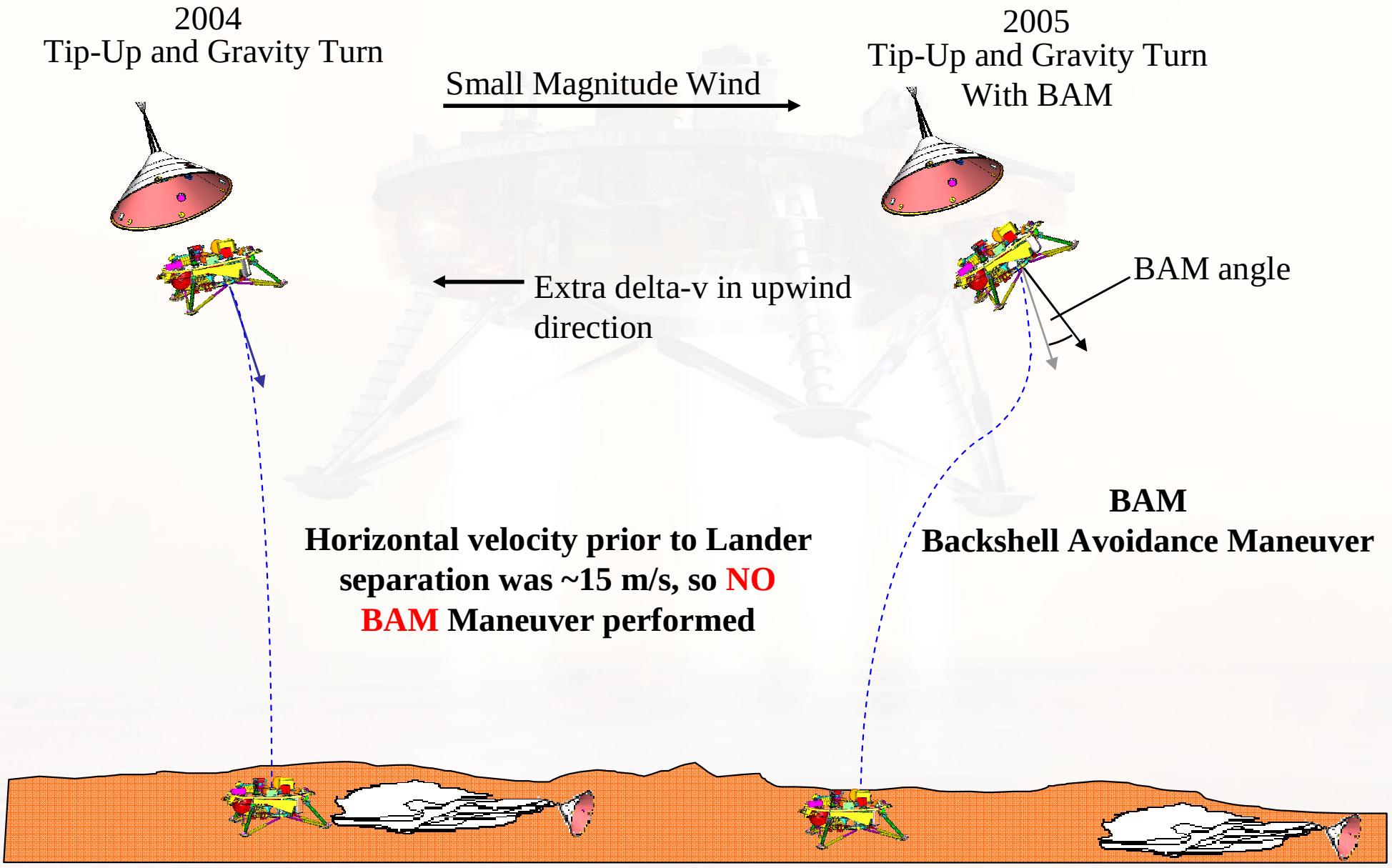
# Terminal Descent Phase



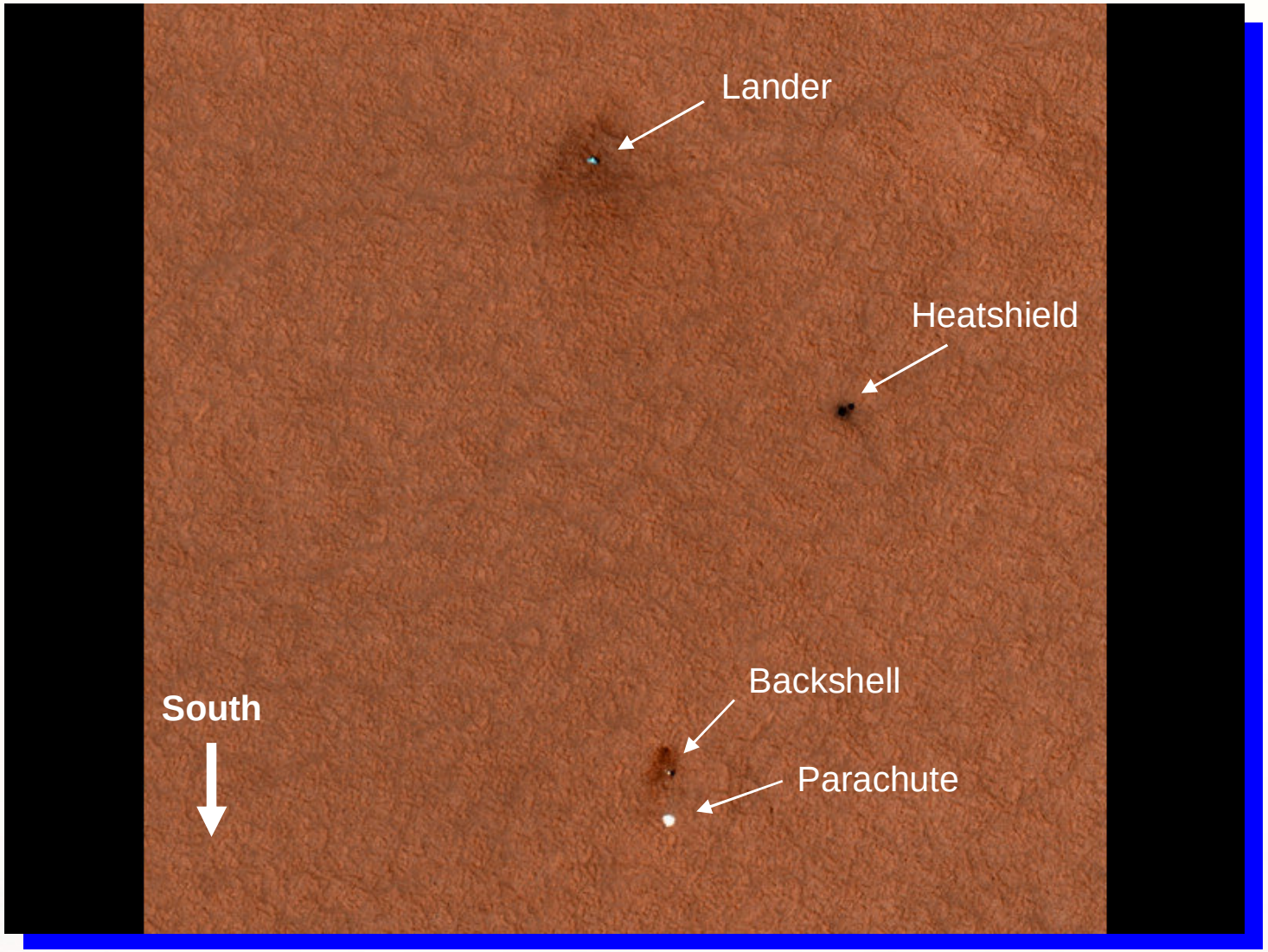




- **Lander rates during terminal descent are very benign relative to worst-case simulation prior to landing**

# EDL Modifications: Terminal Descent Subphase Evolution

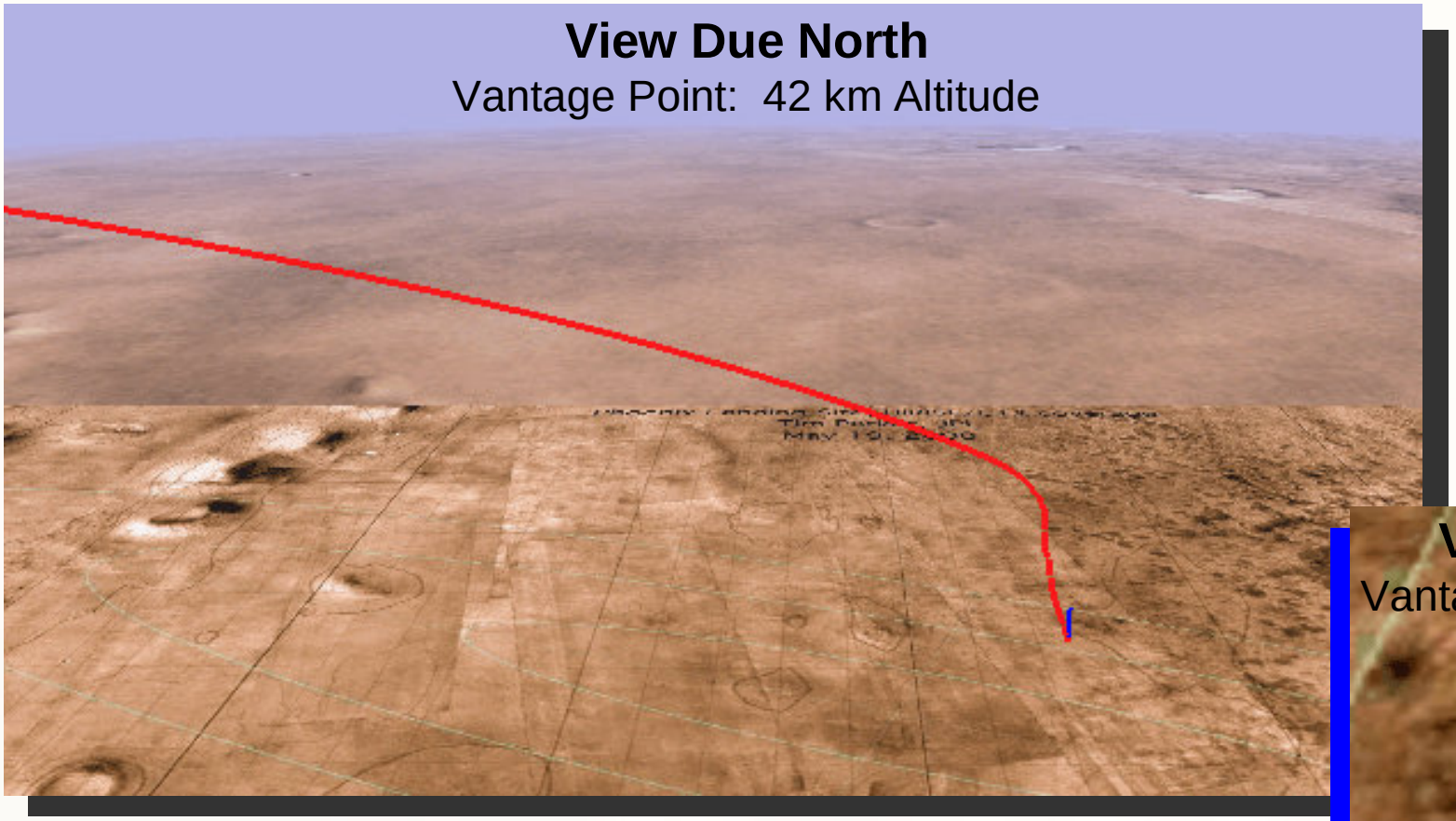


# MRO Surface Image



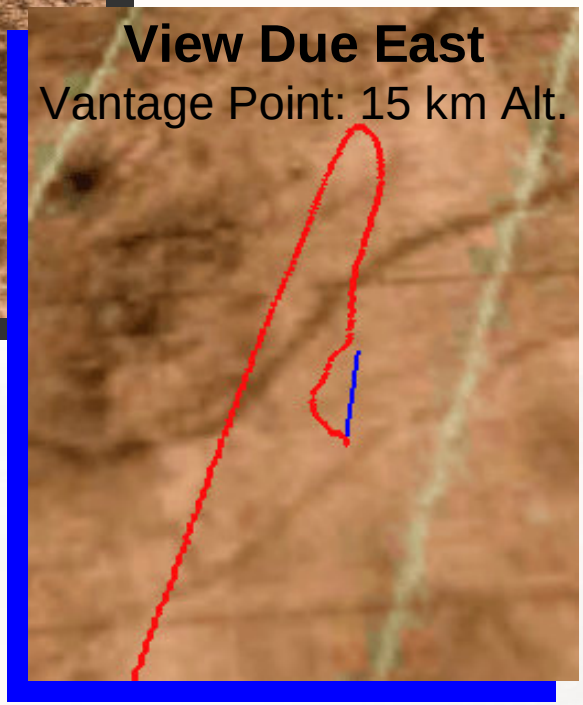
# Trajectory Reconstruction

**View Due North**
Vantage Point: 42 km Altitude



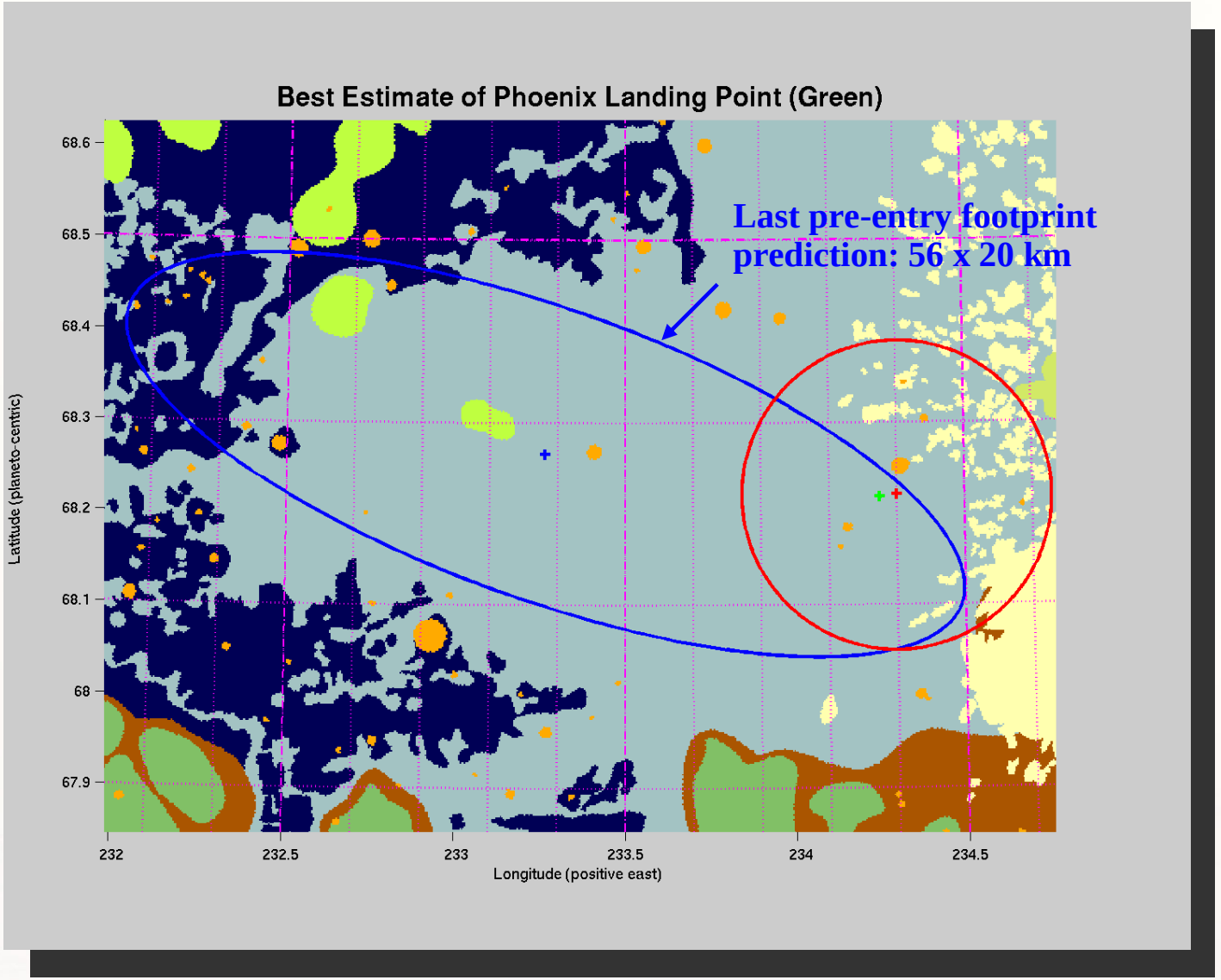
**Trajectory Visualization**

**View Due East**
Vantage Point: 15 km Alt.



- **Trajectory created by back propagation of 200Hz IMU data**
- **Influence of winds appears apparent during descent on parachute**

# Landing Footprint



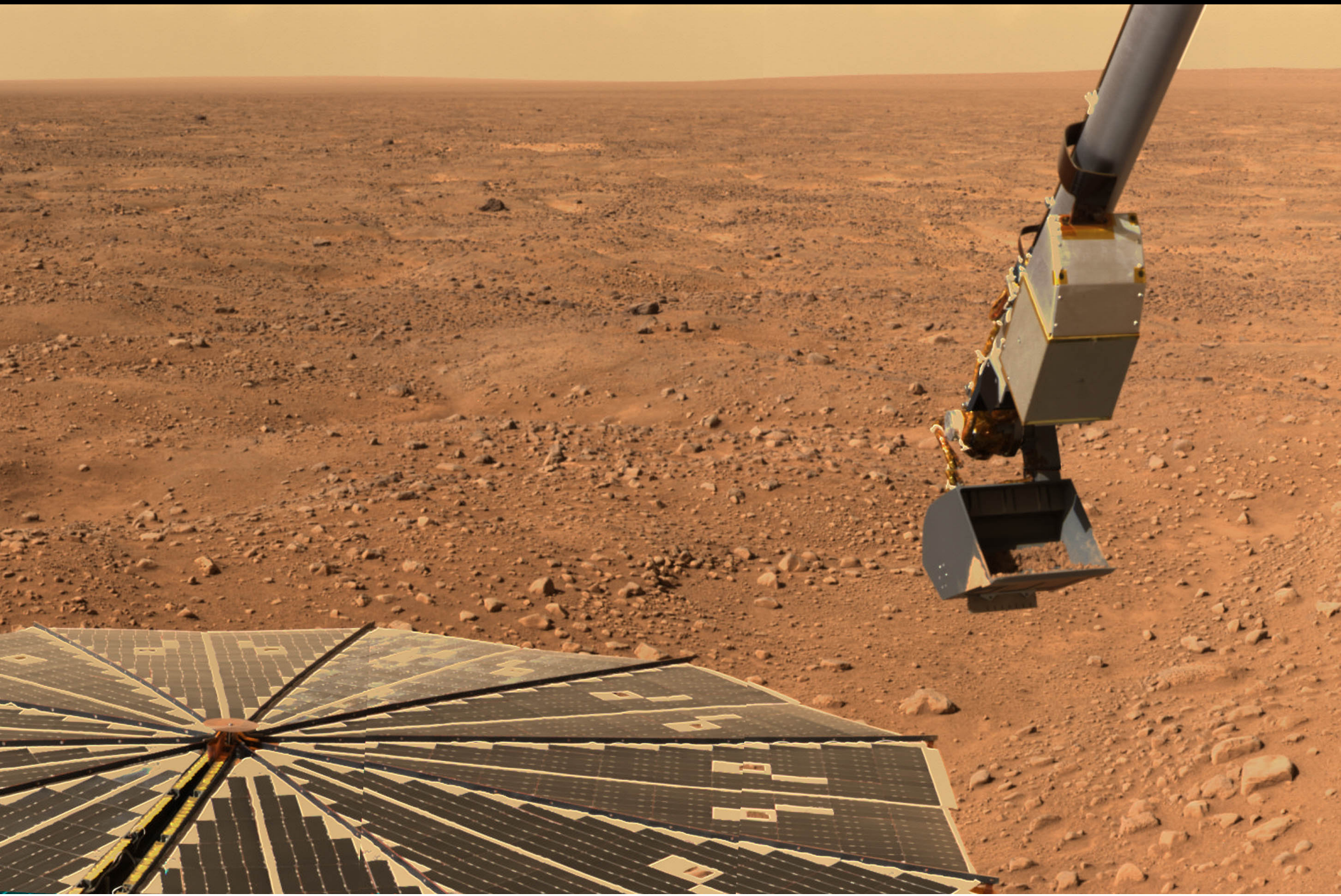

**Design Footprint**
**Requirement: 110 x 20 km**

# Baseline Simulation vs Flight

| Parameter | Units | 6-dof Monte Carlo 99% Low | Mean | 99% High | Preliminary Reconstructed Flight Value |
|---|---|---|---|---|---|
| **Hypersonic Flight** | | | | | |
| Peak Acceleration, Time from Entry | sec | | | | 122.5 |
| Peak Acceleration | Earth g | 8.76 | 9.25 | 9.79 | |
| **Parachute Deployment** | | | | | |
| Time from Entry | sec | 211.3 | 219.9 | 229.4 | 227.9 |
| Height | km | 10 | 12.7 | 15.7 | 13.13 |
| Dynamic Pressure | Pa | 452.5 | 490.5 | 533.0 | 492.0 |
| Mach Number | | 1.45 | 1.64 | 1.89 | 1.68 |
| Total Angle-of-Attack | deg | 0.20 | 2.30 | 7.30 | |
| Attitude Rate | deg/s | 0.40 | 4.50 | 16.20 | 9.2 |
| **Heatshield Jettison** | | | | | |
| Time from Entry | sec | 226.4 | 235.0 | 244.5 | 242.9 |
| Height | km | 8.4 | 11.1 | 14.0 | |
| **Lander Separation** | | | | | |
| Time from Entry | sec | 348.5 | 392.7 | 437.2 | 404.9 |
| Height | m | 923.4 | 977.3 | 1260.8 | 960.0 |
| Vertical Velocity | m/s | | | | 55.1 |
| Horizontal Velocity | m/s | | | | 15.0 |
| Total Angle-of-Attack | deg | 0.78 | 8.50 | 23.80 | |
| Attitude Rate | deg/s | 3.7 | 37.0 | 109.8 | 18.0 |
| **Touchdown** | | | | | |
| Time from Entry | sec | 391.8 | 436.2 | 480.9 | 446.2 |
| Vertical Velocity | m/s | 1.46 | 2.13 | 2.74 | 2.38 |
| Horizontal Velocity | m/s | 0.05 | 0.48 | 1.20 | 0.06 |
| Total Prop Usage | kg | 35.1 | 37.4 | 41.6 | 37.6 |

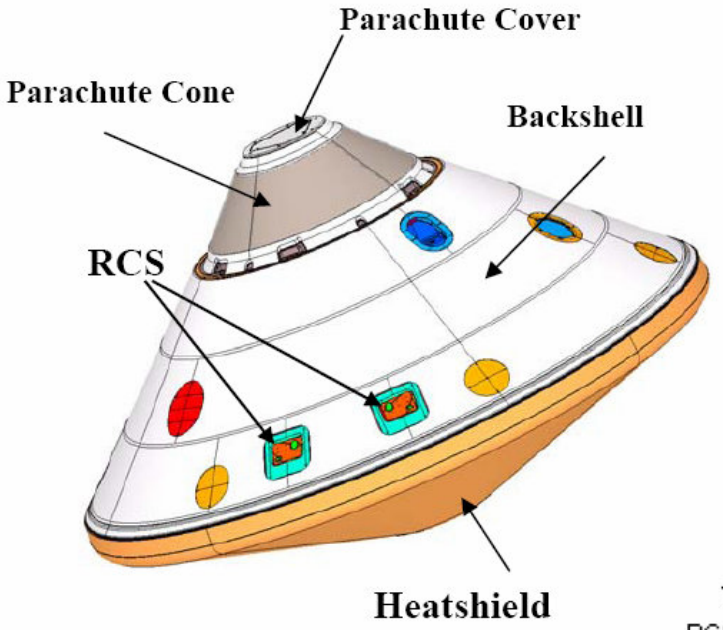
# JPL & LaRC EDL Operations Team

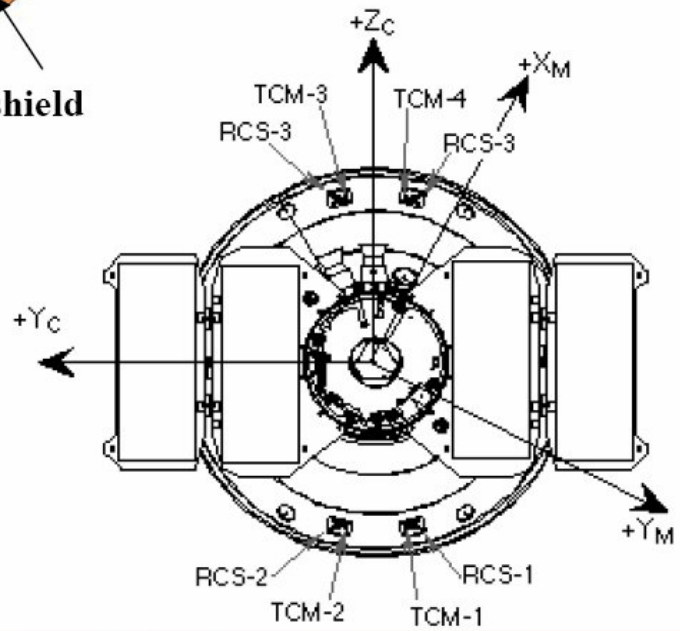
# Phoenix on the Northern Plains of Mars!



# Back-Up Slides

# Phoenix Thruster Geometry



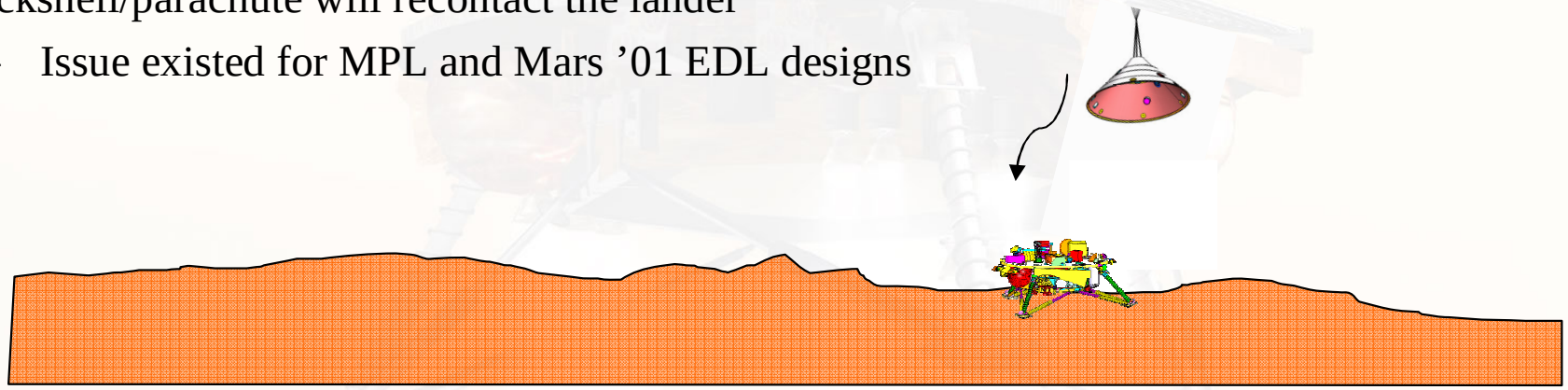

- TCM thrusters used for Pitch/Yaw control
- RCS thrusters used for Roll control

# EDL Modifications: Terminal Descent Subphase Evolution

## Terminal Descent Redesign Driver

In cases of low wind and no wind terminal descent scenarios, there is an increased probability the backshell/parachute will recontact the lander

- Issue existed for MPL and Mars '01 EDL designs



**New Requirement**

The distance between the center of mass of the lander and center of mass of the backshell shall be greater than 35m from 5s after lander separation to touchdown of both bodies