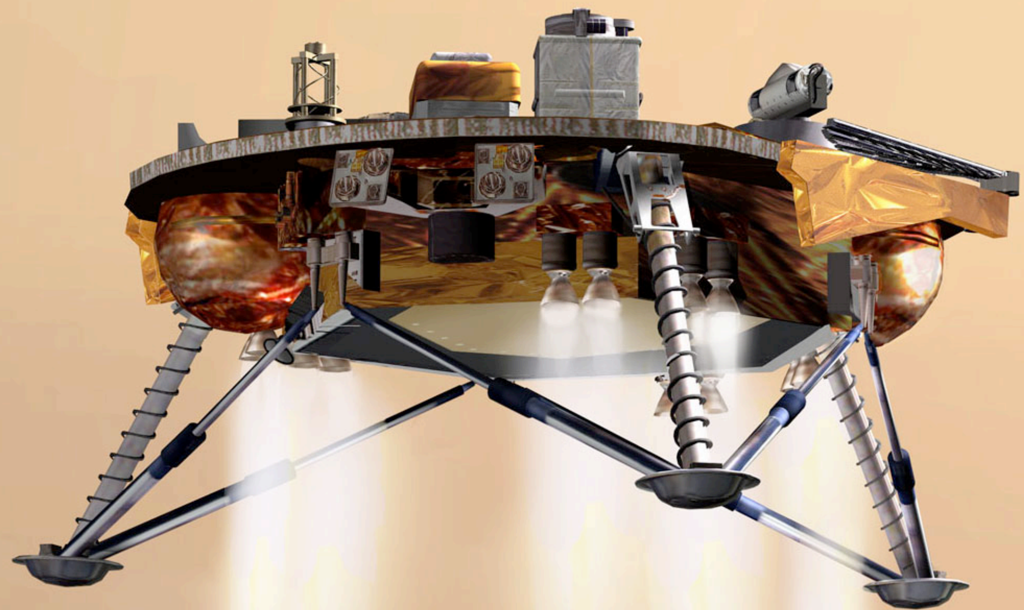
Evolution of the Phoenix EDL System Architecture



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International Planetary Probe Workshop 5
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Bordeaux, France

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

Presentation Overview

- The Phoenix Story
- Spacecraft Overview
- Phoenix EDL Overview
- Mission Design Comparison
- Hypersonic Subphase Evolution
- Terminal Descent Subphase Evolution
- Summary

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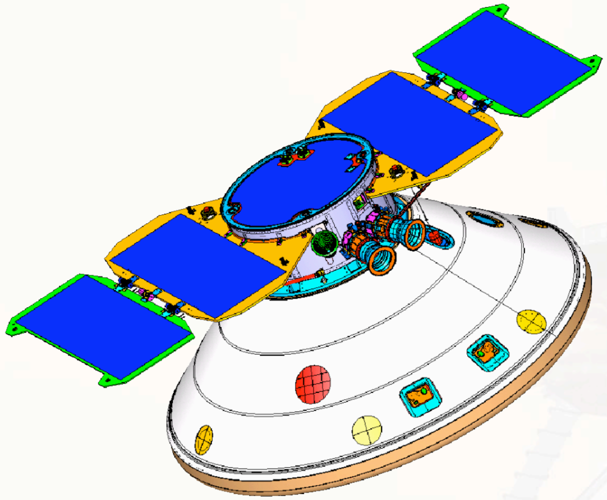
The Phoenix Story

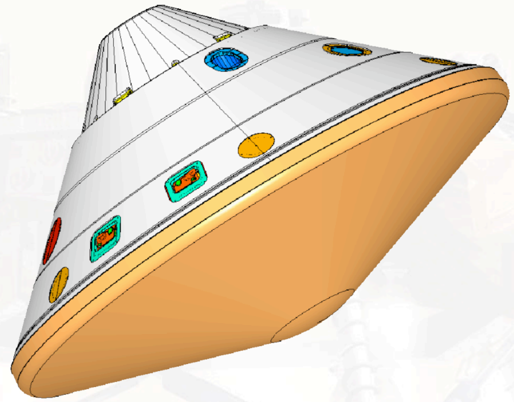
- **Started as Mars Surveyor 2001 Lander**
  - **Faster, better, cheaper spacecraft**
  - **Sister spacecraft of Mars Polar Lander**
  - **Cancelled after Mars Polar Lander failure in 1999**
    - **Not enough time to address findings of MPL failure review prior to 2001 launch window**

- **Reborn as Phoenix in 2003**
  - **Same spacecraft, modified science payloads**
  - **Enhanced radar**
  - **Addition of EDL communication subsystem**
  - **Enhanced test program**

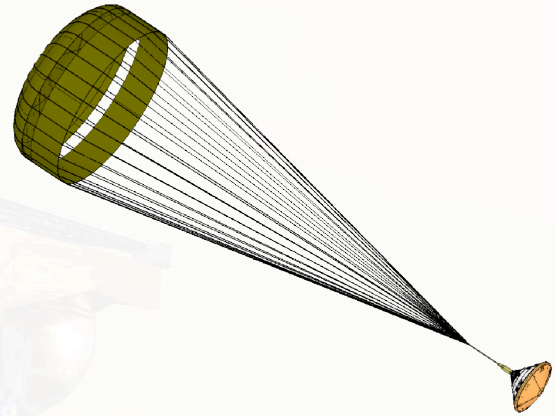
Spacecraft Overview



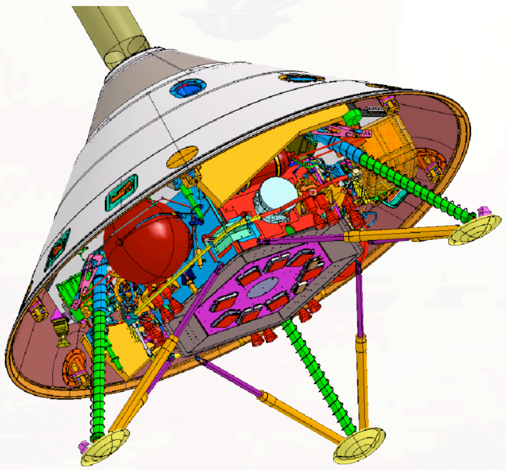
Pre-Entry Configuration



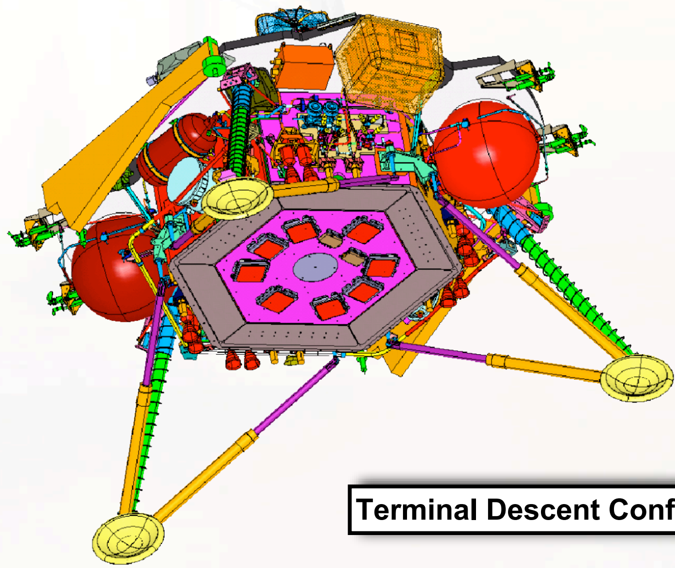
Entry Configuration



Parachute Configuration



Post HS & Leg Deploy Configuration



Terminal Descent Configuration

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Phoenix EDL Overview

Communications: UHF-band to Orbiters

Entry Prep

- **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-419s, **125 km***, r=3522.2 km, 5.6 km/s, γ = -13.0 deg

Hypersonic

- **Peak Heating:** 45 W/cm^2 **Peak Deceleration**: 9.3G

Parachute

- **Parachute Deployment:** E+224s, L-195s, **11.5 km**, Mach 1.46
- **Heat Shield Jettison:** E+239s, L-180s, **9.8 km**, 109 m/s
- **Leg Deployments:** E+249s, L-170s
- **Radar Activated:** E+259s, L- 160s
- **Lander Separation:** E+382s, L-37s, **0.94 km**, 53 m/s

Terminal Descent

- **Throttle Up:** E+385s, L-34s, **0.72 km**
- **Constant Velocity Achieved:** E+404s, L-15s, **0.047 km**
- **Touchdown:** E+419s, L-0s, **0 km**, Vv=2.4 ±1 m/s, Vh<1.4 m/s

Lander Prep

- **Dust Settling:** L+0 to L+15min
- **Fire Pyros for Deployments:** L+5s
- Solar Array Deploy: L+15min
- Begin Gyro-Compassing: L+75min

Landing at -3.5 to -5.0 km Elevation (MOLA relative)

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

Note: Information in this graphic represents a nominal entry (67.5N Open, -3.7 km site elevation). Dispersions exist around all values.

Apr 2007

Mission Design Comparison

- **Mars 2001 Lander**
  - **Equatorial landing region**
  - **7.2 km/s entry velocity ⇐**
  - **+2.5 km (w.r.t MOLA) landing site elevation ⇐**

- **Phoenix Lander**
  - **Northern landing region: 65° N to 72° N**
  - **5.8 km/s entry velocity ⇐**
  - **-3.5 km (w.r.t MOLA) landing site elevation ⇐**

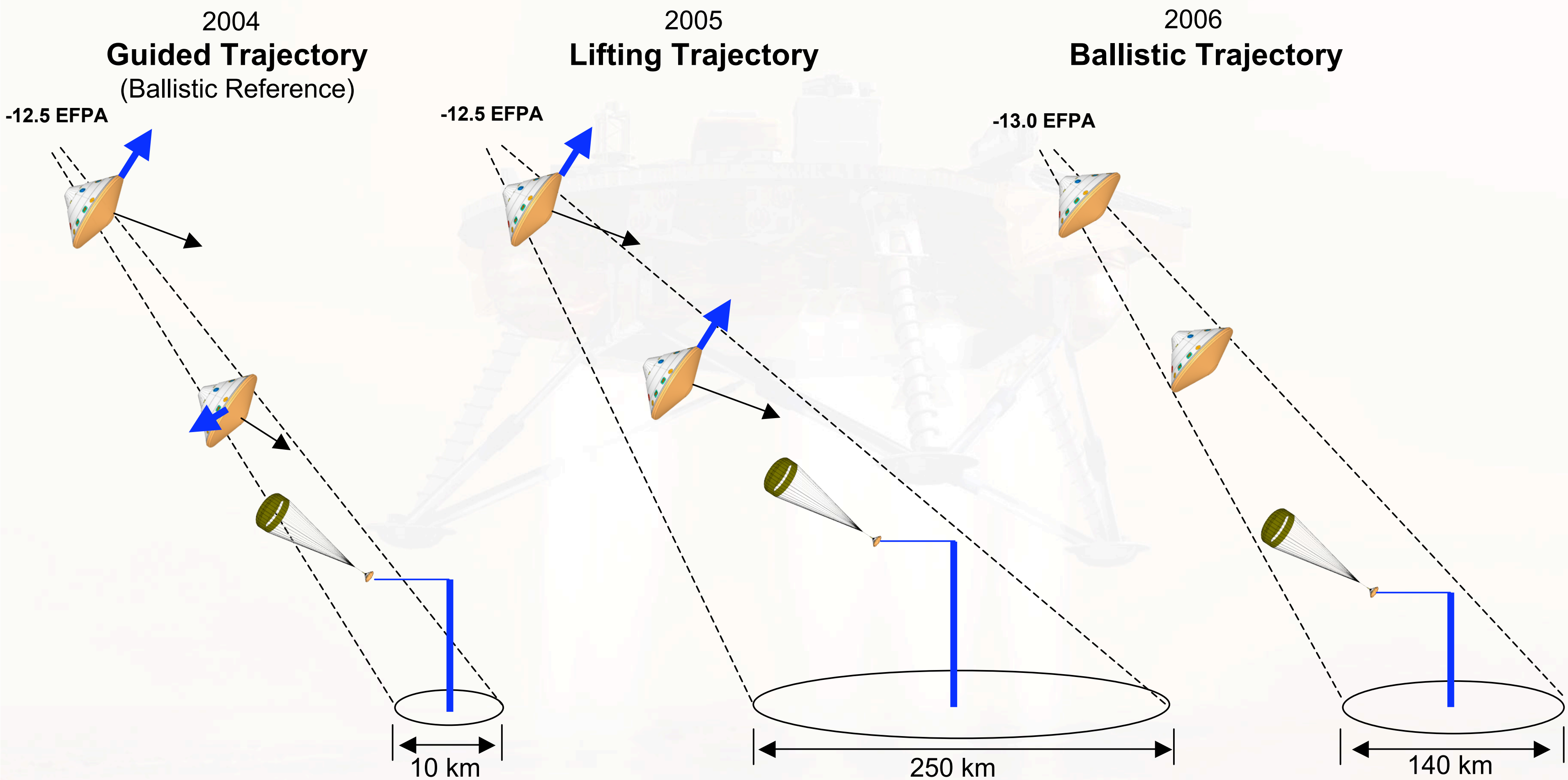
Driving Constraints at Chute Deploy

- **Parachute Deploy Opening Loads**
  - **Lander structure load limit is 12,700 lbs (51,893 N)**
  - **Constrains parachute opening dynamic pressure to 520 Pa**
  - **Results in EDL systems most rigid constraint**

- **Parachute Deploy Mach Number**
  - **Transonic instability forces need to keep Mach at chute deploy comfortably away from Mach 1.0**
  - **Angle of attach at chute deploy is critical for three reasons:**
    - **Parachute inflation qualification limits**
    - **Off-axial load limits on Lander structure**
    - **Vehicle oscillatory dynamics (wrist mode) while hanging from parachute**

- **Parachute opening load drives down chute deploy point while Mach constraint drives up chute deploy point**

Hypersonic Evolution (1/3)



Redesign Drivers

- **Reduced complexity**
- **Higher chute deploy Mach & altitude**

Redesign Drivers

- **Reduced footprint**

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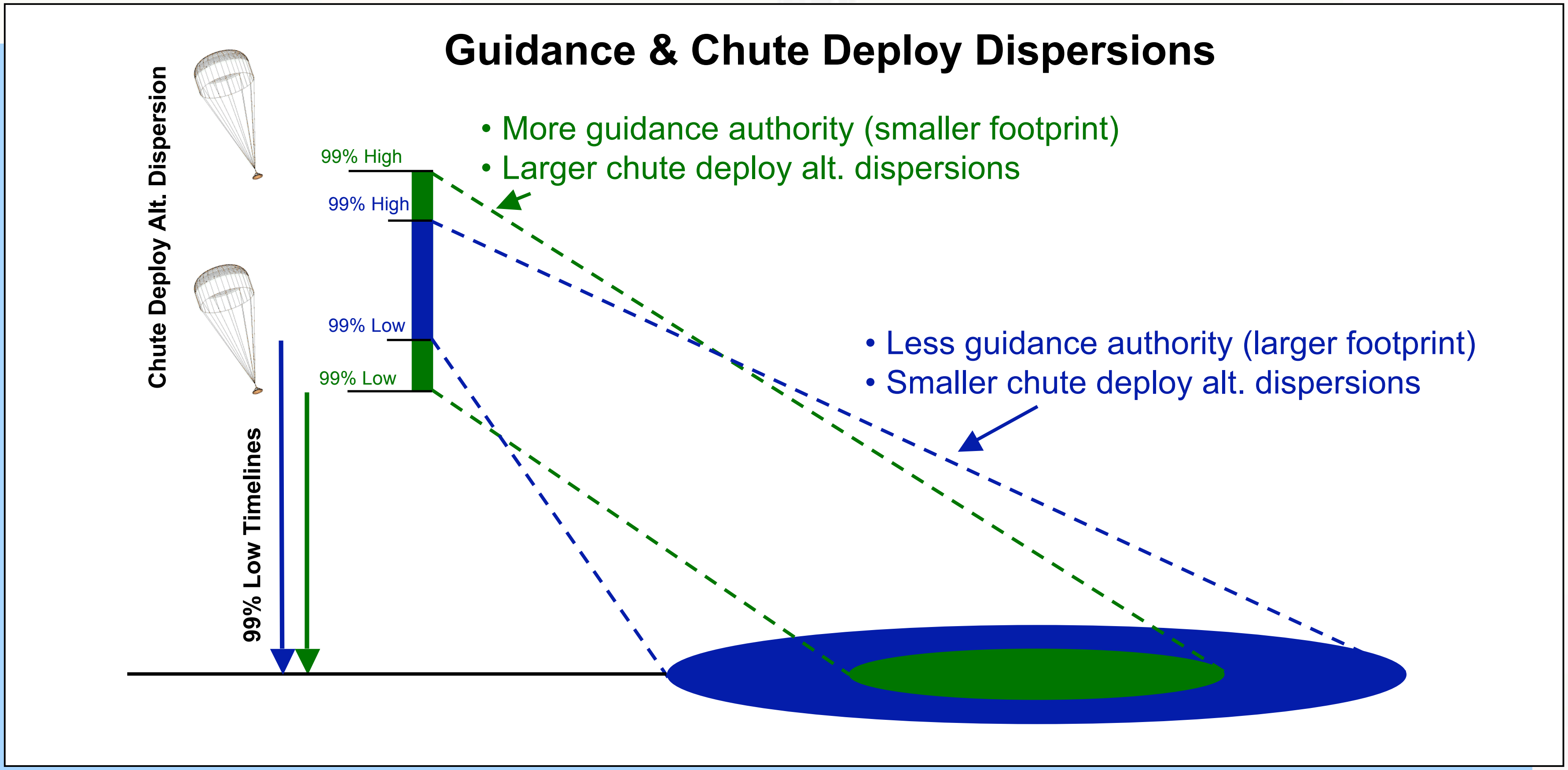
Hypersonic Evolution (2/3)



Hypersonic Evolution (3/3)

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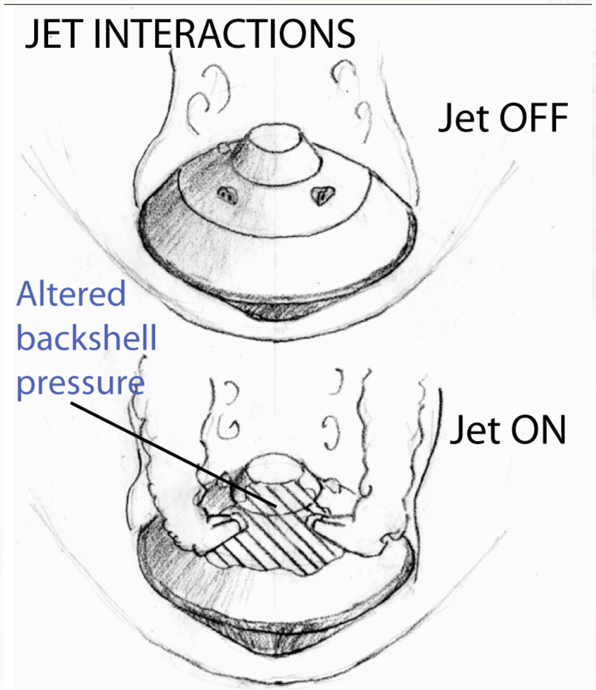
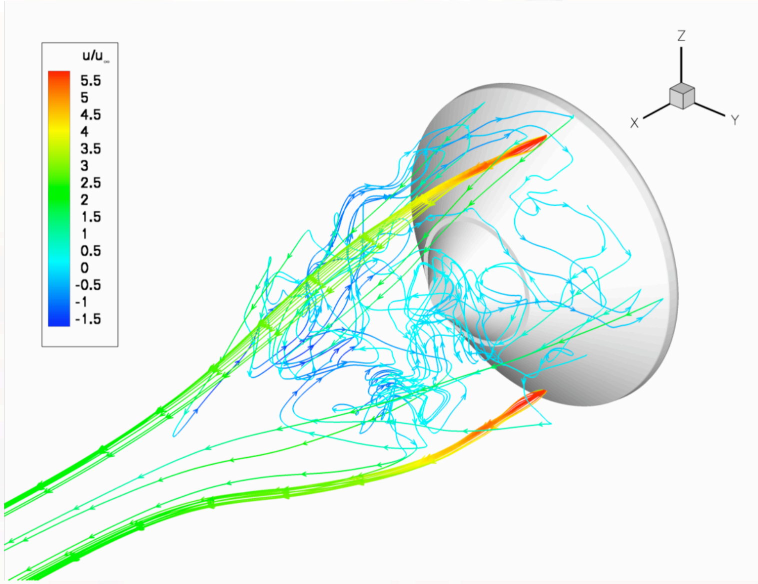
Aero/RCS Flow Interaction Phenomenon



- **CFD of Aero/RCS flow field shows potential for strong interaction from hypersonic regime to parachute deployment**
  - **RCS Pitch authority is degraded**
  - **RCS Yaw authority is low to non-existent (potential for control reversal exists)**
  - **Baseline is to increase control system deadbands to minimize/eliminate RCS thruster firings to avoid this flow interaction**



CFD of Yaw Thruster Firing

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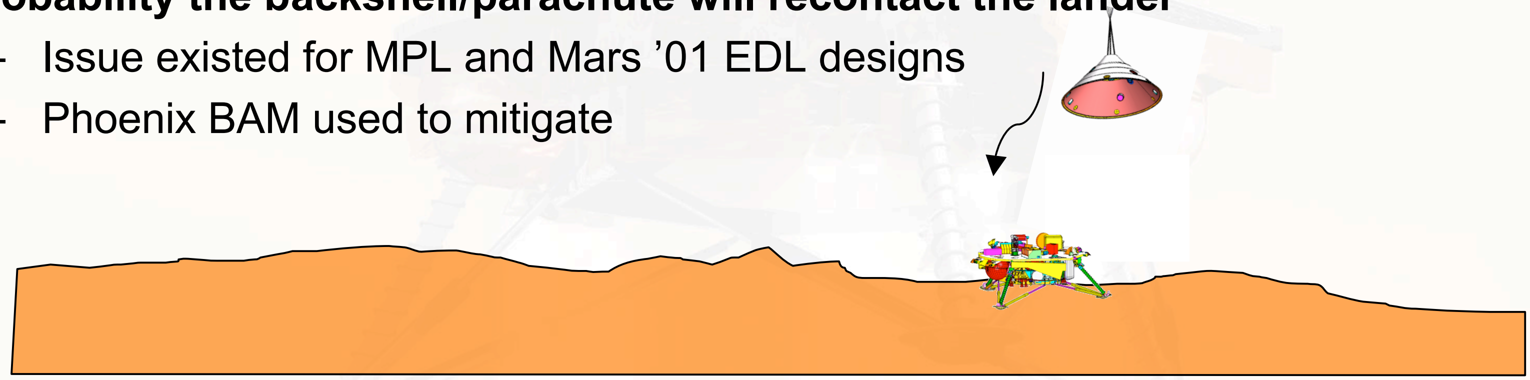
Terminal Descent Evolution (1/2)

Backshell Avoidance Maneuver (BAM)

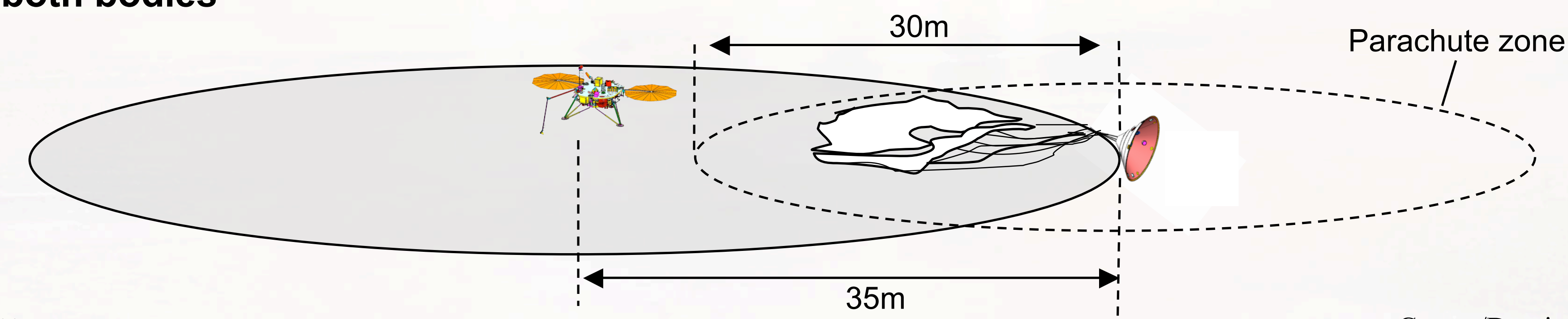
In cases of low wind and no wind terminal descent scenarios, there is an increased probability the backshell/parachute will recontact the lander

- Issue existed for MPL and Mars ’01 EDL designs
- Phoenix BAM used to mitigate



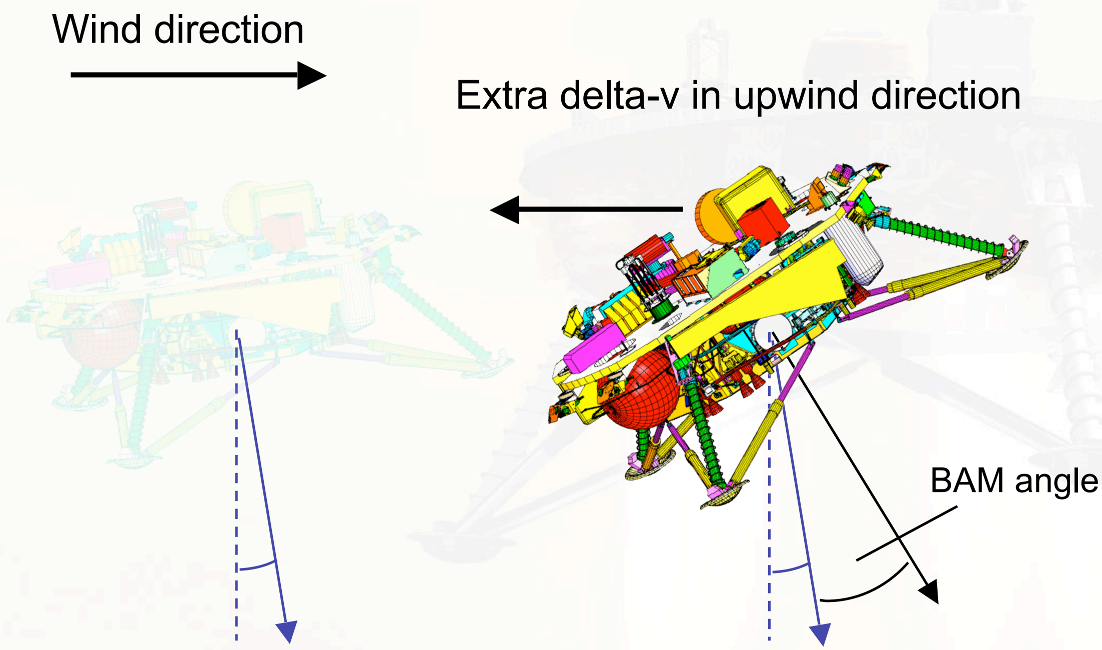
New Requirement

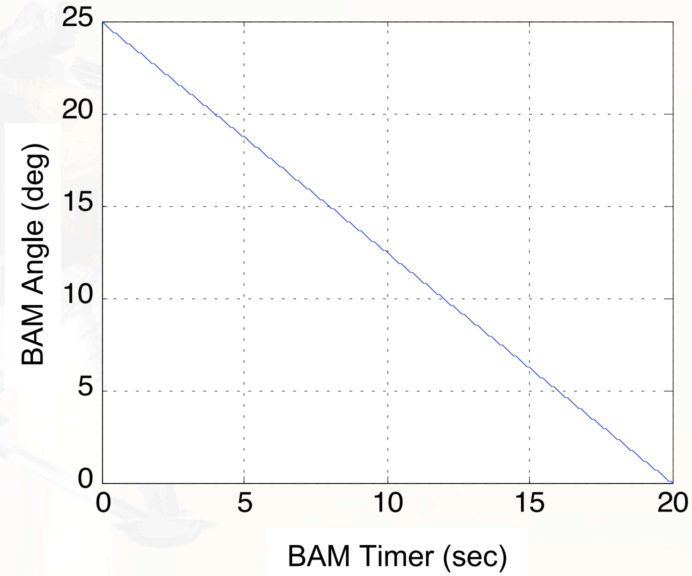
The distance between the center of mass of the lander and center of mass of the backshell shall be greater than 35m from 5s after lander separation to touchdown of both bodies



Terminal Descent Evolution (2/2)

BAM Design





- Aim the maneuver upwind (Assumption: all residual horizontal velocity is due to wind)
- Upwind direction is estimated from the navigated horizontal velocity
- Start the BAM at tip up
- Compute the angle from horizontal velocity
- Two conditional tests constrain conditions of use

Summary

- Phoenix is a return to flight of the cancelled Mars ’01 Lander, emphasizing thorough and extensive testing
- Mission design leads to more benign entry velocities and a much lower landing site elevation relieving pressure on EDL timeline
- Due to complexity, hypersonic guidance was de-scoped in favor of simple ballistic entry
- Immature understanding of thruster effectiveness in hypersonic/supersonic low led to relaxed attitude control
- A backshell avoidance maneuver was added to mitigate risk of backshell/parachute recontact of the Lander during terminal descent and at touhdown
- Changes to Phoenix EDL system architecture provides a more robust design for Mars EDL