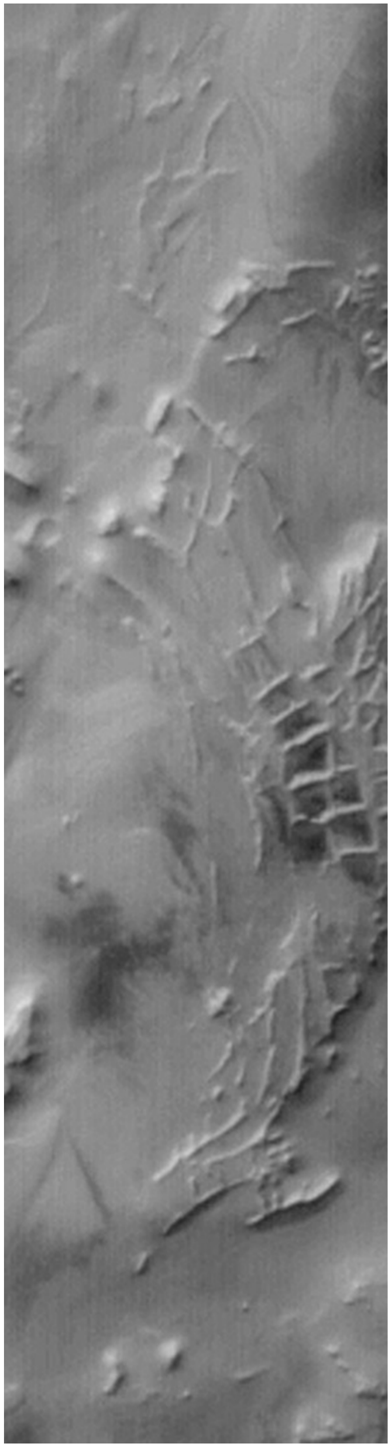


IEEE Aerospace Conference 2011

Assessment of Mars Phoenix EDL Performance

David Oberhettinger

Office of the Chief Engineer

NASA/Caltech Jet Propulsion Laboratory

March 7, 2011

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Introduction

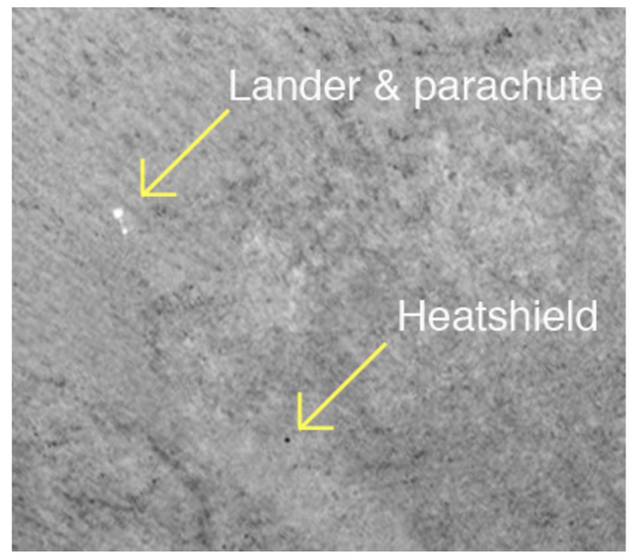
- The Entry, Descent, and Landing (EDL) phase of a planetary mission typically presents the highest risk
  - Most Mars landings have failed
- Study of actual EDL performance and comparison with pre-entry predictions has not been given a high priority
  - Most landers don't provide detailed EDL performance data
- Mars Phoenix EDL was very successful
  - NASA was very interested in identifying the reasons why
- Hence, NASA OCE funded JPL to analyze Phoenix EDL data

Methodology

- Phoenix produced detailed EDL data
  - Dedicated transmitter for downlink during EDL
- Downlinked data available for analysis:
  - Channelized engineering telemetry
  - Non-channelized gyro, accelerometer, and radar data
  - Navigation data on the spacecraft entry state
  - The landing location coordinates
  - Radiometric data on EDL communications

EDL Performance

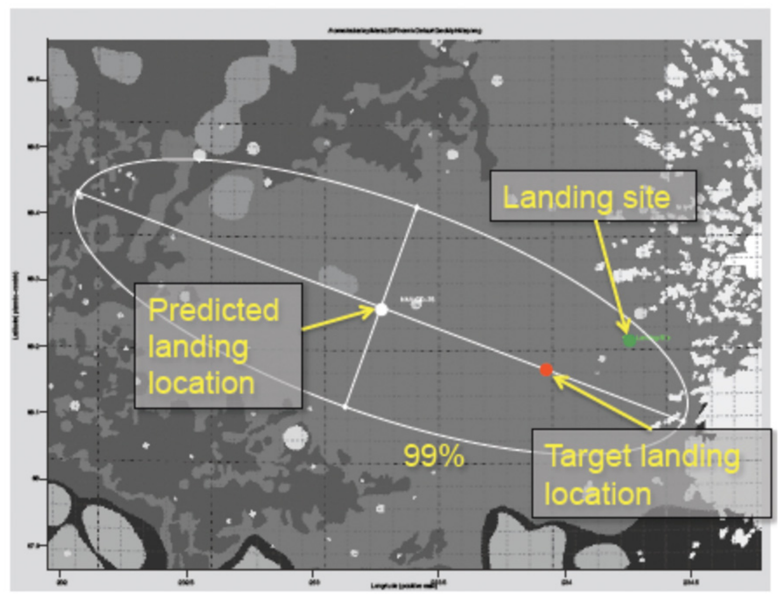
- Phoenix EDL was very successful
  - *Cruise Stage Separation* was nominal, with no indication of lander recontact with the cruise stage.
  - During *Hypersonic Entry*, the lander trimmed at a higher angle of attack than predicted. The decision to widen the Reaction Control System (RCS) deadbands to prevent control reversal was justified by the results.
  - *Parachute Deployment* was nominal, except for some delay due to the higher angle of attack.
  - *Heatshield Separation* was nominal, with no indication of recontact with the lander.
  - The *Terminal Descent* trajectory closely matched the pre-entry prediction, with no terminal descent or radar performance surprises.



Questions Answered by the Study (1)

- Several questions arose following the Phoenix landing

1. *Why did Phoenix land long?*
   - Landed 21 km downtrack and 5 km crosstrack from the predicted site
   - Primary cause: the higher-than-predicted angle of attack during hypersonic entry
   - Adjusting for this (+ air density, winds, nav error), we landed within 2 km of the predicted site



Red dot: target site

White dot: landing site prediction updated after TCM-6

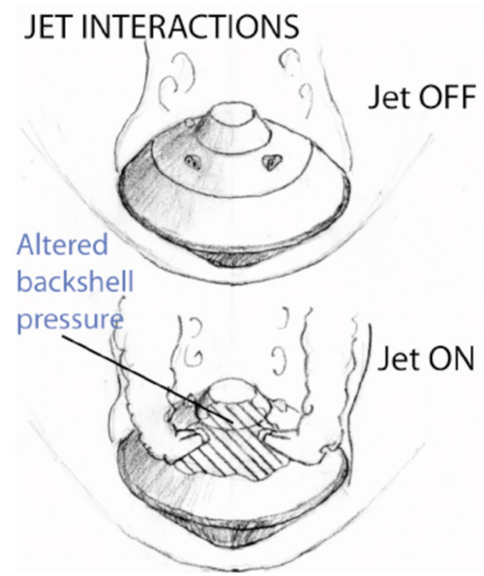
Green dot: actual landing site

Questions Answered by the Study (2)

2. *Why did Phoenix have an unexpectedly high angle of attack during Hypersonic*
   - A different angle than predicted results in unexpected aerodynamic forces/torques, especially when it occurs at high altitude
   - Most likely cause: larger-than-expected radial offset in the capsule center-of-gravity location, combined with a slight overestimate of the capsule hypersonic aerodynamic stability
   - EDL data was insufficient to conclusively identify the cause
3. *Why did Phoenix roll during Hypersonic?*
   - Roll torque produced a 0.7 deg/sec roll rate that continued through parachute deployment
   - Data showed that bounded aerodynamic instability and a center-of-mass radial offset could caused it, but findings not conclusive

Questions Answered by the Study (3)

4. *Were there any indications of thruster jet interactions with the structure?*
   - This can alter pressure on the backshell, resulting in different control moments than intended, causing:
     - Degraded RCS pitch authority
     - Low or non-existent yaw authority
     - Leading to risk of "control reversal"
   - It can also cause a large attitude error at parachute deployment, causing
     - Excessive "wrist mode dynamics" that can degrade radar performance
   - Thruster jet interactions were not an issue because Phoenix did not fire thrusters during descent
     - Relied instead on the inherent capsule stability throughout descent



Questions Answered by the Study (4)

5. *How did the radar perform?*

– Modifications from the inherited MPL/Mars ‘03 design included
    - Lower minimum altitude
    - High-resolution Doppler mode
    - New antenna design and configuration
    - New antenna switch design
    - Lower pulse repetition frequency (PRF) for range ambiguity protection
    - Numerous firmware updates

– The radar worked well in the environment for which it was tuned (flat terrain, near vertical descent), and its performance matched simulations and field tests

Questions Answered by the Study (5)

6. *Was there a plasma blackout?*
   - Communication may be interrupted due to the ionized plasma caused by compression and heating of surrounding air
   - Downlink was maintained from 2 minutes prior to Entry, until 1 minute after touchdown
   - EDL telemetry suggests there was a short radio brownout or blackout during the period of peak heating

7. *Was there fault protection activity/anomalies during EDL?*
   - All fault protection counts during EDL were either expected or understood:
     - 315 X-axis attitude control error counts during parachute descent (expected)
     - 531 radar reliable counts (expected)
     - 1 Fast Fourier Transform (FFT) Frozen count (understood)
     - 1 FFT Done count (understood)
   - There were no other EDL anomalies.

Conclusions

- Unless you analyze EDL performance soon after landing, it may be hard later to reconstruct data critical to the success of future missions
- Utilize the Phoenix findings for the improvement of future EDL models and prediction tools, and for optimizing future system and mission designs for EDL
  - Use to fine tune the NASA Aero Database
  - Validated the Phoenix high-fidelity radar model for future use
  - Decreased uncertainty in EDL predictions will increase confidence in future EDL designs; enable mission concepts would have been viewed as too risky
- Consider allocating resources in flight project budgets for an EDL reconstruction to be scheduled as soon after planetary landing as feasible.