Mars EDL Capability Drivers and Technology Needs

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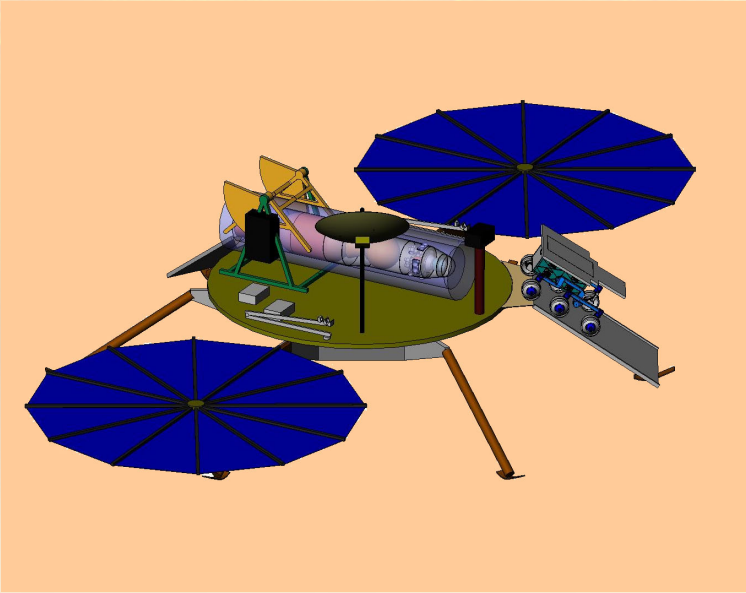
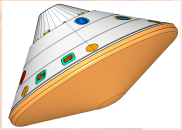
Mission Drivers for Mars EDL

- ***Mars Sample Return***
  - *High mass, large volume*
    - *~1.5 x MSL*
  - *Pinpoint landing for surface rendezvous, < 1 km (caching)*
  - *Similar requirements for AFL, MSR more driving on precision*
  - *Reliable, robust EDL*



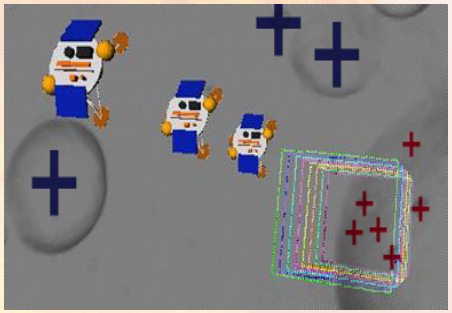
- ***Network Landers***
  - *Low mass (~100 to 200 kg)*
  - *Low cost to permit several (≥4)*
    - *Seismology*
    - *Meteorology*
  - *Simplify: no propulsion, RADAR*
  - *Rough — with parachute, or …*
  - *Hard (DS-2 style) — without parachute (simpler, or not?)*
  - *Reliable, robust EDL*

Hypersonic Guidance and Smart Deploy



- *Key approaches to correcting for atmospheric uncertainties during entry are inertially directed …*
  - *Hypersonic guidance — adjust direction of a small amount of lift*
  - *Smart parachute deployment — allow timing of parachute deploy to vary within Mach and Q constraints in order to adjust downtrack*
- *These approaches bring the accuracy to the ~10 km level*
- *Problem H1: don't know how to combine those two assets well*
  - *Develop algorithms to optimize the use of these together **
- *Problem H2: recently discovered that we don't understand the use of thrusters in a flow field*
  - *Research thruster interactions with the flow field to enable informed designs with predictable performance **
- *Problem H3: use of fixed CM offset for lift has resulted in large, ejected ballast masses*
  - ✓ *Study and trade approaches to direct CM control with moving solid or liquid masses, or direct CP control with movable surfaces*

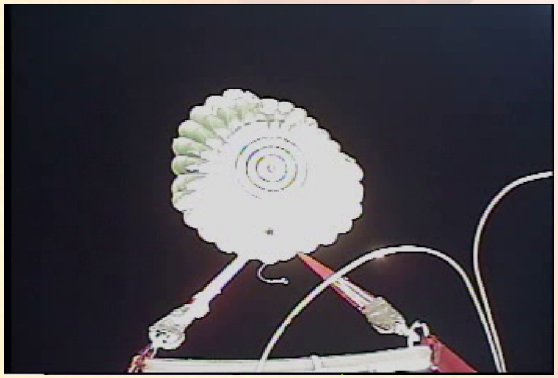
Terrain Relative Guidance Approach



- Key approach to pinpoint landing, order of a 1 km error or better, is to:
  - Start by doing hypersonic guidance and smart deploy to get within 5-10 km, possibly with enhanced approach navigation
  - Use a sensor to map the terrain below and in real time correlate that to onboard data to determine the vector to the target
  - Fly the vehicle to the target using the terminal descent propulsion system
- Alternative approach is:
  - Do hypersonic guidance, smart deploy, enhanced navigation
  - Then drive out the remaining distance with a highly capable mobility system (e.g. ATHLETE)
- Problem P1: Don't know which approach is better
  - Mission dependent of course — conduct trade studies to identify mass and cost impacts: propellant likely more than mass and volume of high mobility system; on the other hand, propellant is cheap and you don't have to land it

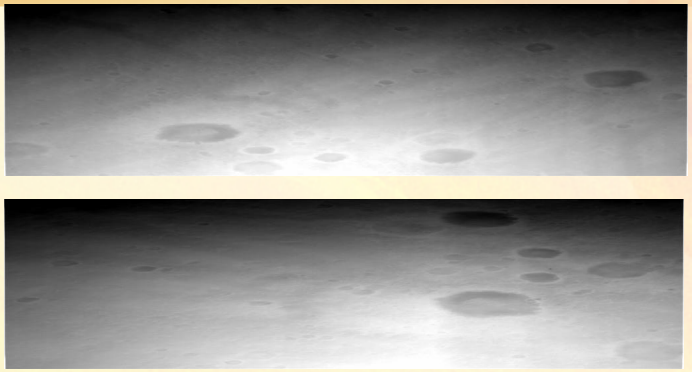
Terrain Relative Guidance Trades

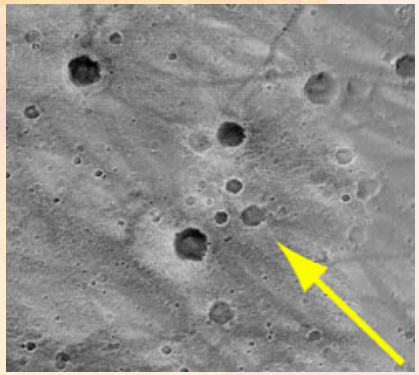
- For either approach, could use a steerable parachute to reduce wind drift that you would otherwise have to fly/drive out of
- Problem P2: is the gain worth the complexity?
  - ✓ Characterize steerable parachute capability (Boeing/Irvin)
  - – Evaluate benefit of the capability in pinpoint landing system studies



- Problem P3: responses to counter wind are reactive,only after damage already done
  - – Evaluate cost/benefit of active wind sensing ahead of the current trajectory (doppler lidar)
- Problem P4: might want to land at night for reduced winds or due to geometric constraints
  - – Develop approach for passive infrared terrain imaging
  - – Develop approach for active strobe / flare visual terrain imaging

Terrain Relative Guidance Maps





- *Correlating orbital data to descent images in real-time is fraught with peril …*
- *Problem P5: lighting and geometric differences (time of day, opacity, altitude, view angle) result in false negative correlations*
  - *Develop algorithms for a priori and real-time processing of orbital data, possibly re-rendering 3D models, to estimate appearance at time of landing **
- *Problem P6: have an embarrassment of riches in the variety of orbital data available*
  - *Develop algorithms to integrate THEMIS, HRSC, HiRISE, CRISM, other data into a form that can be readily and reliably correlated to descent images **

Entry Reliability and Robustness (1)

- *Heritage is a tricky thing*
- *Theorem: for any currently accepted application of a heritage capability, there exists a deeper level of scrutiny at which the heritage will no longer be applicable*
- *This applies all too well to thermal protection systems given their complicated application environments*
- *Problem T1: the modeling of TPS environments, responses and coupling are inadequate to predict flight performance in new applications (both fore and aft bodies)*
  - *Using test and analysis, improve / develop models of:*
    - *Performance limits and failure modes (recession, spalling, melt flow), including coupling of shape changes back to environment*
    - *Shock layer radiation*
    - *Turbulence and shear interactions*
    - *Gas-surface interactions, catalysity*
    - *Real gas effects*

Entry Reliability and Robustness (2)

- *Problem T2: existing test capabilities for thermal protection systems has limited ability to combine effects, and does not replicate the chemistry at Mars*
  - *Invest in CO_2 test facilities that combine heat flux, shear, and pressure effects*
    - *Initial CO_2 / air comparisons have been done at SIMOUN (~10 km from here?)*
- *Problem T3: little to no validation of models in flight*
  - *Modeling is the link between test and flight, in situ measurements are the link from flight back to test*
  - *Usual approach is open loop validation, combined with prayer*
  - ✓ *Develop TPS sensors for key uncertainties*
    - *Temperature, recession (distinguish from spalling?), calorimeters, catalycity*
  - *Use them!*
  - ✓ *MEDLI on MSL is a good step forward*
  - *What are the ExoMars requirements for EDL characterization?*

Rough Landers

- *Mars Pathfinder was supposed to be the prototype network lander — turns out it was too complicated and too expensive*
  - *That landing system found another application though …*
- *Reduce cost by eliminating systems: propulsion, RADAR*
- *Consequence: higher impact velocity*
- *Problem R1: Crushable materials are required to mitigate the landing loads*
  - *Develop a range of crushable materials, tunable to the desired strokes and accelerations*
- *Problem R2: The parachute might drape over the lander*
  - *Develop and test a system to provide positive separation of the parachute from the lander, perhaps using small solid rockets **
- *Problem R3: Need long life, but solar cells, deployment mechanisms vulnerable to high G impacts*
  - ✓ *Characterize the performance of existing systems to ~1000 G impact loads over a few milliseconds*
  - *Develop and test mitigation approaches for deployed solar panels*

Many More …

- *Areas not covered due to limited time for this talk:*
  - *Entry body shapes for better volumetric usage, improved lift and drag*
  - *High fidelity parachute modeling in lieu of expensive high altitude tests*
  - *RF transparent TPS and optical windows in TPS for guidance*
  - ✓ *Spacecraft-to-spacecraft and beacon enhanced approach navigation*
  - ✓ *Terminal descent RADAR / LIDAR development*
    - ✓ *Improved altimetry and direct velocimetry*
  - *Algorithms for optimal propellant use in pinpoint landing **
  - *A priori hazard avoidance using terrain relative guidance*
  - ✓ *Real-time hazard avoidance sensors and algorithms **
  - *Pyrotechnic device bus and sensor wireless communication to reduce wiring mass, cable cutting*
  - *Customized, dedicated EDL GN&C computers for very fast reboot and re-engagement*
  - *DS-2 style impact mitigation for long-lived landers*

Prioritization

- Not enough money out there to cover all the bases
  - Or even first base
- Focus areas must be make-or-break for mission success
- Assuming current objectives (they change often):
  - Entry reliability, specifically TPS performance and environments
  - Surface rendezvous for MSR sample caching
  - High G impact survival for low-cost network landers
- Within those areas, prioritize using careful system studies to identify highest leverage against performance or uncertainty
  - Evaluate effectiveness and cost of additional margin against reduced uncertainties (TPS thickness and density)
  - Evaluate mission impacts of reduced performance (pinpoint landing vs. time to drive to target)
  - Look for sweet spots in complexity vs. mitigation (rough landing)
- Coordinate international investments
  - National capabilities are nice, but we cannot afford a lot of duplication — where we do tend to duplicate, strive to complement