Entry, Descent, and Landing (EDL) Considerations

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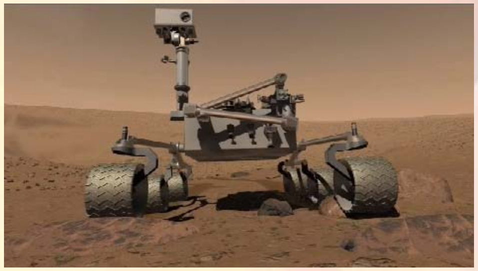
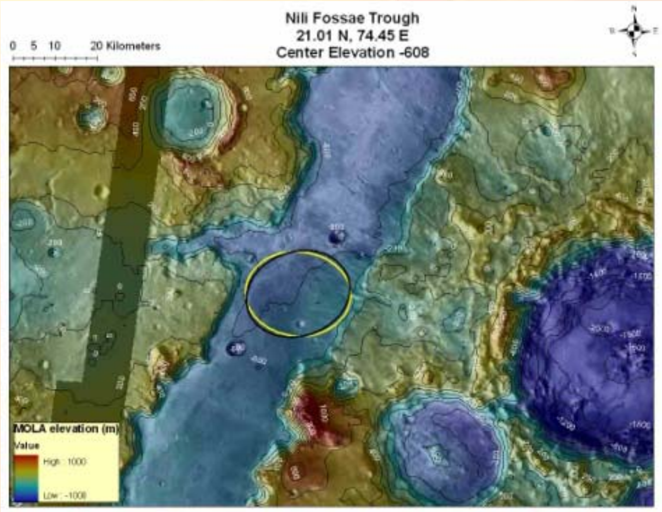
Landing: where can we land?

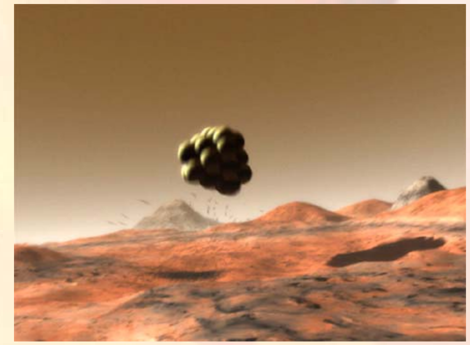
- *Major parameters for landing are:*
  - *Mass of the lander*
  - *Accuracy of landing*
  - *Altitude of landing site*
  - *Safety of landing target site*

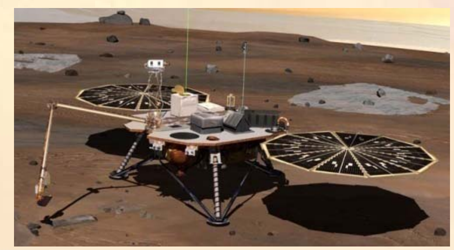


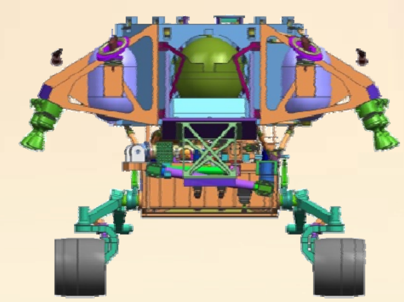


Lander Mass

- *Recent Mars landers have used airbags and chemical thrusters to land assets on Mars*
- ***Airbag landers** can land roughly ~200kg on the surface of Mars. Landing heavier masses require more elaborate airbag systems that have to be developed and tested and may or may not work*
- ***Soft landers** have been used in the past and recently. Current capability (not yet flown) is about 2000kg wet mass at ignition, of which about 400kg is propellant and 900kg is the useful payload (i.e., MSL rover)*
- *Landing site elevation and mass of a lander have direct relationships. Raising the landing site requires lowering the landing mass*





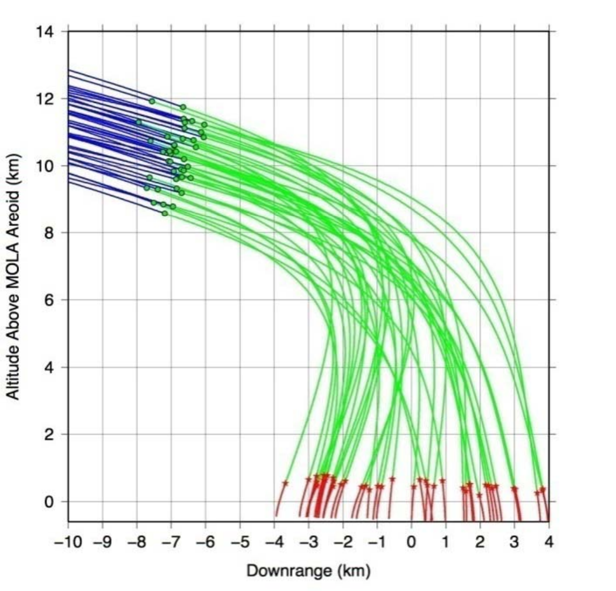


Accuracy of Landing

- *Typical ballistic entry can result in landing accuracy of 75km- 200km, depending on entry precision*
- *Guided hypersonic entry can correct for atmospheric / aerodynamics uncertainties resulting in landing accuracy of 10km radius (planned for MSL, but not demonstrated on any previous mission)*
- ***Precision landing may increase accuracy to 3-4km radius***
- ***Pin-point landing may increase landing accuracy to 10s of meters***

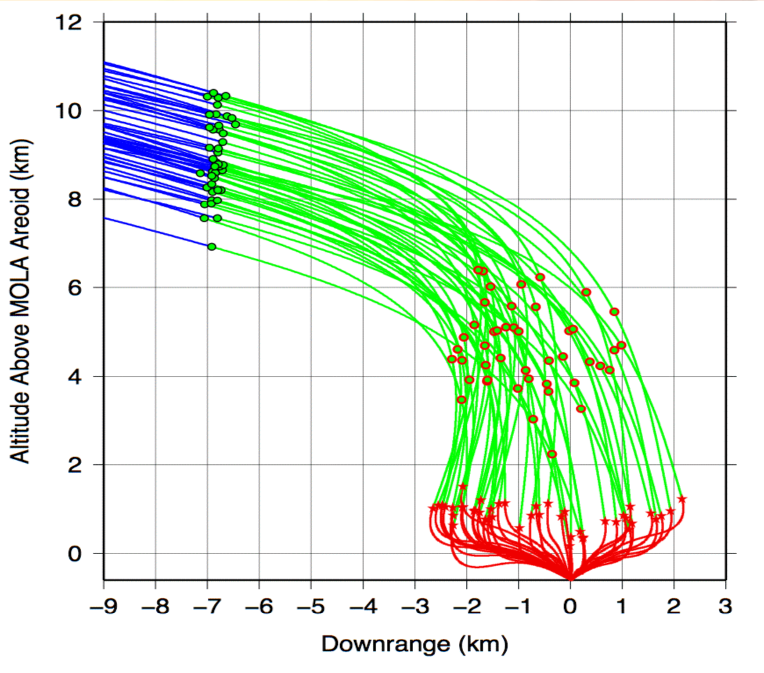
Precision Landing

- *Analysis have shown that errors at parachute deploy can be reduced to ~2.5 km by improving entry knowledge (use of optical navigation techniques), better aligned IMUs, and guided entry*
- *After parachute deploy, winds speed of ~25m/s can introduce additional errors. This error can be reduced if **position trigger** rather than **velocity trigger** is used to open the parachute, thus resulting in 3-4km landing error*
- *The feasibility of this technique is currently being debated within EDL community*
- *Advantage of this technique is that additional fuel is not required to reduce errors*



Pin-Point Landing

- *Terrain relative navigation techniques can be used with additional propellant to further reduce the landing error*
- *This is achieved by taking images of Mars starting at couple of km altitudes and via real-time image processing, comparing these images to stored onboard maps obtained from orbital imagery*
- *After establishing spacecraft's actual location, thrusters can be utilized to land the spacecraft within the accuracy of features on the map (<100m)*
- *Precision and pin-point landing can also be used to achieve collision avoidance*



Science Targets

- Science targets may be outside of the landing ellipse
  - If targets are at locations that can be accessed by MER/MSL type rovers, there does not seem a need for new mobility system development
  - If targets are in extremely sloped regions, then a specialized mobility may be required

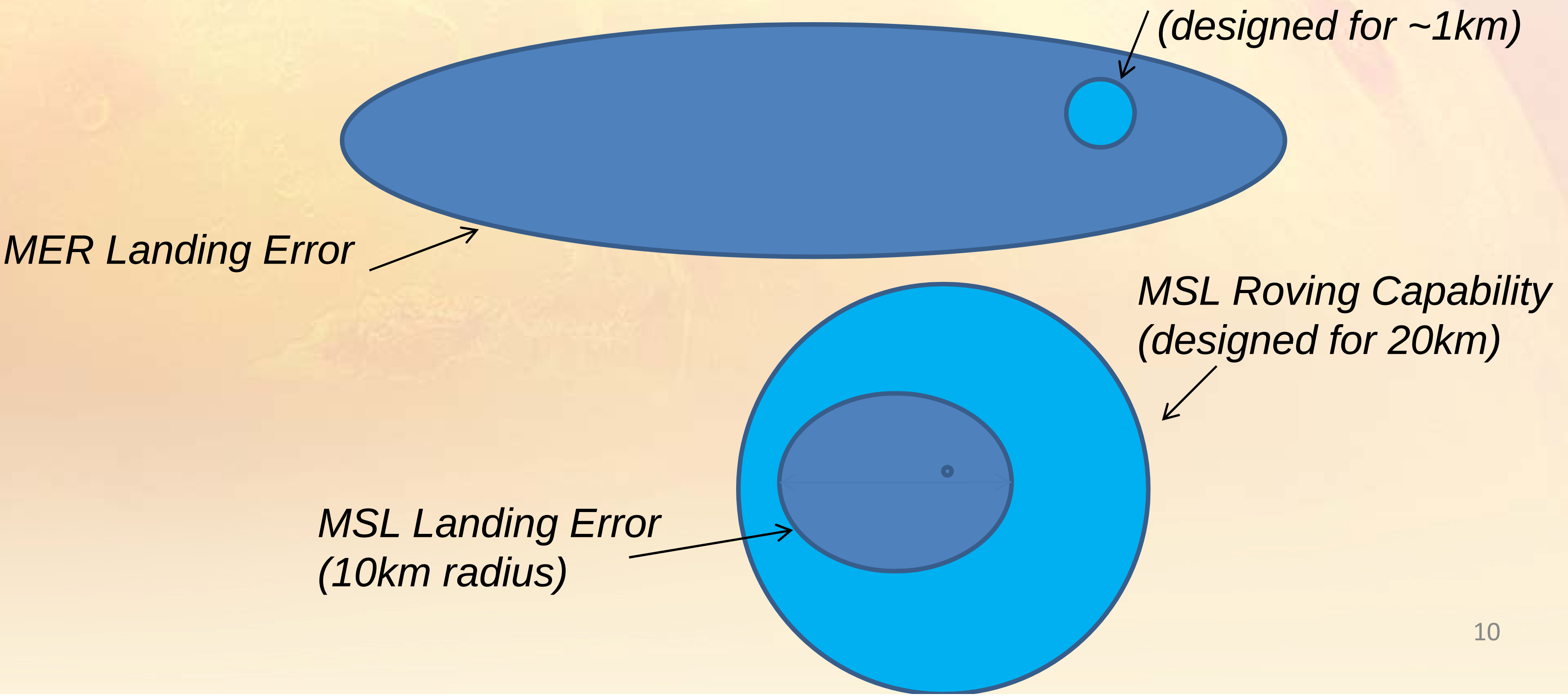
Rover Family Portrait

Rover Performance

Capability	Present	Future
Physical / Traverse		
Distance	~15 – 20 km	Similar
Speed	< 120 m/hr (limited by power) < 30 m/hr (limited by computation)	Similar 30 m/hr – 120m/hr
Slope	< 30°	< 30° for similar rovers 0°-90° for specialized rovers
Payload		
Mass	8% – 16% rover mass	Slightly improved with more efficient designs and materials
Intelligence		
Hazard Avoidance	Limited geometric obstacle avoidance Limited slip detection	Avoidance of multiple hazards during entire traverse
Targeted Instrument Placement	Multi-sol instrument placement	Single- and multi-target single-sol placements
Onboard science decisions	Very limited	Decisions based on on-board analysis guided by scientists

Roving: Where can we go?

- *There is a relationship between landing accuracy and roving capability*
  - *MPF and MER rovers could not access specific science sites on Mars due to large landing error (75 to 200km) and limited roving capability (MER design was ~1 km)*

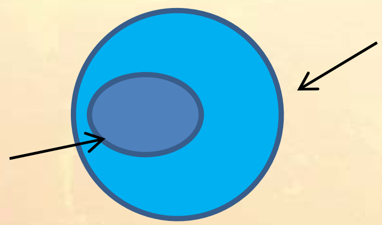


Roving: Where can we go?

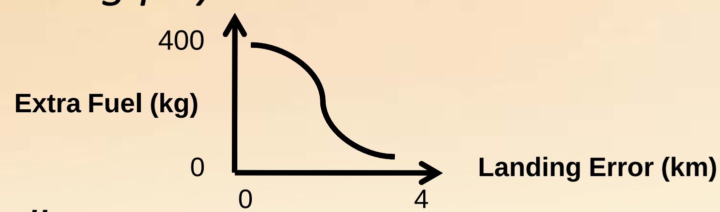
- *With precision landing of 3-4 km radius, rover does not have to be designed for 20km. This means that smaller and non-nuclear rovers can perform the task*

Roving Capability (designed for ~6km)

Landing Error 3-4 km radius



- *With pin-point landing, one can land an asset very close or on the target. For example, if deep drilling is required on a particular site, a stationary lander with a major drilling payload can land on the target*



Pin-point landing (landing error can be selected from 3-4 km radius to ~100m)

Summary

- *Highly sloped regions can be reached by*
  - *Precision landing thus requiring 6-8 kms of traverse (worst case) without any fuel penalty*
  - *Pin-point landing requiring 10s of meters of traverse. Pin-point landing will require 100s of kg of additional fuel*