Landing, Roving, Sample Acquisition and Sample Manipulation: Existing and Plausible Capabilities

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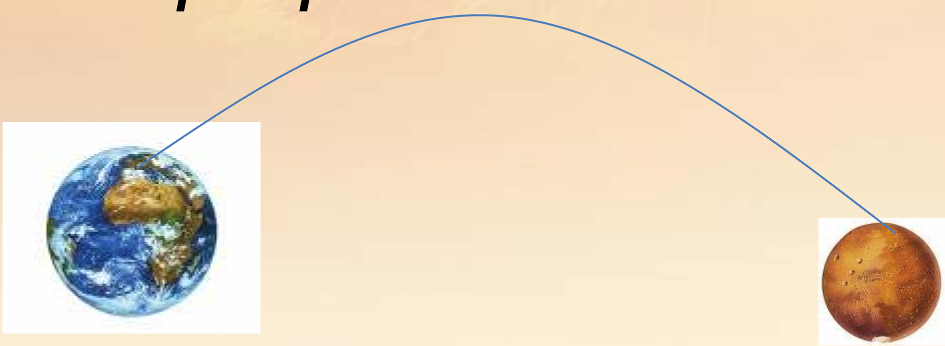
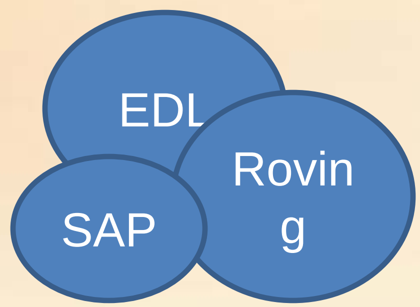
In-Situ Exploration of Mars

Goal is to get specific samples to science instruments

- *Landing: Where can we land?*
- *Roving: Where can we go?*
- *Sample Acquisition and Preparation (SAP): What can we sample and how do we prepare them?*





In-Situ Exploration of Mars

- *Landing: Where can we land?*
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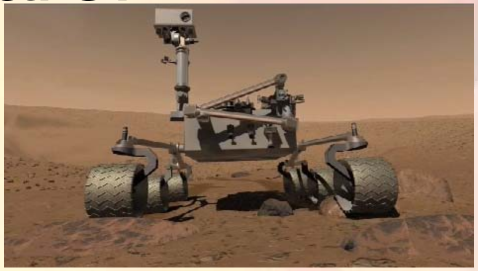
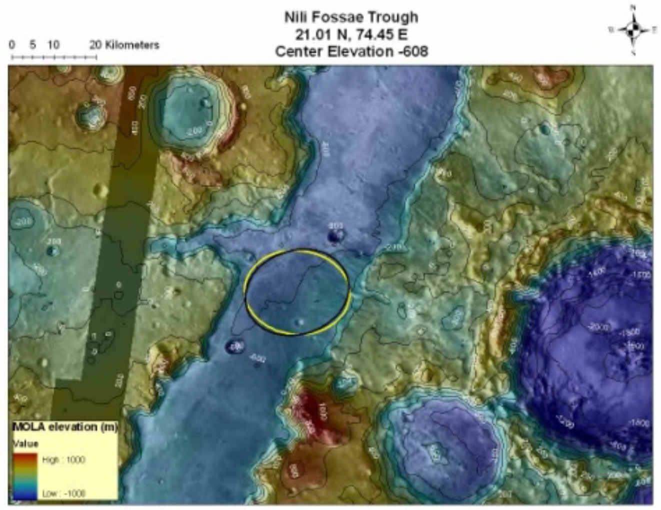
Landing: where can we land?

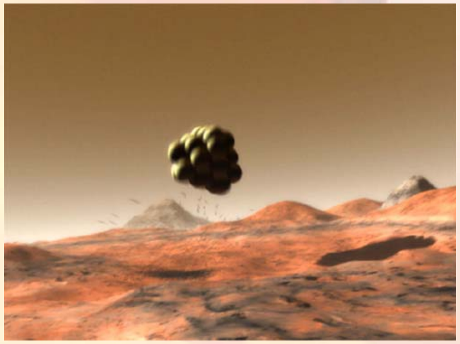
- *Major parameters for landing are:*
  - *Mass of the lander*
  - *Accuracy of landing*
  - *Altitude of landing site*
  - *Safety of landing target site*

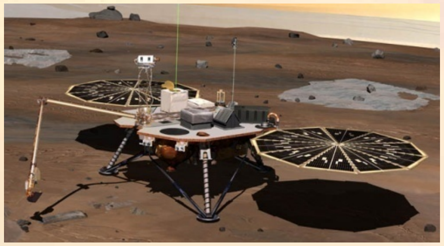


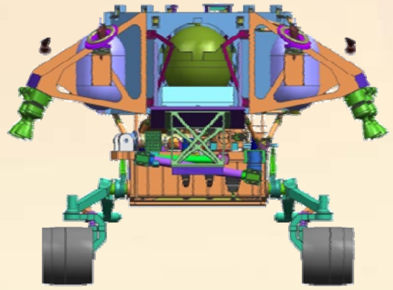


Lander Mass

- *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*





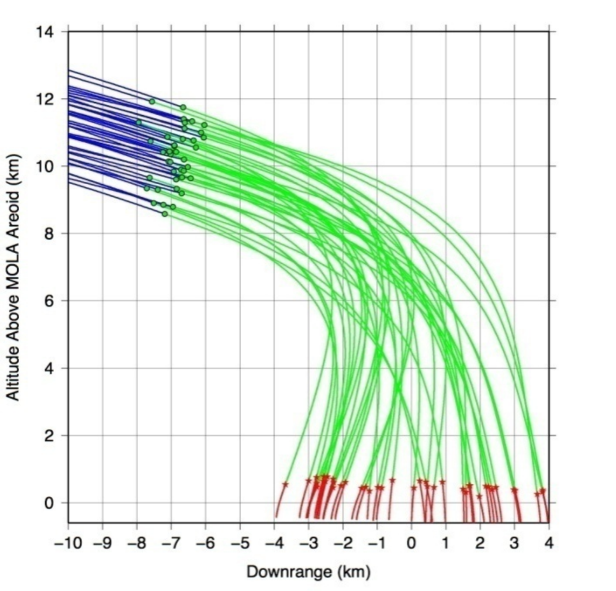


Accuracy of Landing

- *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***

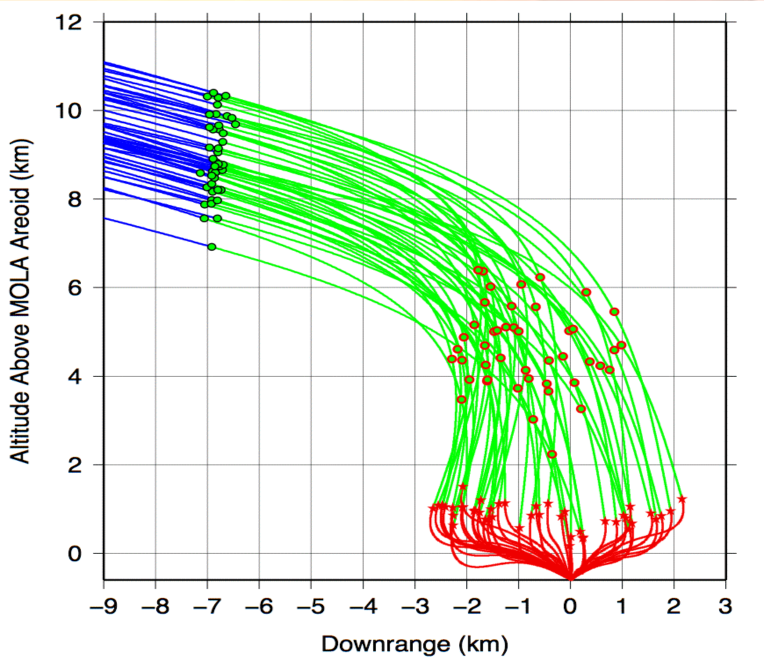
Precision Landing

- *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*



In-Situ Exploration of Mars

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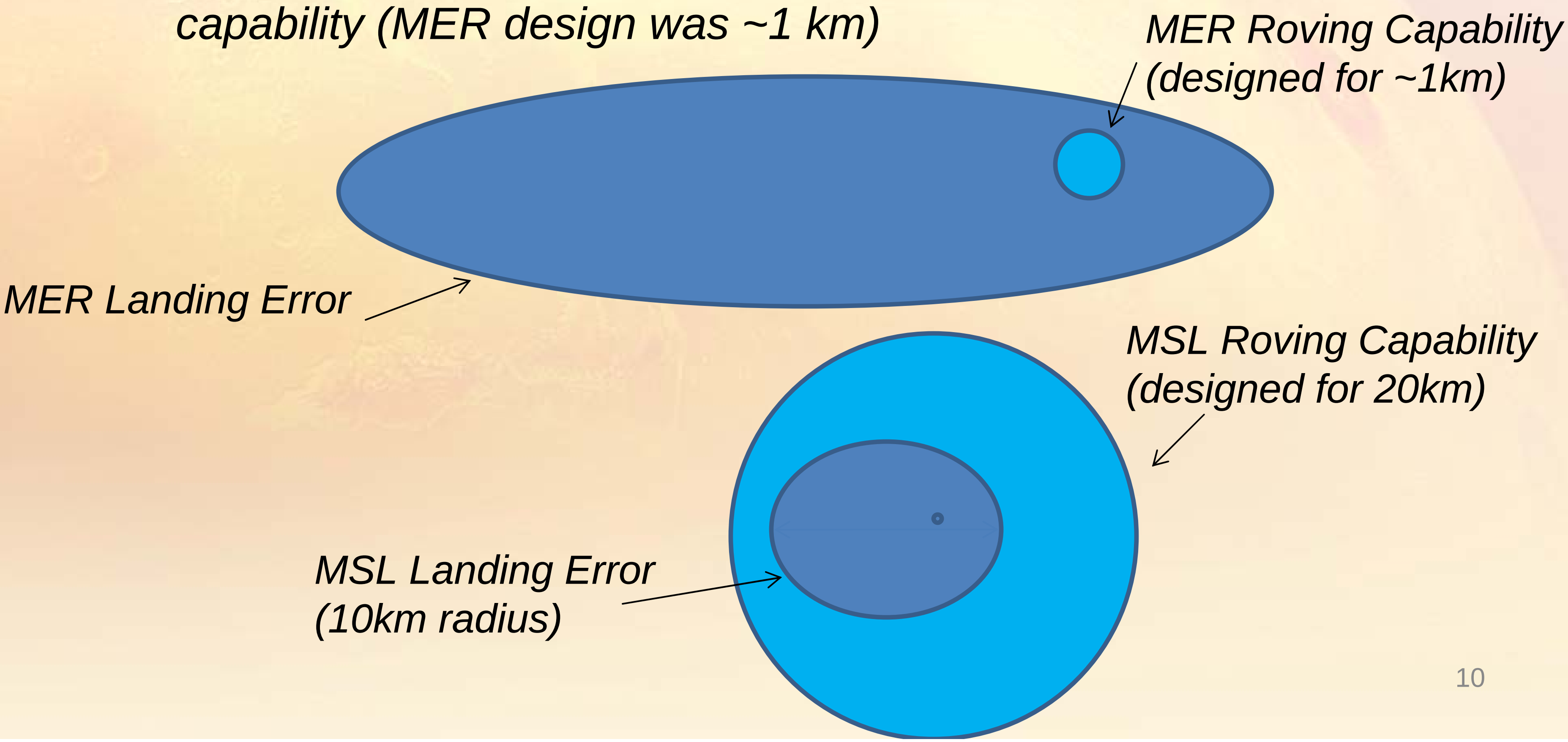
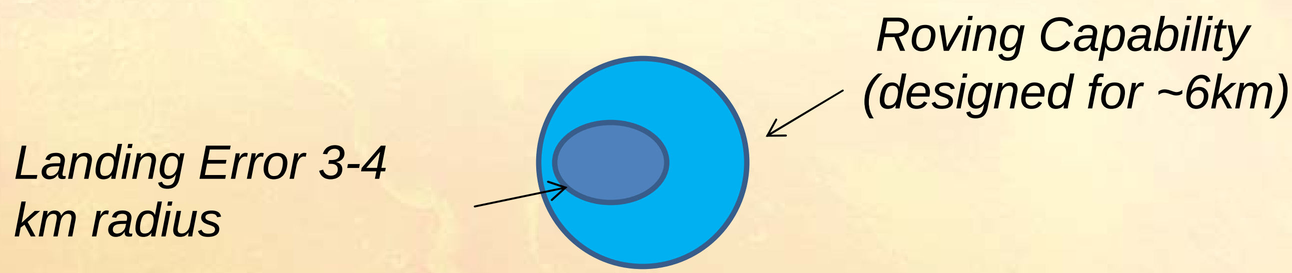
Roving: Where can we go?

- *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)*

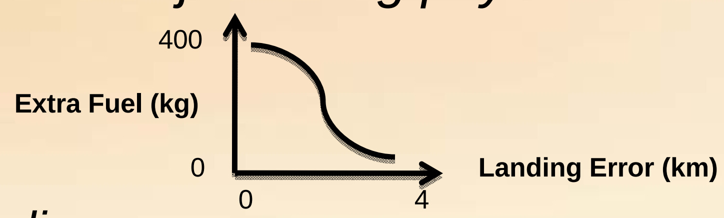


Roving: Where can we go?

- *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*



- *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)

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	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
Intelligence		
Hazard Avoidance	Limited geometric obstacle avoidance	Avoidance of multiple hazards during entire
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

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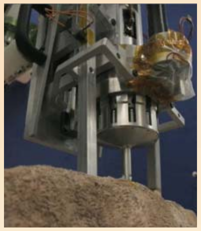
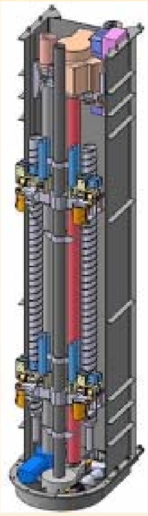
Sample Acquisition and Handling is New Technology for Mars Application

- *Viking lander was able to scoop regolith and transfer the samples to a hopper*
- *MPF did not have any sampling system*
- *MER did not have a sample system. RAT created some holes on rocks (9mm max)*
- *Phoenix used a scoop and a rasping device to sample regolith and create powder*
- *MSL will use a drill to create powder (2011)*
- *ExoMars plans to use a drill system to drill up to 2 meters (2016)*





Why is it so Hard?

- *Planetary drill must be:*
  - *Light weight (for a MER size rover, typical design is ~5kg)*
  - *Must be low-power (~50 W)*
  - *Must overcome difficulty of starting a hole*
  - *If drill bit gets stuck, the drill system or the bit must be severed from the rover*
  - *Dry drilling as oppose to wet drilling on Earth*
  - *Core break off*
  - *Core Ejection*
  - *Etc.*

Report for the R&TD Task
Integrated Mars Sample Acquisition and Handling (IMSAH) System

State-of-the-art of Corers with potential applicability to MSR

Yoseph Bar-Cohen,
Group Supervisor, 355N, x4-2610, yosi@jpl.nasa.gov

Recent Survey

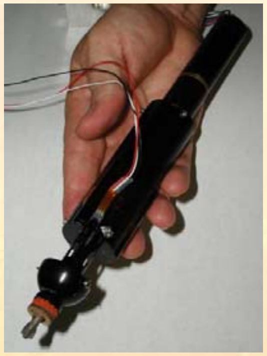
January 15, 2009

A complete drill system must do

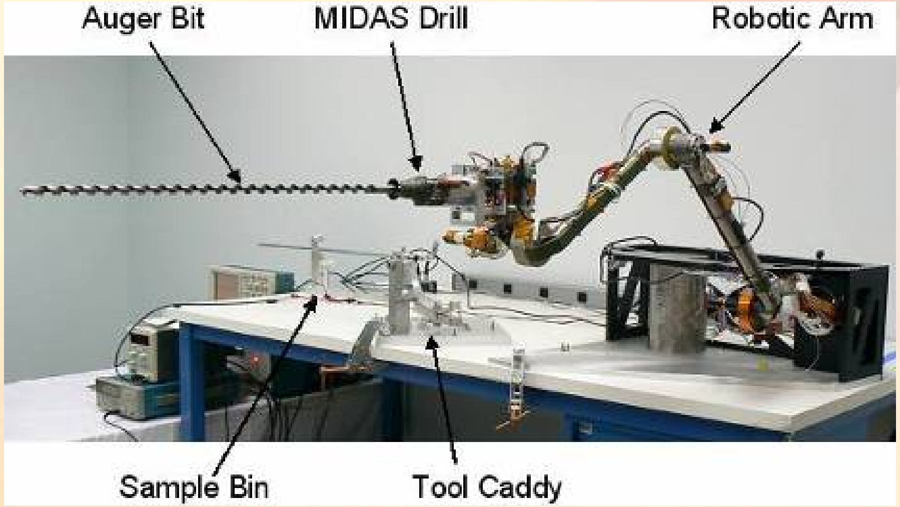
- *<u>Coring</u> (rotary, percussive, rotary-percussive)*
- *<u>Core Break-Off</u> (Eccentric tubes, grab and twist, core tilting, …)*
- *<u>Core Retention</u> (Shutter, pinches, …)*
- *<u>Core Ejection</u> (Tool pushrod out, external push rod in, …)*
- *<u>Bit Change-out</u> (quick coupling, chuck)*

Recent Planetary Drilling Technology Developments

50 cm

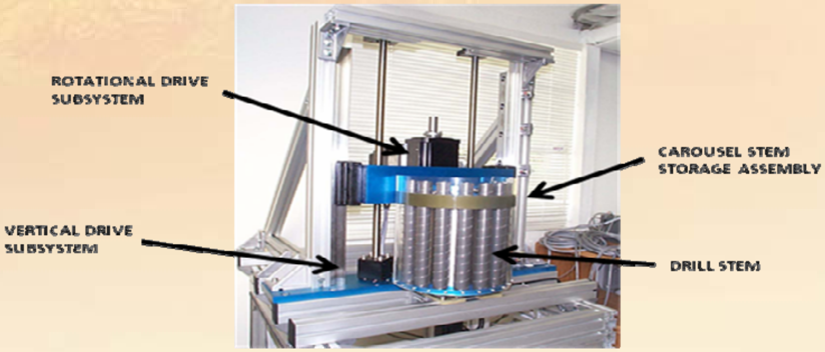


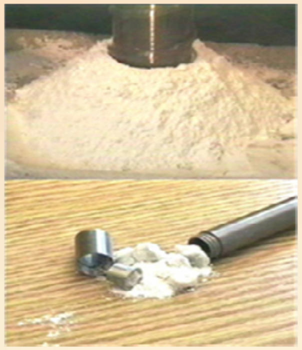
Low-force Sample Acquisition System (LSAS)



Alliance Spacesystems, LLC (Alliance)

50 cm to 10m





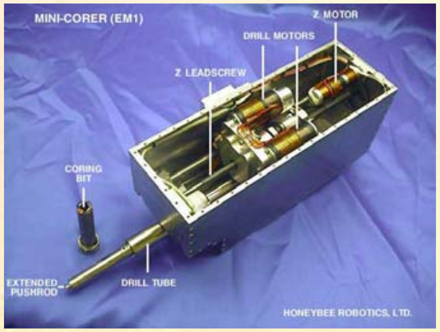
ATK Space (formerly Swales Aerospace)

Recent Planetary Drilling Technology Developments

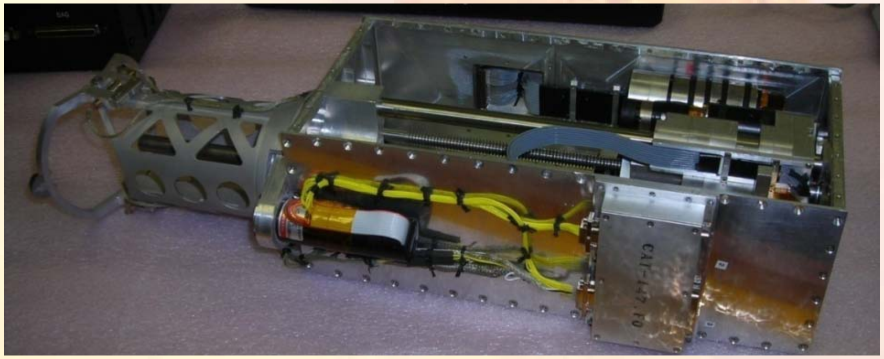
The Honeybee Robotics/JPL Subsurface Sampler

Ultrasonic/Sonic Driller/Corer (USDC)

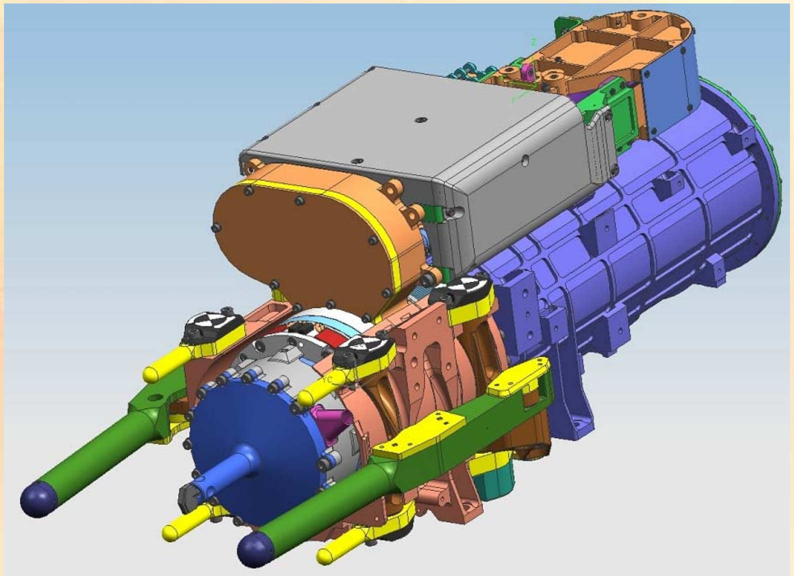
Recent Planetary Drilling Technology Developments for Flight Applications



Mini Corer (MSR)

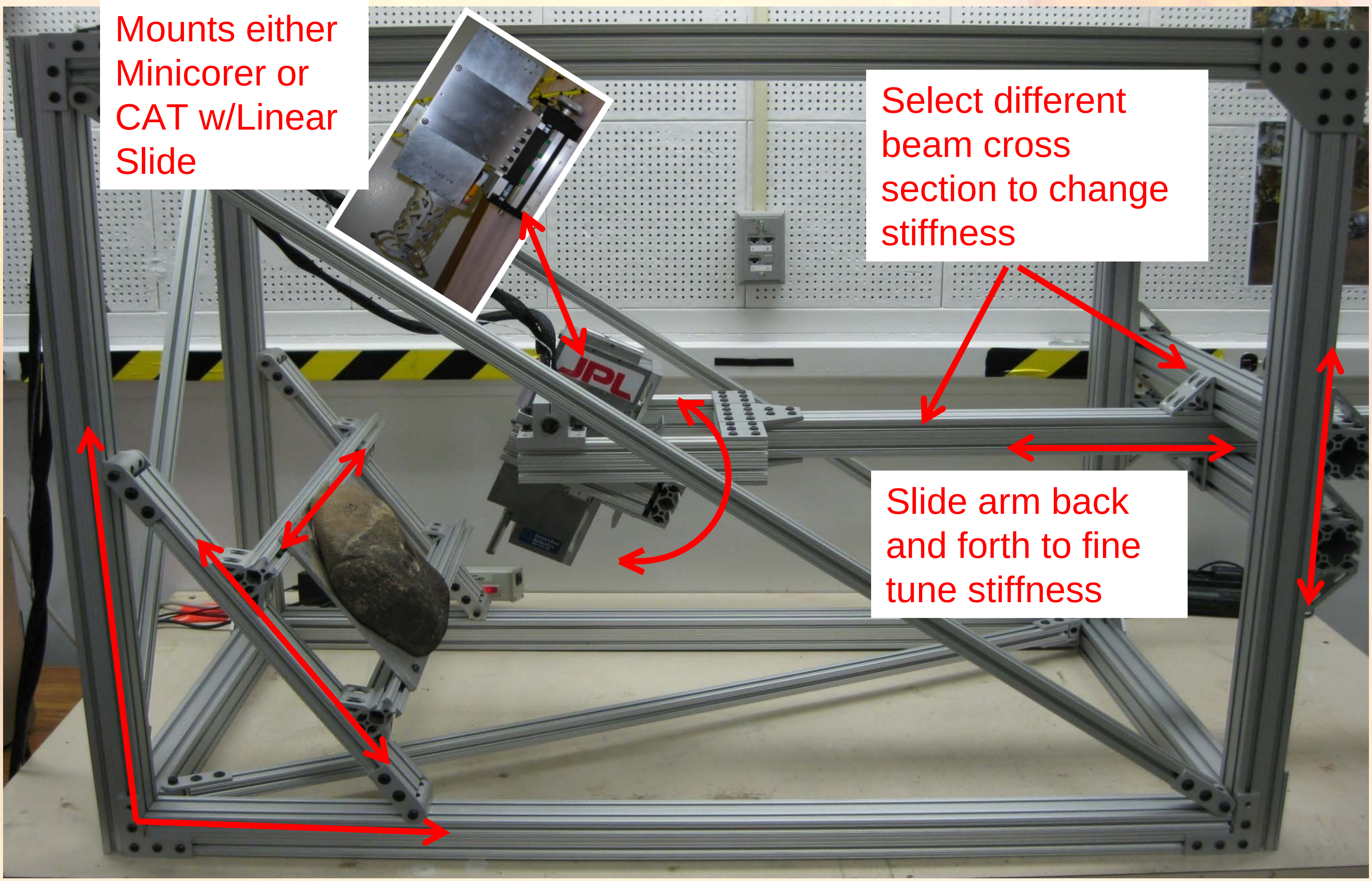


CAT (MSL)



Mars Science Laboratory (MSL) drill

Recent Tests



Recent Tests

Drill Automation

Drilling performance can be improved by adding "intelligence"

- **Drill automation technology was developed by Ames research Center to provide real-time feedback as drilling proceeded**
- **This technology uses rule-based techniques to learn and use models for responding to drilling sensory feedback**
- **Possible drilling faults are:**
    - Auger Binding
    - Auger Choking
    - Bit Jamming
    - Bit Inclusion
    - Drilling Hard Material
    - Auger Corkscrewing
- **Demonstration: Several successful demonstration have been conducted that indicate the feasibility of this approach. Artificial fault situations are introduced to observe the reaction of the system.**

Field tested in permafrost on Devon Island in Canadian Arctic in 2004, 2005 and 2006

Summary

- ***EDL technologies*** *are mature. Capabilities beyond MSL require development:*
  - *Accuracy of landing (JPL internal investment is underway)*
  - *Mass greater that 900kg require enhancements or new development*
- ***Rover technologies*** *are mature. Capabilities beyond MER/MSL require development:*
  - *Increasing payload to rover mass ratio (new avionics is a key for MER size rover)*
  - *Long lived solar rovers*
  - *Steeper train access greater that 30 deg slope*
  - *Greater autonomy (on-board decision making, single cycle instrument placement, etc.)*
- ***Sample Acquisition and Preparation***
  - *Currently no flight ready capability exists (in the US) to core rocks or drill into regolith*
  - *Limited sample handling capability exists, but further development is required*
  - *Sub-Sampling (obtaining designated pieces from a core) not available*
  - *JPL's internal investment through R&TD program (2009-2011) is a significant development activity that may be leveraged*