PLANETVAC: REGOLITH SAMPLE CAPTURE AND RETURN USING PNEUMATICS

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SRR, Golden, CO
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HONEYBEE ROBOTICS
Spacecraft Mechanisms Corporation

Honeybee Robotics Spacecraft Mechanisms Corporation
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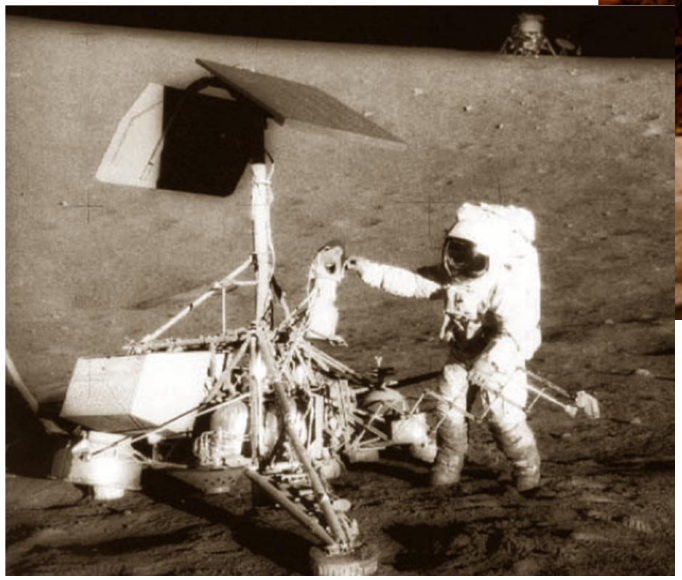
"Conventional" Planetary Samplers

Robotic arm/scoop approach

- Actuators, Volume, Mass
- Time to deploy, capture, deliver
- Need to be dust tolerant
- Survive thermal swings

Source: NASA

Source: NASA



Source: NASA

Pneumatic systems on Earth

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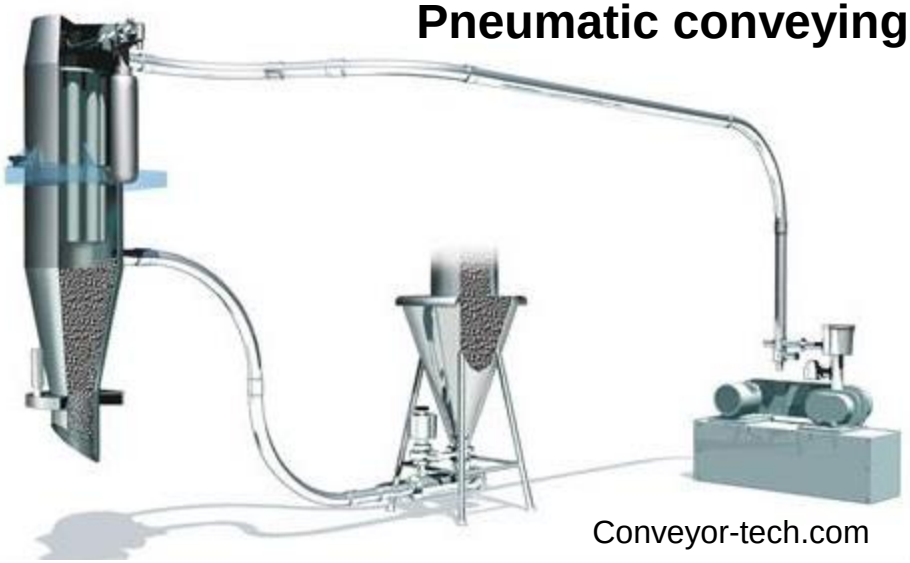
Ideal for dust or dirty applications

Vacuum Cleaners

Pneumatic conveying



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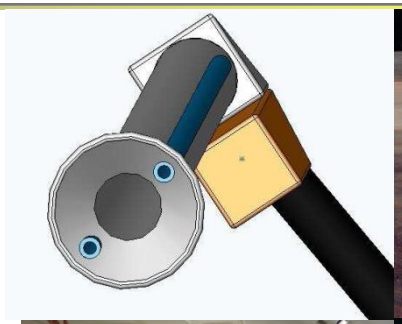
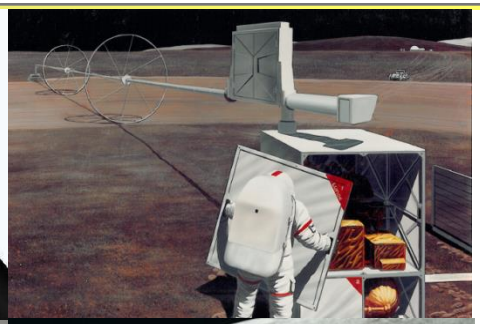
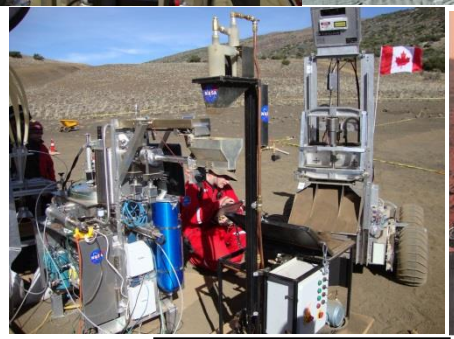
Pneumatic Tools

Pneumatics in Space Exploration

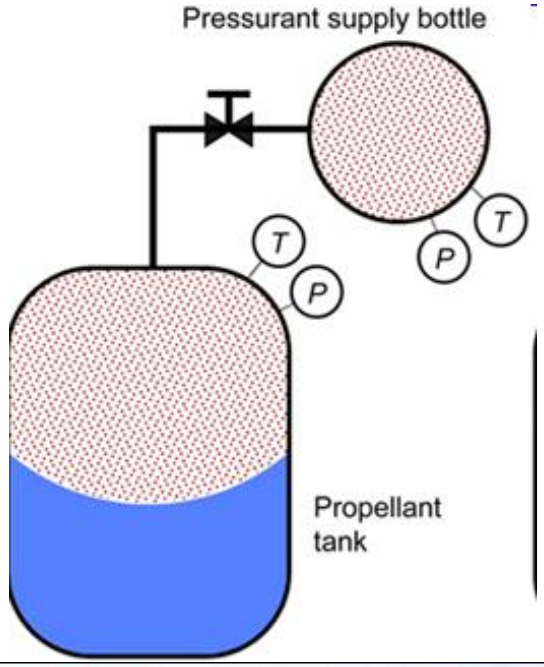
- **Dave McKay Lunar Miner**
  - Choking velocity 1/3rd at 1/6th g
- **Berkeley Pneumatic Mining**
  - Early designs and vacuum chamber experiments with promising results
- **Honeybee Pneumatic Excavator**
  - 1 g of N2 at 6 psia can lift 6000 g of soil in vacuum and 1 g
  - Touch and go pneumatic sampling
- **NASA KSC closed loop system**
  - Delivering feedstock to ISRU plant
- **HBR and The Planet. Soc. PlanetVac**
  - Demonstration of a touch and go pneumatic sampler
- **Osiris-REX**
  - Pneumatic sampling of asteroid regolith

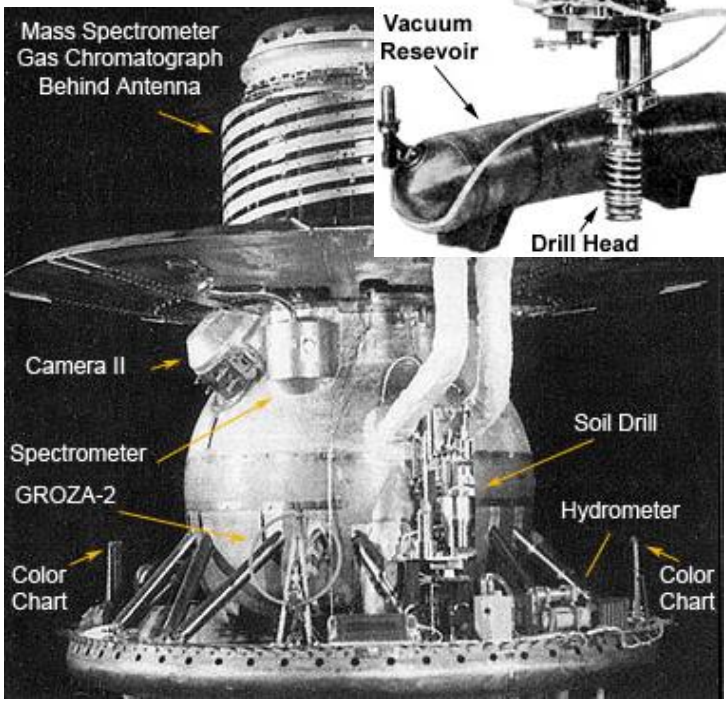


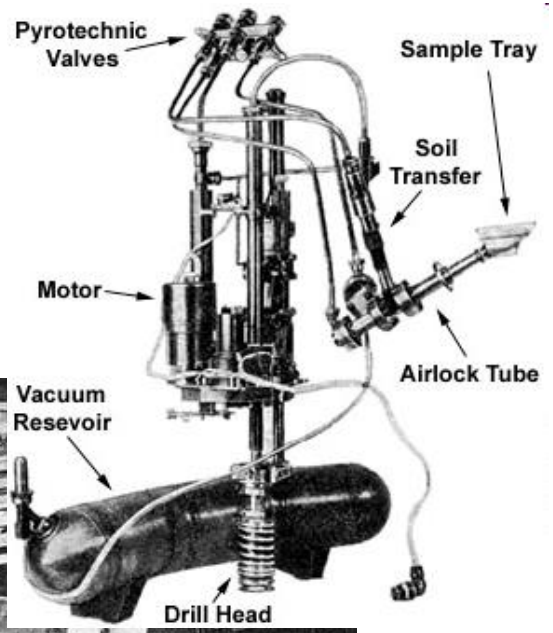
Pneumatic systems in space

Propulsion



Venus Drill

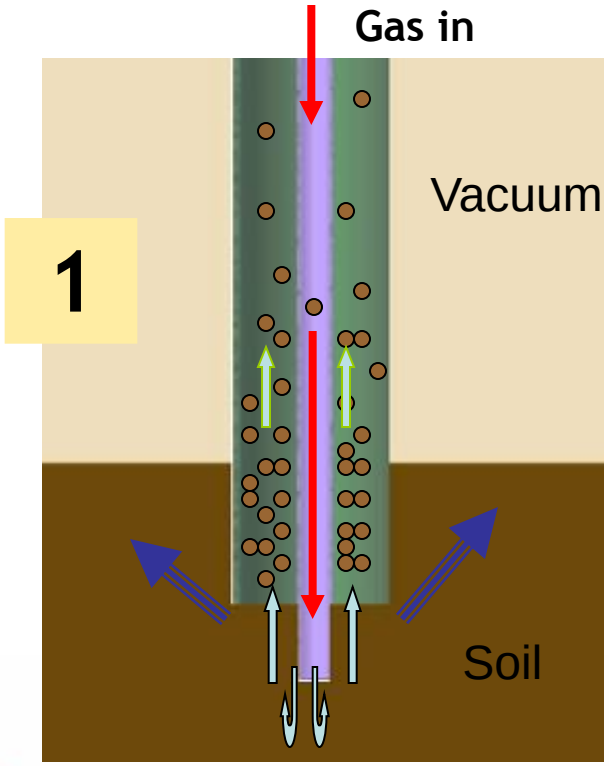


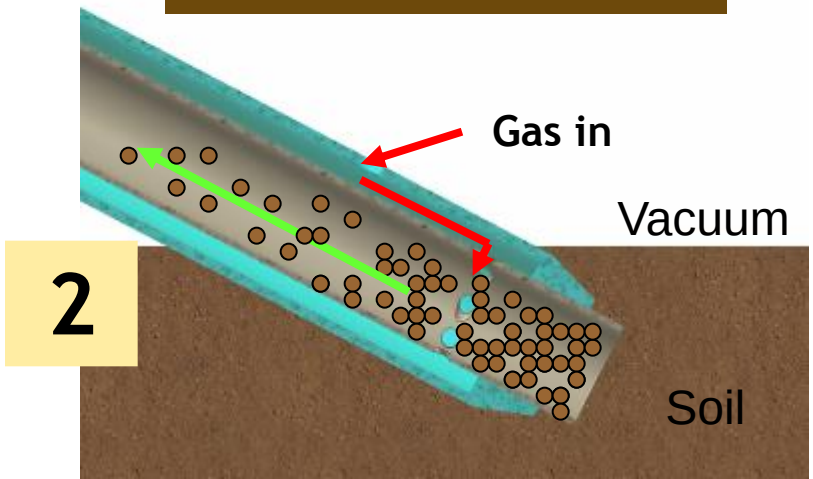


Pneumatic Sampling

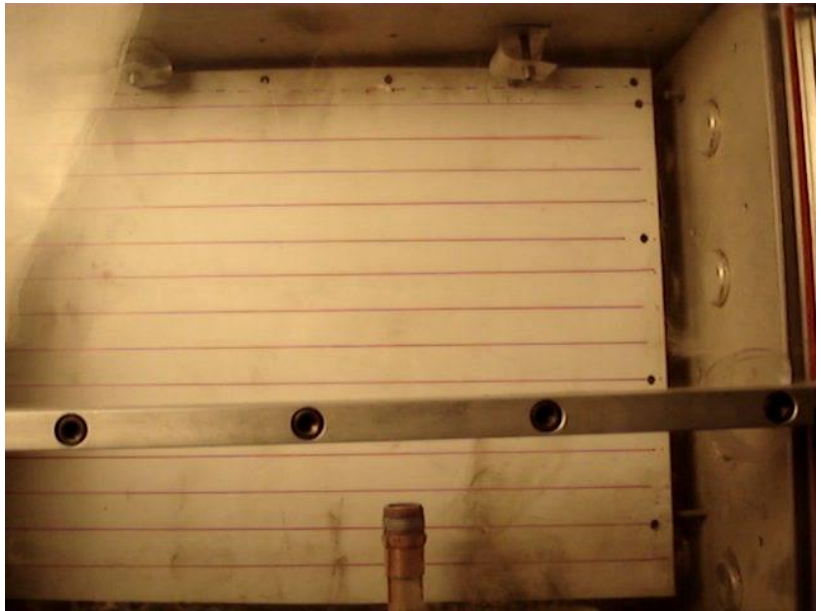
- **Principle of operation:**
  1. Gas is injected into regolith and as it escapes it exchanges momentum with soil particles lifting them up
  2. Regolith trapped inside a tube is lifted by injected gas

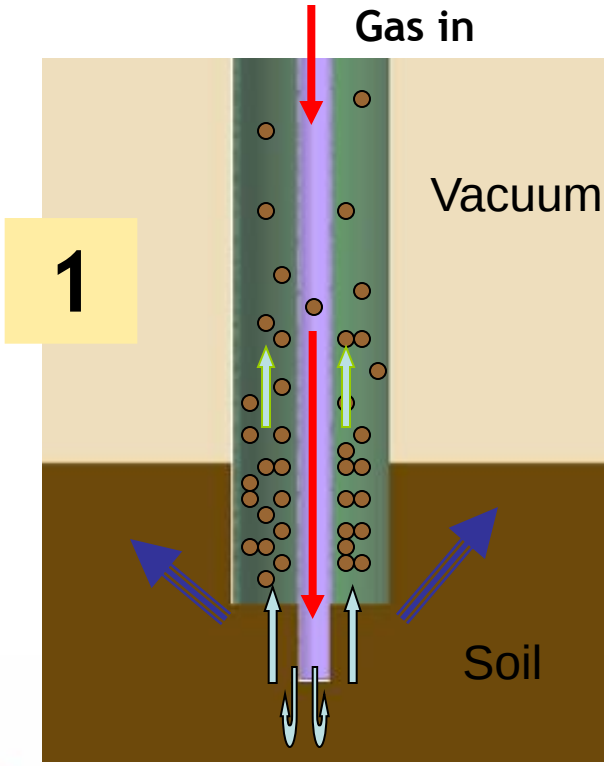
- **Gas sources:**
  - Propulsion pressurant gas: Helium
  - Dedicated gas tank

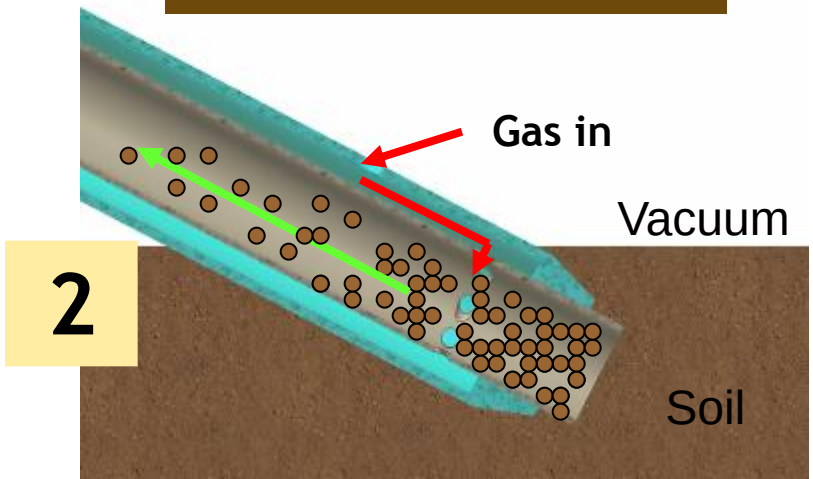




Proof of Concept



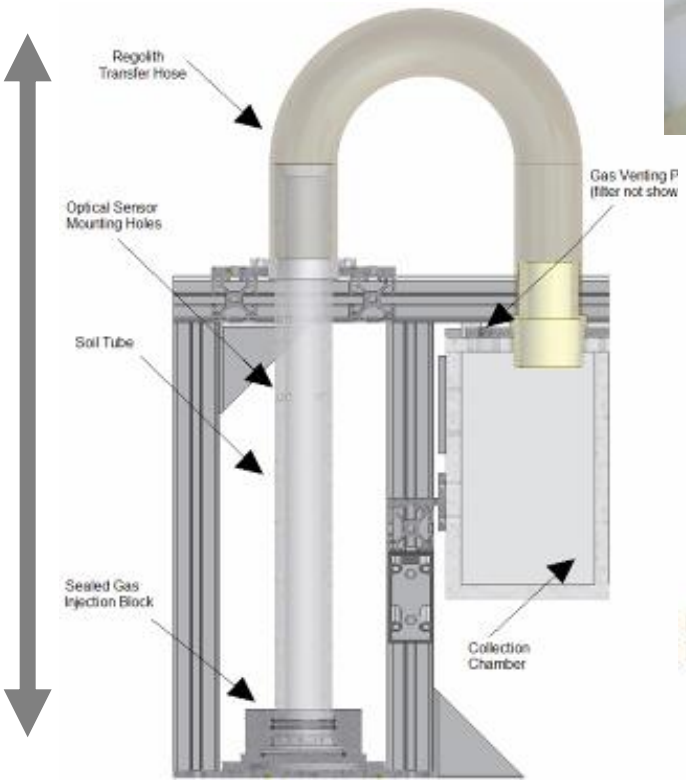


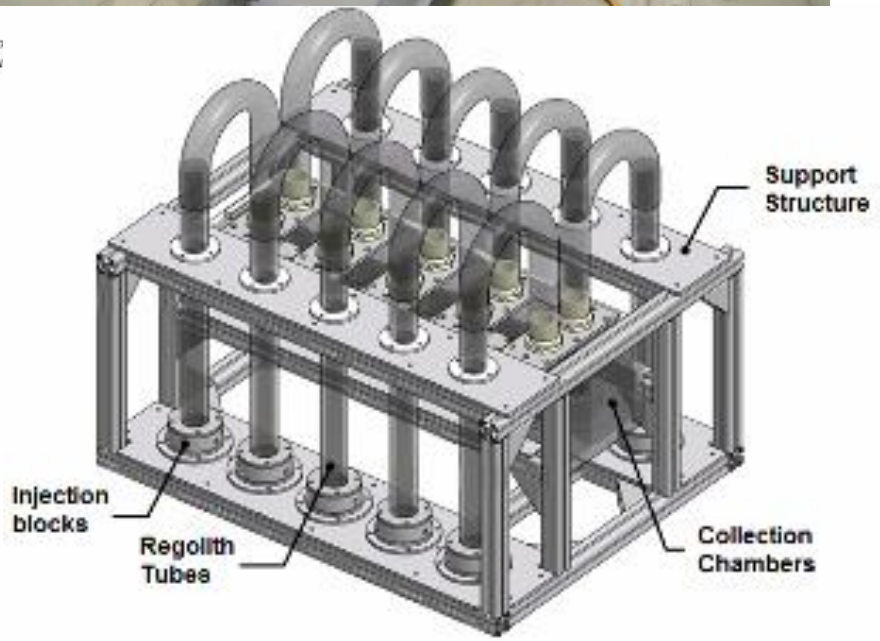


Tests at Lunar G and in Vacuum

- Gas: Nitrogen @ < 9 psia
- Initial Soil Mass: 50g or 100 g
- Material: JSC1-a
- Chamber Pressure: ~ 1-4 torr
- Gravity: 1.67 and 9.8 m/s^2

2 Feet



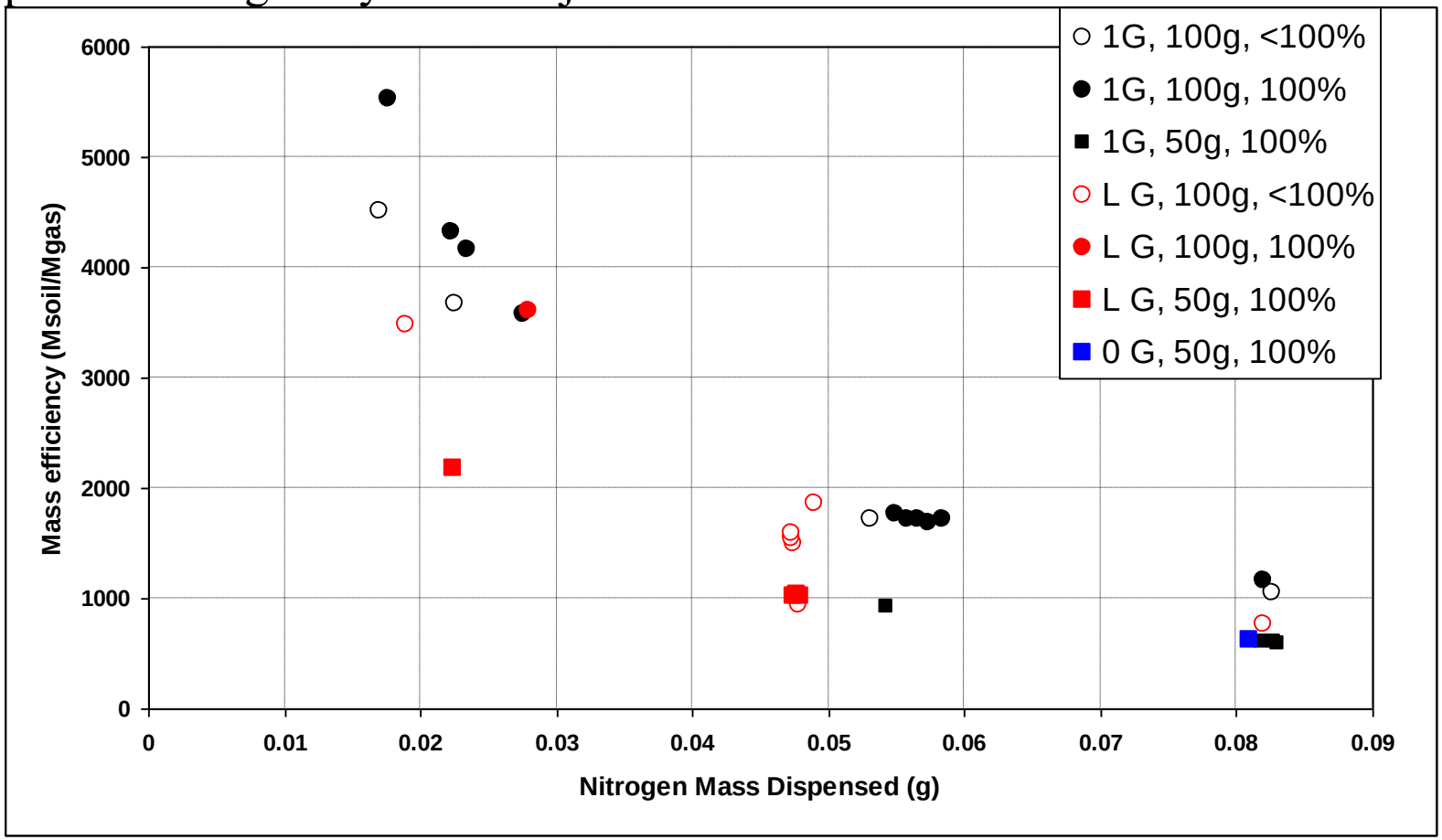


Test Results:

- 1 gram of N_2 at 7 psia can lift over 6000 g of soil
- Gas exit velocity (momentum) is function of pressure ratio (not ΔP)

$$u \approx \sqrt{2RT\left(\frac{P_{canister}}{P_{atm}} - 1\right)}$$

- For pulsed flow gravity not a major factor



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Spacecraft Components

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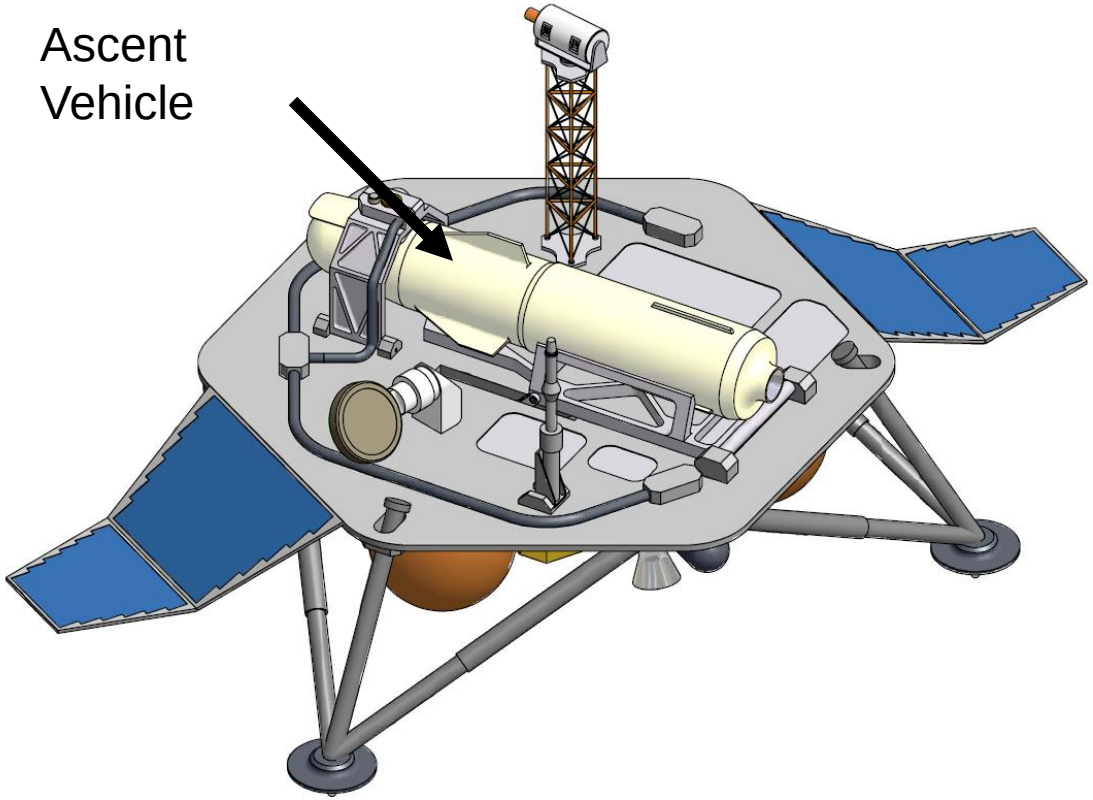
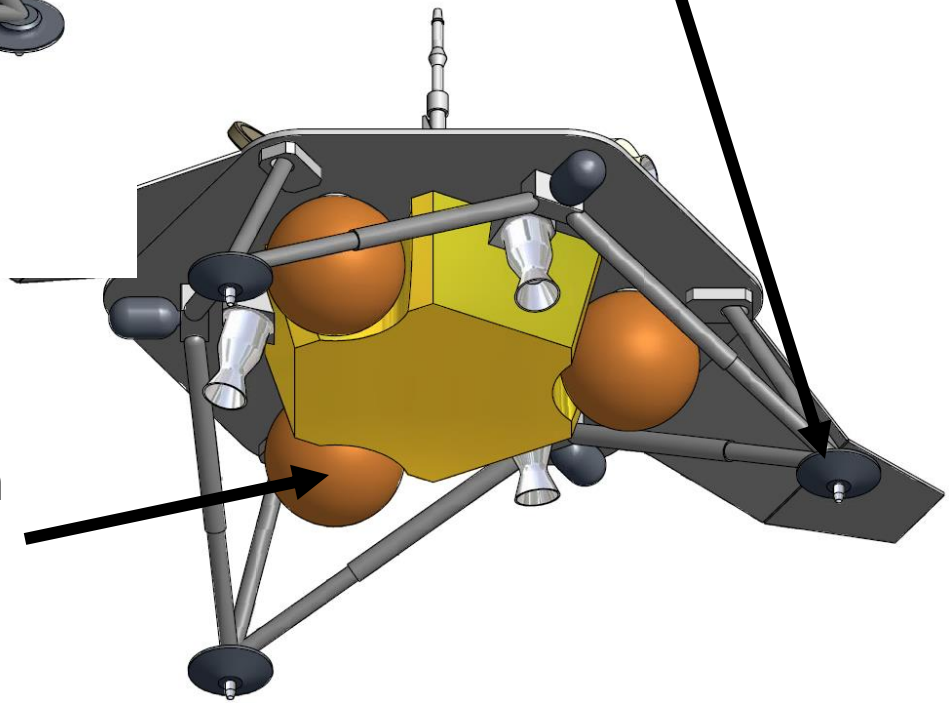
Ascent Vehicle



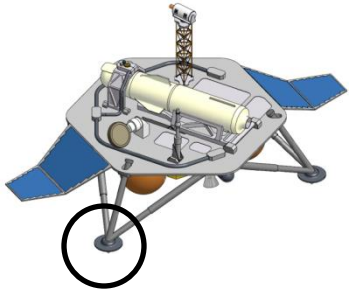
Soil Sampling Tube

- in each leg for redundancy

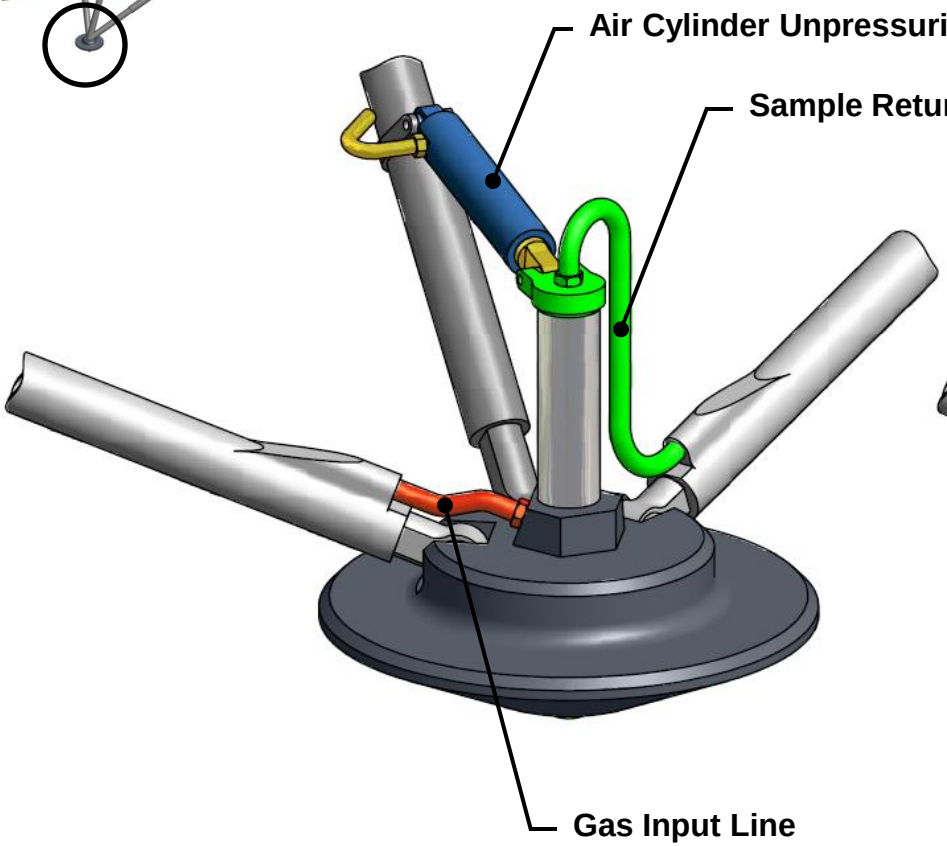


Propulsion system with Helium Pressurant Tanks

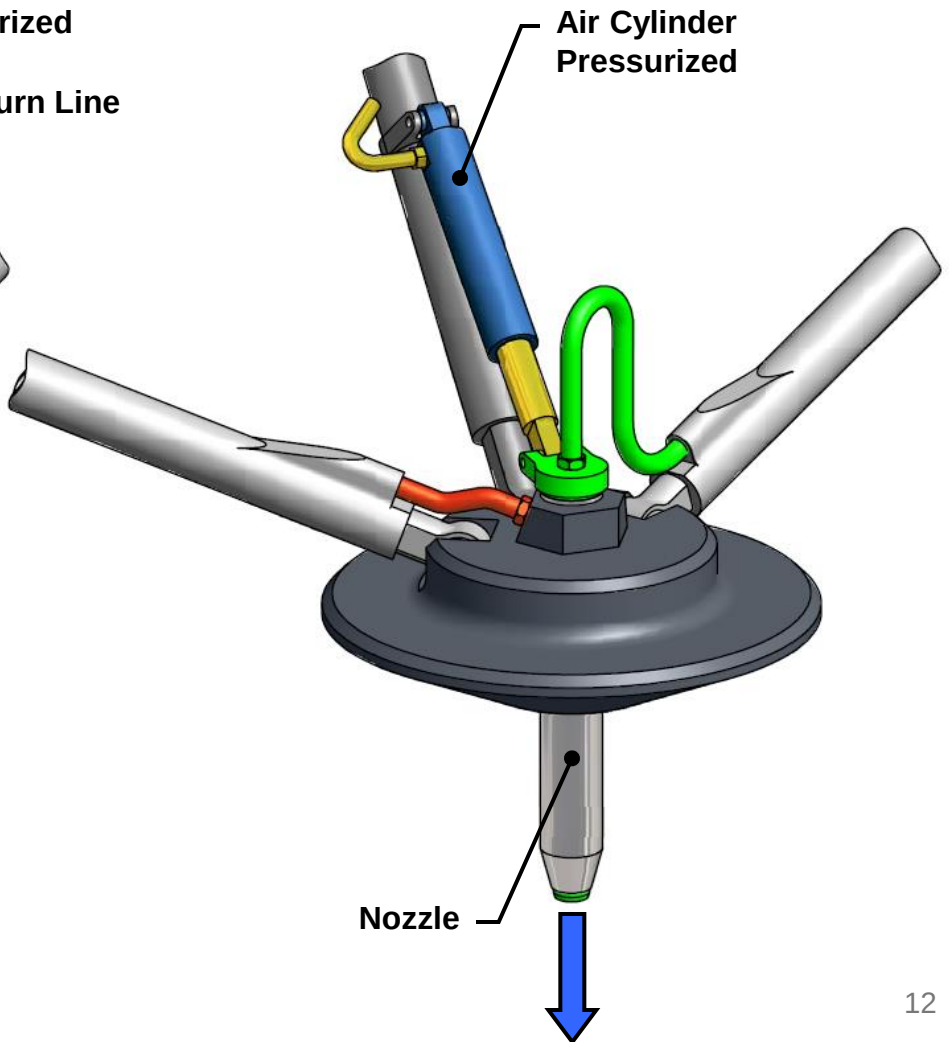
Sample Tube Details



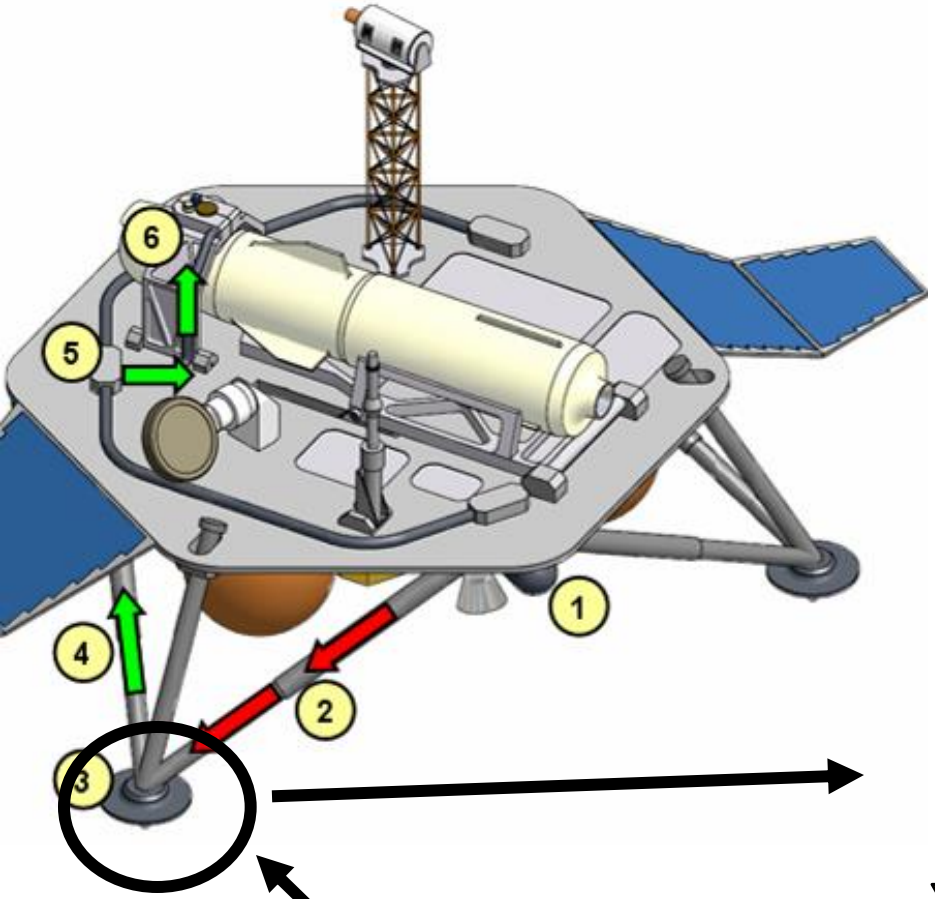
Stowed

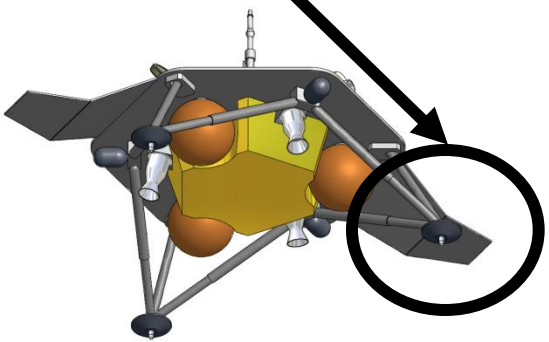


Deployed



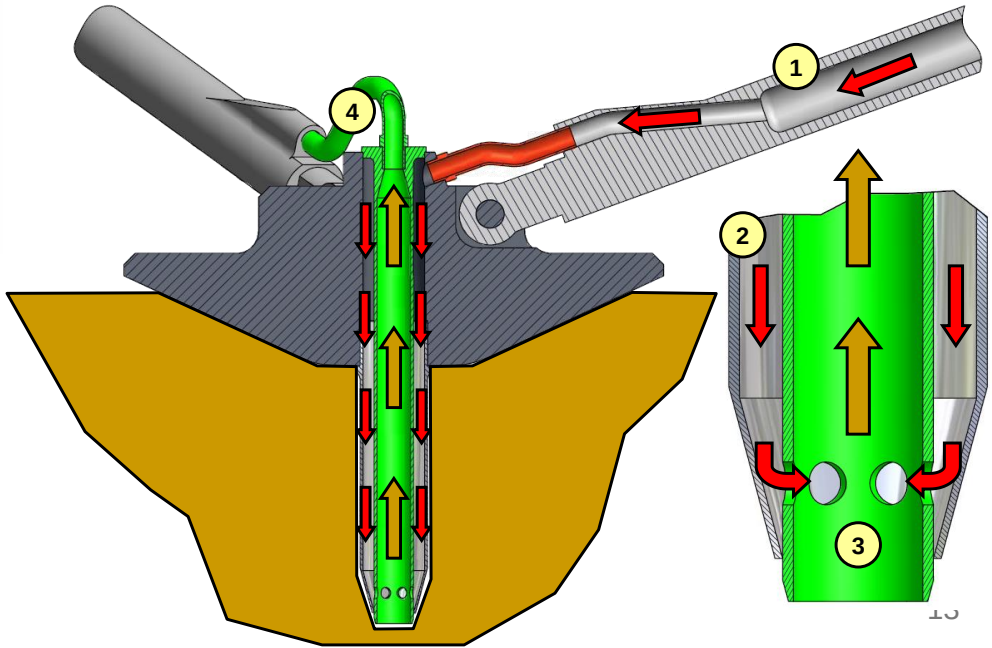
Regolith Acquisition



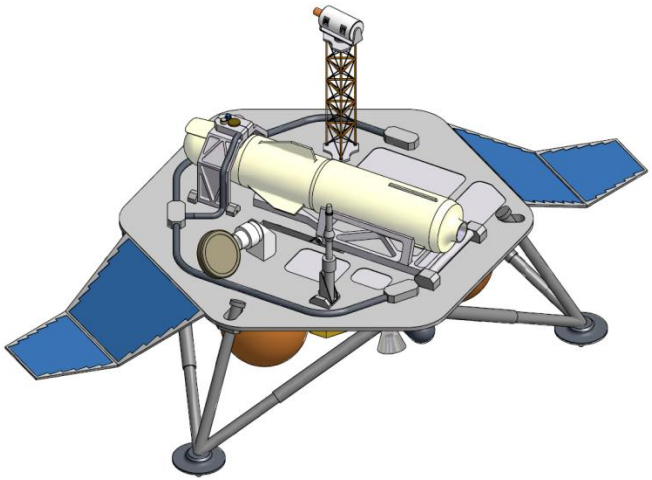


Soil gets pushed into the tube upon touch down.

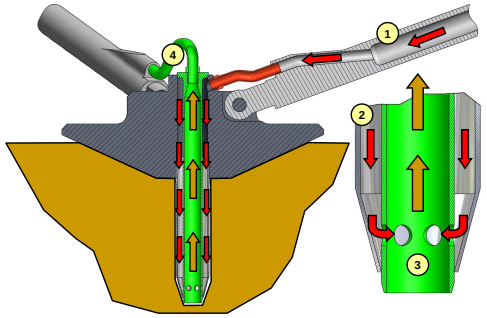
Gas lofts acquired soil into a sample return container



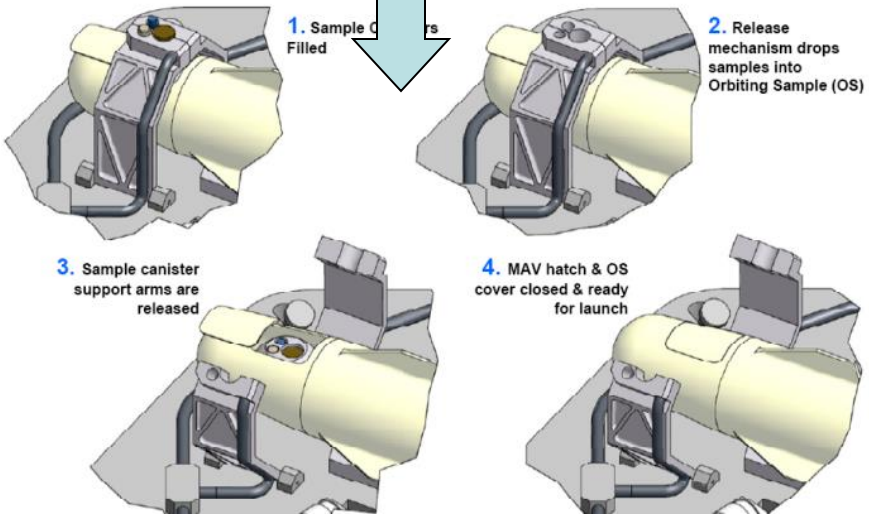
Mission Summary: 4 Steps



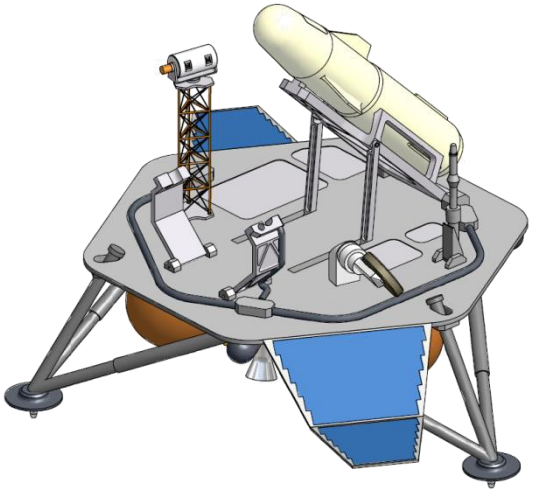
Step 1: Land



Step 2: Open Gas Valve and move soil into Sample Canister



Step 3: Close Sample Canister.



Step 4: Launch

Various soil probe architectures

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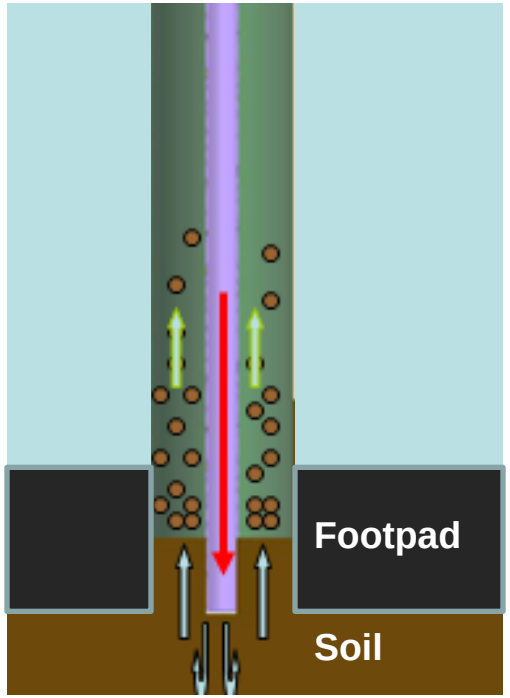
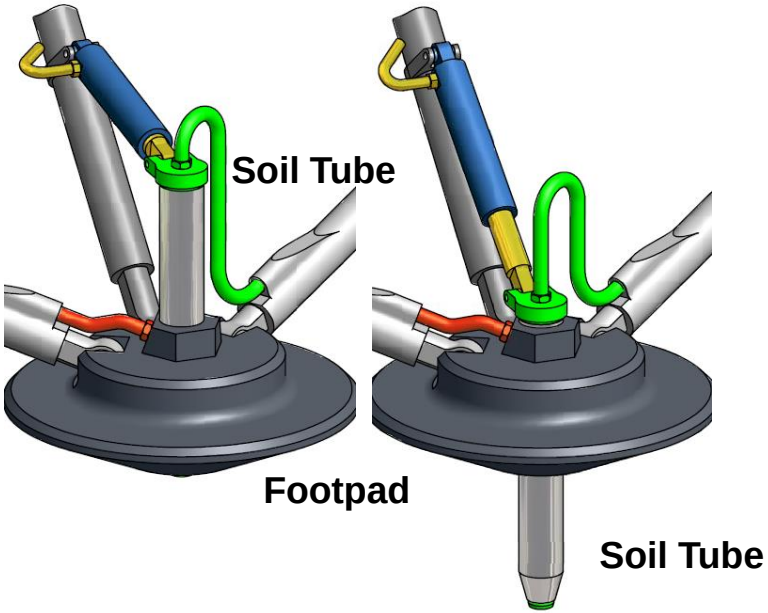
Sampling tube flush with the foot pad.

- Nozzle protected within footpad
- Near surface regolith only



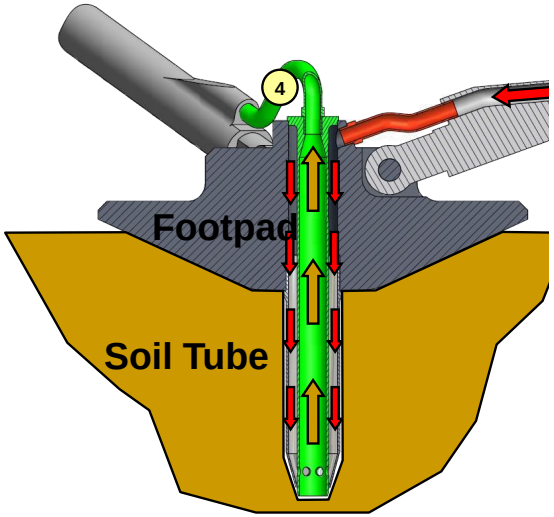
Sampling tube deployed after touch down

- Tube protected from bending during landing
- Deployed by a passive system (gas, spring)
- Soil within the tube is transported
- Possibility of capturing small rocks



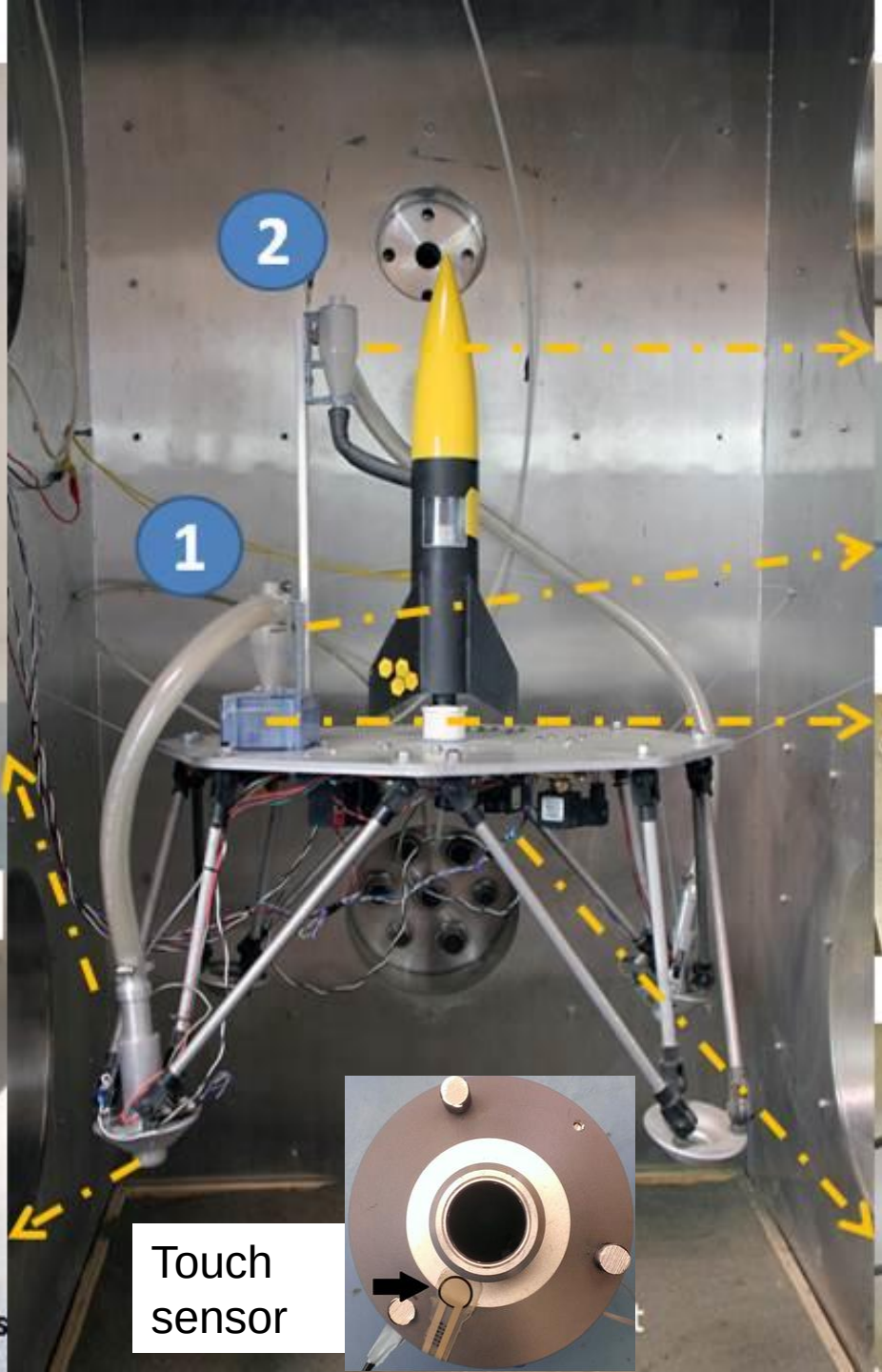
Sampling tube fixed below the foot pad

- Simplest option (no tube deployment)
- Horizontal velocity must be zero
- Possibility of capturing small rocks

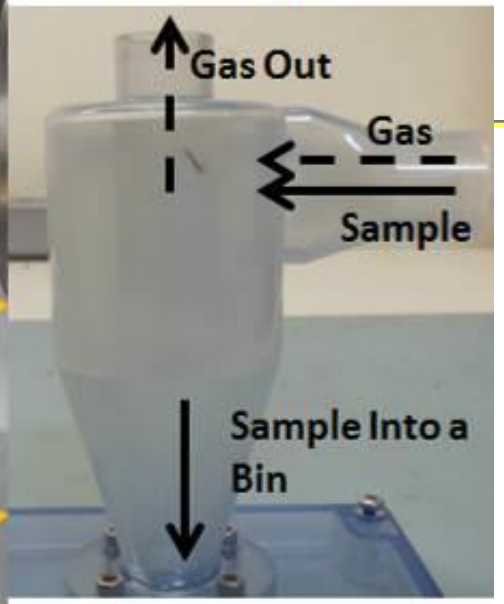


Sample Tube Assembly

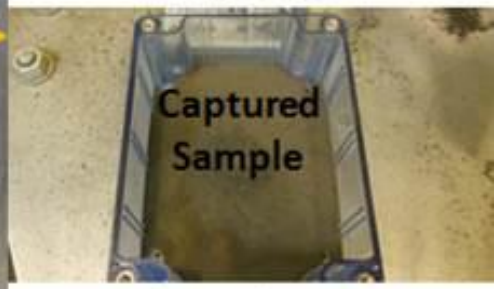
Sample Tube



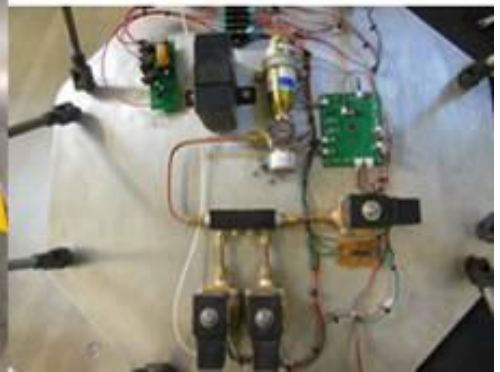
Cyclone Separator



Soil Bin

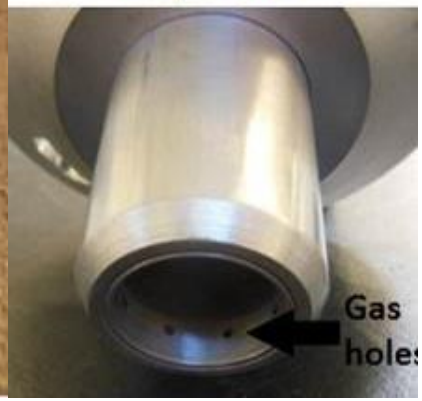


Controls and Pneumatics

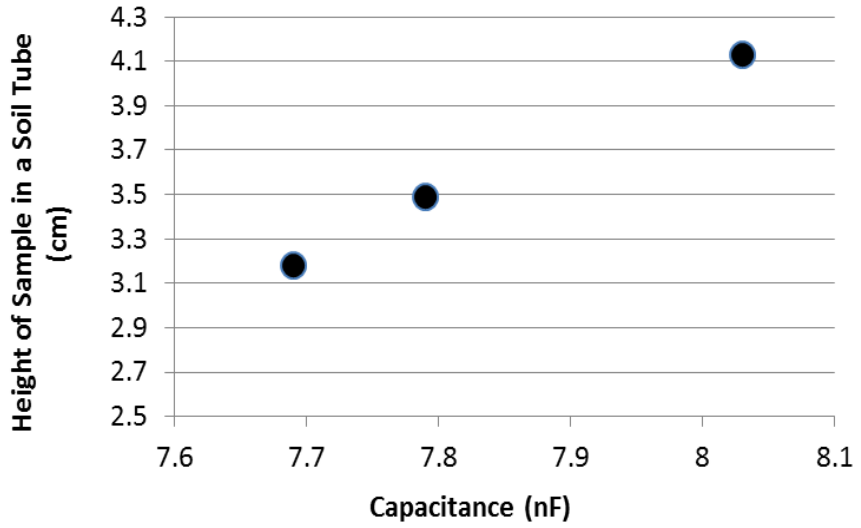


Measuring soil volume

Sample Tube

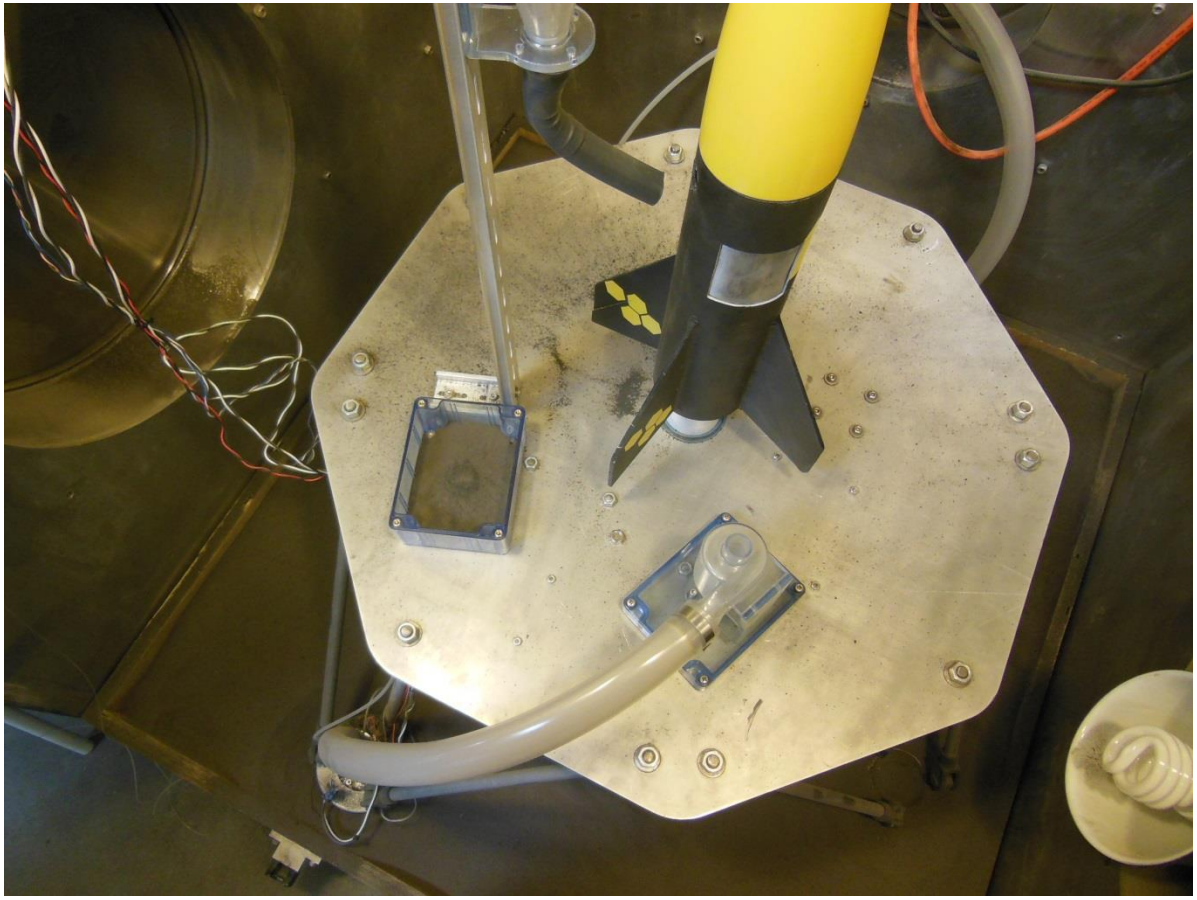


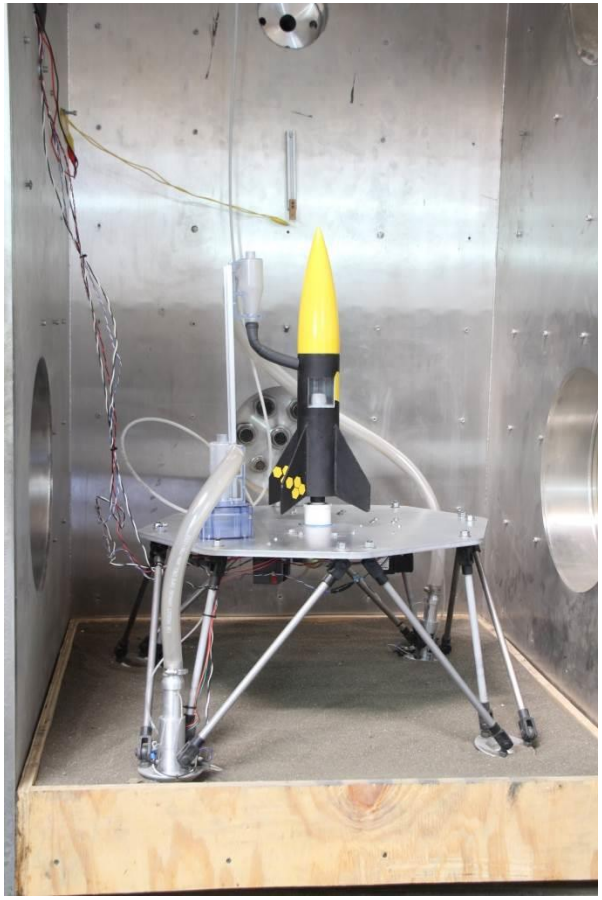
Regolith Type	Height of sample in Tube (cm)	Capacitance (nF)	Captured mass (g)
MMS	3.18	7.69	26
MMS	3.49	7.79	25
MMS	4.13	8.03	24



Results

- Higher gas pressure resulted in more sample
- Average sample mass captured: 20 grams
- Average gas mass at 160 kPa: 0.02 gram
- 1 gram of gas at ~160 kPa could loft over 1000 grams of soil



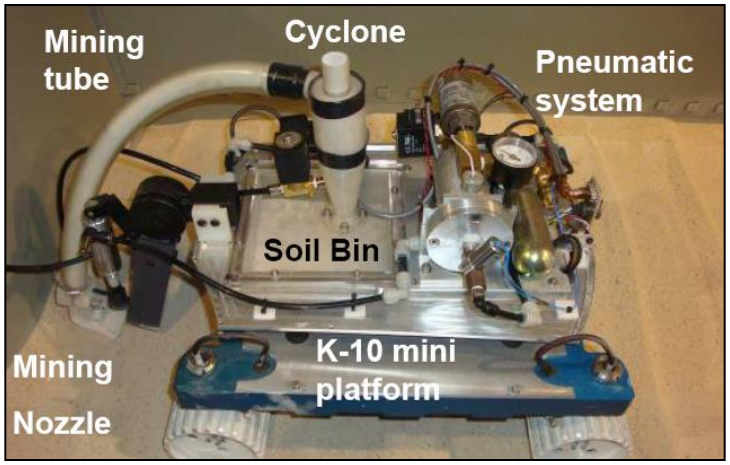


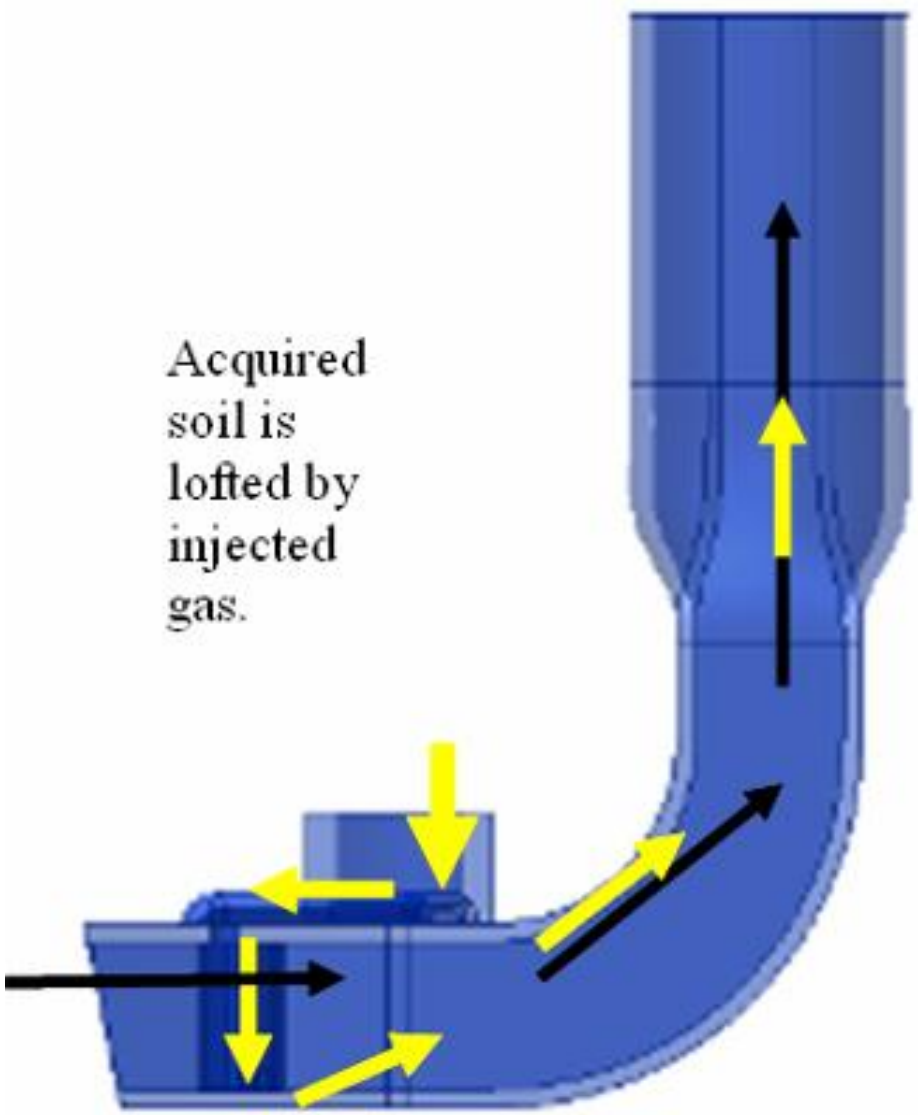
https://www.youtube.com/watch?v=DjJXvtQk6no

Rover based pneumatic systems

Pneumatic Excavator

- Vacuum cleaner-like nozzle is dragged behind a rover and acquire regolith
- A puff of gas lofts the regolith into a soil bin/ISRU plant via cyclone separator
- Possibility of sorting (lofting finer fractions only)
- Simple and Robust
  - No moving parts (drag a nozzle behind a rover: like a vacuum cleaner)
  - Well suited method for very abrasive lunar soil
- Deployed on 10kg K10 mini





• 10ft long GRC-1 lunar simulant bin
• Vacuum

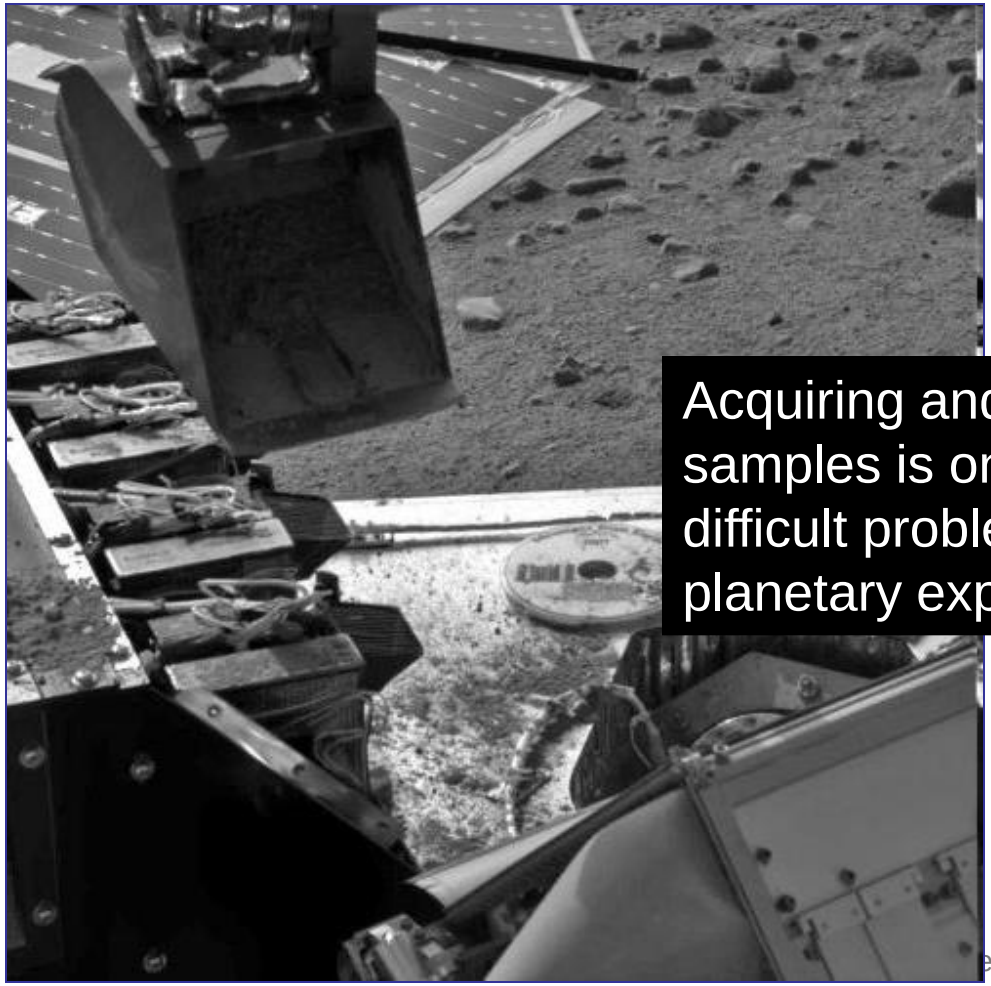
Pneumatic Scoop

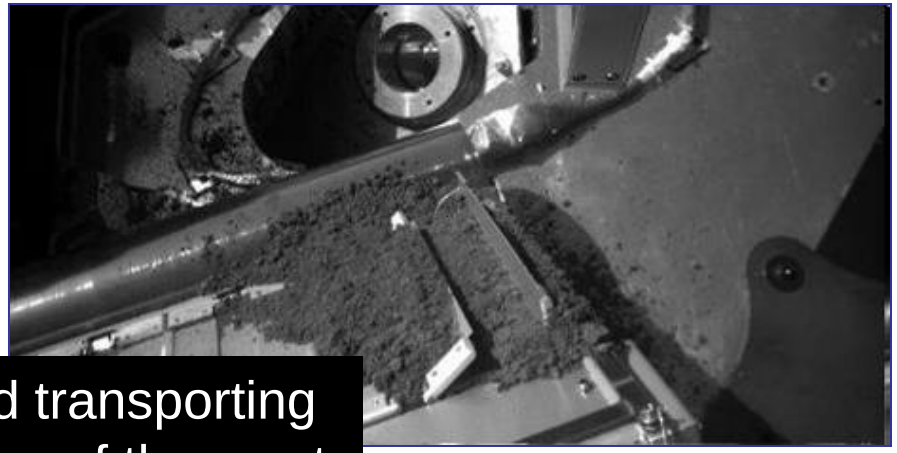
Experience from Mars Phoenix

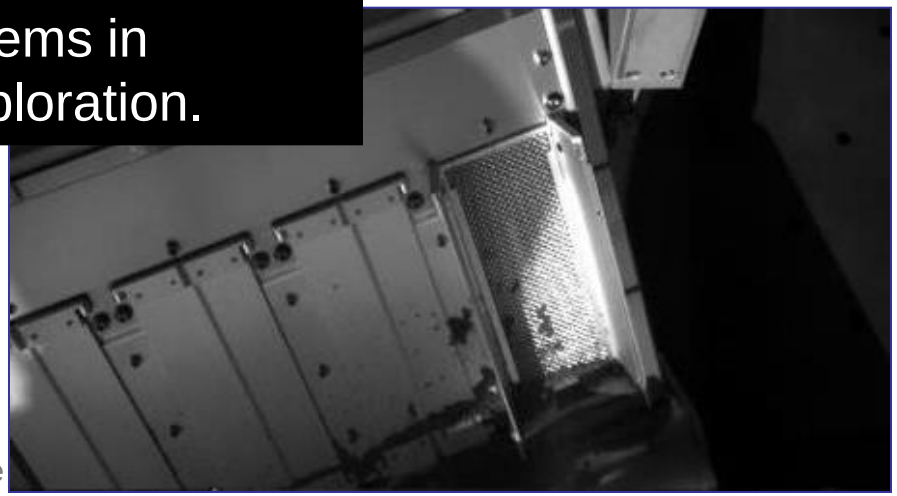
HONEYBEE ROBOTICS

1. *Robotic Arm scoop positioned over the Wet Chemistry Lab delivery funnel. Note the soil all over the place!*

2. *Either too much or too little delivered onto TEGA screens. Sample had hard time passing through the screens.*







Acquiring and transporting samples is one of the most difficult problems in planetary exploration.

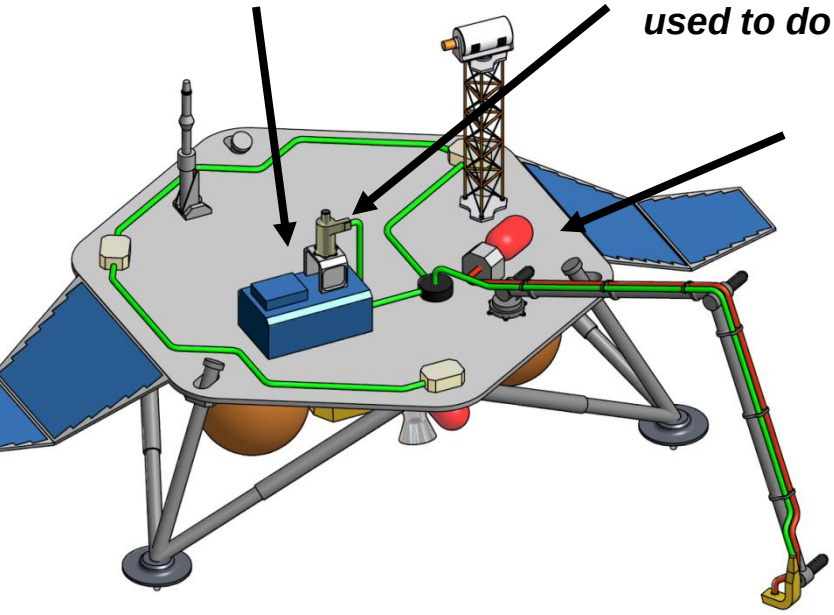
Pneumatic Scoop

- Sample is lofted directly into instrument.
- Pneumatic particle sorting without sieves (no clogging)

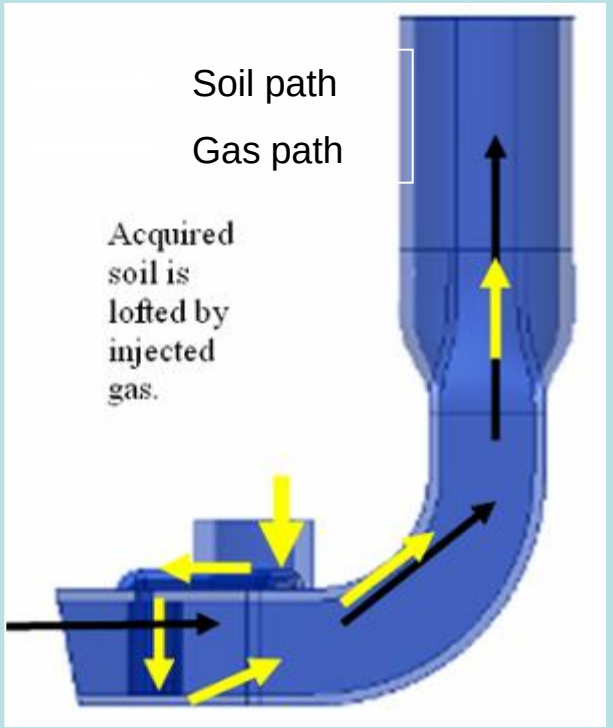
Science instrument or processing plant.

Cyclone soil separator can be used to do particle sorting.

Gas can be supplied from Helium pressurant tank used to pressurize propellant.



Principle of Operation



Acknowledgements

- NASA SBIR
- The Planetary Society

Thank You

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