APPLICATIONS OF BURROWING MOLES FOR PLANETARY AND LUNAR SUBSURFACE ACCESS.

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Introduction: Well established techniques are available to geologists, environmental specialists, geotechnical engineers, and construction professionals for scientific and engineering characterizations of the Earth's soil. Drilling and excavation are the two of the most common approaches which enable investigations of any size. In these cases power, mass, and volume are usually not drivers; reasonable pre-estimates of operating conditions can be made; and direct human control is the norm. For planetary and lunar investigations, power, mass, and volume are severely limited, and, in the near term, robotic operations will be used. Furthermore, the environments that will be encountered are harsh and initial pre-estimates for the mechanical properties of the regolith and rock are difficult due to limited databases and earth analogs. Mechanical advantages required for heavy regolith movement, such as drilling are much reduced due to the lower gravity fields, 16% g on the moon and 38% g on Mars.

A method of subsurface access in regolith using compact, light-weight, low-power devices is needed. For planetary and lunar regolith investigations, mineralogy assaying; water content determination; definition of engineering properties; and quantification of radiation shielding capabilities are high level goals. Burrowing moles, such as the Mars Underground Mole (MUM), developed under NASA's Mars Advanced Technology Program can efficiently address these objectives. MUM is a burrowing mole that uses an internal hammering mechanism to move forward by compacting soil. The mechanism design is an extension of the PLanetary Underground TOol (PLUTO) developed for the Beagle 2 mission [1]. We are developing MUM for planetary subsurface sampling and in situ sensing applications targeted to future Mars and/or Lunar missions.

The MUM body is a pointed slender cylinder that advances into the soil by way of an internal sliding mass mechanism. Part of the energy released by a spring-loaded hammer is transferred to the mole casing with each trip and from there to the regolith, generating displacement. The MUM achieves forward or reverse hammering, and can also open a chamber to collect a sample using a single motor. Additional support components, that are mounted on the surface deployment station, include a launch guide tube, a tether reel/winch, and support power and electronics systems. Deployment stations may include fixed landers or mobilized rovers. Using the tether reel, the mole can be repeatedly deployed and retrieved. The number of deployment cycles is limited only by mechanism wear. Figure 1 shows MUM incorporated onto a rover. Moles are exceptionally attractive for rover application as compared to drills because they do not require any reaction mass from the surface platform and they can be of sufficiently low mass that they represent a single payload element of a rover. For example, MUM weighs only 2 kg. The even smaller PLUTO system weighed less than 0.5 kg.

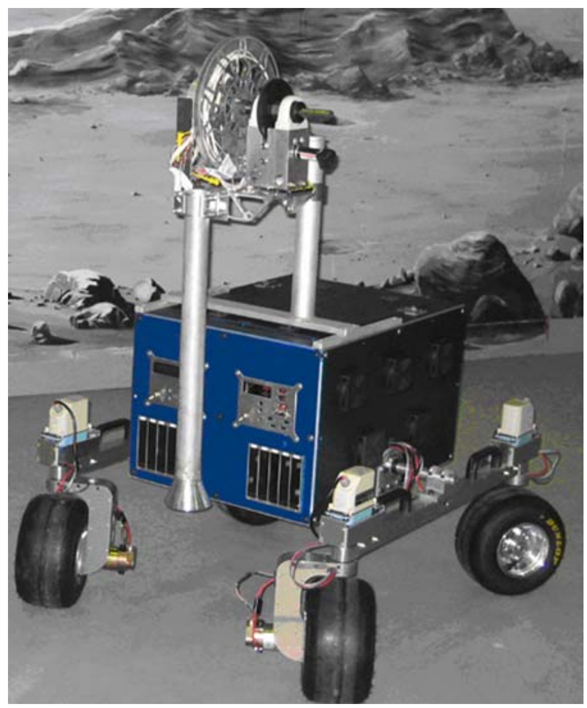

Figure 1. MUM launch tube and tether reel integrated onto the K10 rover.

The MUM prototype can penetrate to a maximum predicted depth on Mars of 5m. In terrestrial laboratory tests it has achieved a penetration rate of 10cm/hour with an average power consumption of 10w while burrowing in sand. For mission applications, power, mass, volume, payload integration, and operating speed are variables. For example, in certain applications, such as the case where the mole and its deployment station may be operating in a permanently shadowed region of the moon, where solar power is not available, higher speed or reduced mass operations may be necessary in order to minimize resource requirements.

Moles can be used for sample collection, and to obtain in situ measurements. MUM has been designed to incorporate light collection optics in a shock mounted subsurface chamber fitted with a Sapphire window. Fiber optics located in the tether transmit light from a surface illumination source and reflected light to a surface detector. Raman spectra are obtained using a Laser for the illumination source, and a Raman spectrometer for the detector. Reflectance spectra can be obtained by using a light illumination source and a spectrometer to analyze the retuned signal. Other downhole instruments can be incorporated for in situ sensing. For example, an x-ray fluorescence instrument has been proposed for incorporation into a small burrowing mole in a proposal to the 2009 Mars Science Lander mission [2]. The mass, volume and power parameters for burrowing moles are scaleable and adaptable to specific applications and operating environments. Figure 2 shows the concept for a mole that both collects in situ observations subsurface and collects samples.

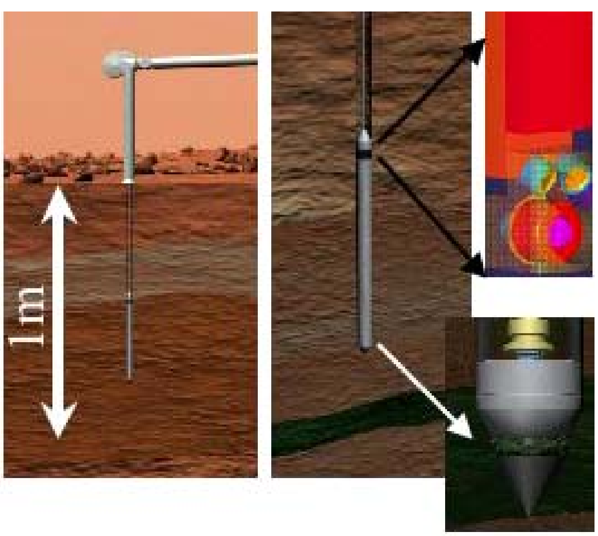

Figure 2. Mole moves subsurface (left), at depth of interest (middle) it collects sample in its tip (lower right). The in situ sampling instrument illustrated occupies a compartment in the rear of the mole (upper right).

References: [1] Richter L., et al. (2002) Development and testing of subsurface sampling devices for the Beagle 2 lander. *Planetary and Space Science*, *50*, 903-913. [2] Richter L., et al. (2004) MOCSS – Mole for soil compositional studies and sampling. *Submitted as proposal to Mars Science Lander Opportunity*.