THE SCARAB ROVER AS DESIGNED FOR LUNAR SCIENCE AND RESOURCE EXPLORATION.
P. W. Bartlett,[1,2] D. S. Wettergreen[1], and W. L. Whittaker[1], [1]Robotics Institute, Carnegie Mellon University; 5000 Forbes Ave.; Pittsburgh, PA 15213, [2]paulbartlett@cmu.edu.

Introduction: The theory, evidence and interest in exploring the lunar cold traps are well established [1]. Finding and analyzing water ice and/or other volatiles at the poles would have a major impact on lunar and solar system science and provide a basis for in situ resource utilization for extended presence on the moon [2].

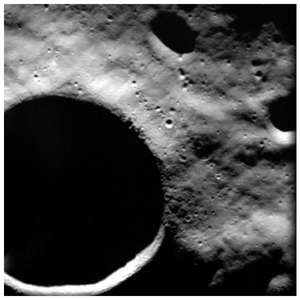

Figure 0: SMART-1 image of Shackleton Crater

To adequately survey the floor of a shadowed crater for in situ evidence, a surface vehicle will be required to support an advanced sampling and sensing payload. The vehicle must provide mobility over the scale of tens of kilometers through regolith slopes and rock fields. Due to the nearly absolute darkness the vehicle must navigate through this terrain using unique sensing methods. And to perform the exploratory tasks, the vehicle must support a payload of instrumentation and, most likely, a drilling system to acquire subsurface samples for analysis.

A team at Carnegie Mellon University's Field Robotics Center is developing the Scarab rover to answer to these requirements, in collaboration with the NASA Glenn Research Center, Ames Research Center, Johnson Space Center, and the Canadian Northern Centre for Advanced Technology (NORCAT).

In the summer of 2007 the primary integration of Scarab, as seen in Figure 2, was completed. Field experiments and laboratory characterization are currently underway, along with continued hardware and software development.

Vehicle design: Scarab was designed directly around the task of drilling on the moon [3]. The ~1 m depth, ~3 cm diameter class of drill served as the design case, with the NORCAT drilling and sampling system as a reference. Given the amount of downward force required for drilling in this class, and the need for a stable platform, a vehicle weight of at least 400 N is required. Due to the lunar surface gravity, a vehicle mass of at least 250 kg is required.

The current prototype of Scarab is roughly 280 kg. Its footprint is just under 1.5 m square. The wheel diameter is 65 cm and traverse speeds range from 3 – 6 cm/s. Power is provided by a supply that simulates the output of a 100 W continuous Advanced Stirling Radioisotopic Generator.

The main challenges for such a cold trap surface vehicle are driving, drilling and darkness. While the requirements for driving and drilling contradict each other in many regards, the vehicle configuration arrived upon serves as a complimentary solution.

Scarab addresses the darkness by designing towards a radioisotopic power supply, a thermal management system that puts the power supply's waste heat to use, and active means of navigation and localization such as laser scanners and gyroscopes. Scarab addresses the drilling challenge by designing the rover configuration around the drill, and providing enough weight for it to operate reliably. And lastly, Scarab addresses the driving challenge with a strong, slow and simple approach that will enable large areal surveys of a crater floor and also access to desirable science targets otherwise inaccessible due to rough terrain and steep slopes.

Figure 2: Photograph of Scarab on a cross-slope

Driving: Scarab's four wheels are each independently driven by actuators in the hubs. The suspension that allows the four wheels to match the shape of the terrain is simple, passive and highly agile. The left pair of wheels is on one rocker and the right pair is on another. A bar linking across the body allows the two rockers to pivot, matching the wheels to the terrain. This linkage arrangement makes driving a relatively simple task to command, lets the rover drive across very rough terrain, and smoothes the motion that the chassis and all of the sensing instrumentation go through. The suspension also provides a highly stiff, stable platform for drilling.

Much of the novelty in Scarab's design lies in its ability to actively reconfigure its suspension. As seen in Figure 3, Scarab can pinch its rockers in and lay them out flat, varying the height of the body. This capability first allows for the rover to kneel down to the surface for the drilling to operate. Second, the rover can vary its belly clearance and center of gravity height during driving. And third, the rover can vary the rockers independently to lean into cross-slopes, as shown in Figure 2. The benefits for mobility are becoming more and more clear with field testing. The effect is a rover that can access rougher terrain and steeper slopes, recover from difficult driving conditions and support heavy work tasks and sensing in situ.

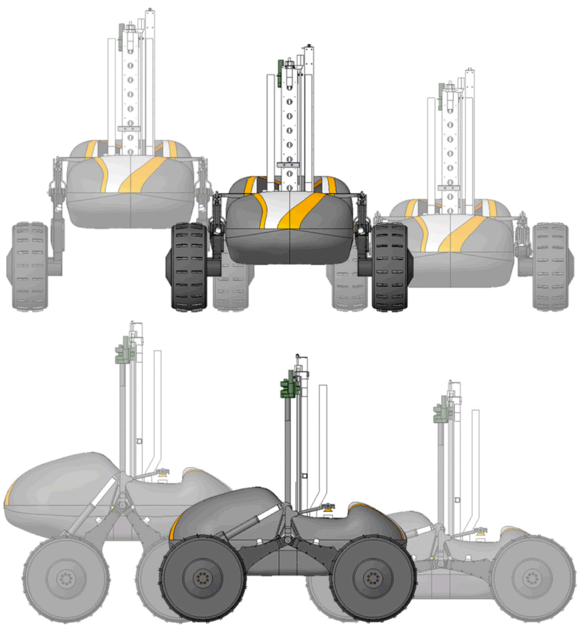

Figure 3: Schematic of Scarab in its range of suspension heights

Drilling: The central chassis connects between the two suspension rockers and forms an open payload volume at the vehicle's center. This volume is open to the ground as well as upwards giving the body a donut topology. The drill benefits from mounting directly to the rover's high stiffness chassis and suspension system. A pair of masts extend upwards to structurally support the drill's linear stage and to mount navigation sensors and antennae. Since the current vehicle prototype was tasked with investigating driving and drilling, no sample processing and analysis systems have been incorporated. Near term plans involve the inclusion of sample crushing and transfer to an oven and instruments to sense for volatile content and to extract oxygen. A demonstration would then follow of the extended payload performing end to end at a lunar polar crater analog field site.

Adapting for missions: The essence of Scarab's design is its suspension configuration. Without the body in place, Scarab can drive in its skeletal form of chassis, suspension and wheels. The design of the skeletal form and body can be adapted and scaled to a range of payloads. Analytical instruments and processing devices of varying scales can be accommodated, as can a range of devices performing mechanical work on the ground such as drills, penetrators and samplers.

Other possible work tasks could include infrastructure building such as tether deployment and beacon emplacement. In all of these cases, the work device becomes the starting point around which the skeletal form is then adapted. The requirements of the device would be met and much of the Scarab design heritage would follow through.

References: [1] Spudis, P., "Ice on the Moon" (2006) *The Space Review*. [2] Sanders, G.B., Chair, "NASA In-Situ Resource Utilization (ISRU) Capability Roadmap Final Report" (2005). [3] Bartlett, P. W., et al., Design of the Scarab Rover for Mobility & Drilling in the Lunar Cold Traps (2008) *i-SAIRAS*.