THE AXEL ROVER: A NOVEL PLATFORM FOR INSTRUMENTS MAKING MEASUREMENTS IN EXTREME TERRAINS. L. Kerber[1] , I.A. Nesnas[1] , [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109 (kerber@jpl.nasa.gov).

Introduction: Many interesting geological exploration targets exist in regions with steep and rough terrain, such as impact crater walls, lava tube skylights, volcanic pit craters, chasms, graben, and fissures. Unfortunately, these places are often out of reach for traditional rover concepts. The Axel rover is a platform that can navigate difficult topography and steep slopes, allowing it to carry a wide variety of instruments to a new array of target sites. The Axel rover consists of two wheels connected by a thick axle containing a winch and a tether [1]. Two Axels can be combined to form a "DuAxel" (**Fig. 1**), or one Axel can replace an axle on a more traditional rover body [1]. Over flat terrains (for example, from the landing site to the investigation area), Axel rover can traverse just like an ordinary rover. Across rough terrain, Axel rover can maneuver across large rocks up to one wheel radius in height. Once it approaches a steep section, the Axel rover can set an anchor and rappel down the steep slope by letting out the tether stored inside the axle [1; **Fig. 1**].

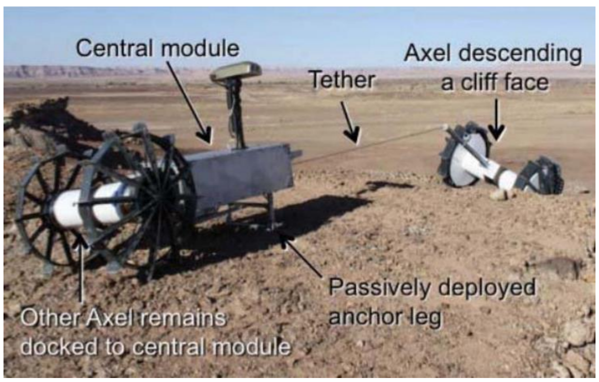

Figure 1. The DuAxel rover configuration at work in the field (figure from [1])

This functionality allows the rover to descend steep to vertical slopes (and ascend them again). The rover can even dangle in free space and continue to let out its tether. The rappelling module is symmetrical top to bottom, allowing it to flip over while navigating steep terrain and remain operational. The rover can communicate through its cable, alleviating common communication problems facing other extreme terrain robots. The rover can also receive power through its tether, meaning that it could leave a solar panel on the surface and still receive power to explore a dark cave or permanently shadowed crater below [1]. At the edge of a steep slope, the Axel rover can anchor itself in the regolith and rappel down the side of the slope using its tether for support, communication, and power. Axel has undergone extensive testing in terrestrial desert environments on steep slopes and various rock types [1].

Figure 2. The Axel rover taking spectroscopic measurements on a slope of 40º (figure from [1]).

Possibility for Carrying Scientific Instruments: Axel can carry scientific instruments in the 8 instrument bays contained within its wheel wells (16 for a DuAxel). When Axel stops, the instrument comes out of the bay and makes a measurement (**Fig. 2**). Before moving again Axel can independently rotate its wheel well to access all of the other instruments in that wheel for collocated measurements of the same target [1]. The Axel wheel can also make a trench in the surface to expose fresh regolith to the instruments. The location of the instruments inside the wheel of the rover protects them from rocks, dust, and falling debris. In addition, whether used as an addition to a traditional rover, or as part of a DuAxel configuration, Axel could scout for interesting targets and collect samples to be carried back to heavier or bulkier instruments located on the main rover body. Commercial off-the-shelf instruments that have been successfully integrated into the rover wheel payload space include a microimager, a miniature spectrometer, and a thermal probe [1].

Moon Diver: A Sample Axel Mission Concept

The lunar mare basalt deposits serve as natural probes into the lunar interior. Recent images returned by the Kaguya and Lunar Reconnaissance Orbiter missions have revealed the presence of deep mare pits containing meter-scale layer stratigraphy exposed in their walls ([2-

4]). Such an exposure would offer a wealth of information about the compositional, petrologic, and emplacement conditions of the mare basalts through time. While normal rovers would not be able to reach these layers, the functionality of Axel rover would allow a mission to examine and characterize the lava layers exposed in the wall of a mare pit crater during abseil descent [**Fig. 3**; 5]. Mineralogy (provided by a VIS/NIR spectrometer), texture (provided by a microimager), elemental chemistry (provided by an X-ray spectrometer), and age (provided by a mass spectrometer situated on the main rover body) would reveal the evolution of the mare lavas through the section. Axel's onboard cameras could record layer thicknesses and document the presence and characteristics of intervening regolith layers. Once on the floor of the pit, the Axel rover could continue to explore. If the pit opened into a lava tube or other subsurface void, the rover could attempt to negotiate the floor up to the length of its tether (currently 250-300 m, potentially up to 1 km; [1]). After exploring the pit, the rover could reel itself back up the wall and either continue roving across the surface or rappel down a different side of the pit.

The Axel rover provides enhanced mobility which would enable it to land, rove to a pit, cave, cliff, or slope, approach the science targets, explore with a suite of high-priority science instruments, and exit, all with existing or highly developed technologies. This approach would revolutionize our capability to carry diverse instruments to many previously inaccessible terrains on a variety of planetary bodies.

References: [1] Nesnas, I. et al. (2012) J. of Field Robotics, 29, 663-685. [2] Haruyama, J., et al. (2009) GRL 36, L21206 [3] Robinson, M.S. et al. (2012) PSS 69, 18- 27. [4] Wagner, R.V. and Robinson, M.S. (2014) Icarus 237, 52-60. [5] Kerber L. et al. (2016) LPSC 47, Abs. 2969.

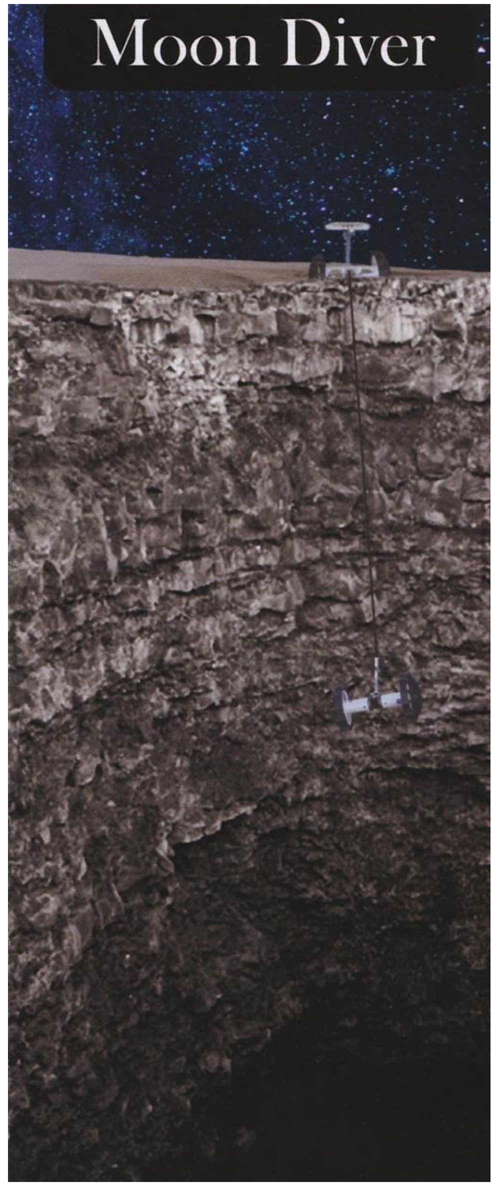

Figure 3. A mission concept using Axel rover's capabilities to bring instruments into a volcanic pit crater on the Moon [5].