**TOWARDS ROBOTIC EXPLORATION OF EXTRATERRESTRIAL CAVES – THE FIRST IN-CAVE TESTS OF THE DLR SCOUT ROVER.** R. Lichtenheldt[1] and M. Schütt[1] and D. Franke[1] and A. Pignede[1], [1]Institute of System Dynamics and Control, German Aerospace Center (DLR) (Roy.Lichtenheldt@dlr.de; Münchener Straße 20, 82234 Weßling, Germany).

**Introduction:** Caves are among the last white spots on our maps. Even on Earth there are still many caves yet to be explored and are of special interest for geology and hydrology. On other planetary bodies, e.g. Mars and Moon, these cavities might even provide shelter to future human explorers. Additionally, caves are of great interest for planetary sciences. They do not only allow for geological insights and measurements of possible habitability, but also to check Martian lava tubes for one of humanity's oldest questions: Did any life exist outside of our own planet?

On Earth, unknown caves are explored by humans due to their superior adaptability and locomotion skills. The high risks imposed on the explorers are mostly overcome by specialized equipment and rigging [1]. For extraterrestrial cave exploration, the required life support units even increase the ordeal for human explorers. Moreover, high costs as well as technological challenges prevent from any near future manned exploration missions.

Hence, robotic explorers are the only feasible way for first explorations of extraterrestrial caves. For this purpose, a mission concept for robotic cave exploration, centered on the DLR Scout rover was developed as introduced in [2]. This article will focus on the testing, preparation, execution and results of the first in-cave test of the Scout rover.


**Figure 1***: Setup of the rover in the cave, photo courtesy of Sarah Lichtenheldt*

**The Rover** is designed to be as robust as possible and only as complex as needed. Therefore, a modular design of the mobility system was selected. Each module consists of a body with two flexible rimless wheels [3]. The modules are connected with compliant vertebrae. In this configuration, the system is able to perfectly adapt to uneven terrain. Since the individual wheels are not steerable, vehicle steering is achieved by the skid steering method. Its main characteristics are shown in Table 1, while the rover is shown in Figure 1.

**Table 1:** *Characteristics of the Scout rover*

| | |
|---|---|
| Rover mass | ~18kg |
| Payload capacity per aux module | >6kg, 5l volume |
| Maximum speed | ~1.7m/s |
| Max. obstacle height | >400mm |
| Tested drop height | >1.5m |
| Battery runtime (Li-Ion) | ~10h |
| Size of the rover | 1.0 x 0.5 x 0.4m |

Dropping the rover off ledges is normal operations by design. It survives drops of >2m on flat surfaces and >10m in sloped and stepped terrain [4]. This is of major importance to enter most skylights of lava tubes on Mars and Moon without the need of complex tethering technologies. The mission will be one way, solely relying on battery power in-cave and sending data out via communication relays [2].

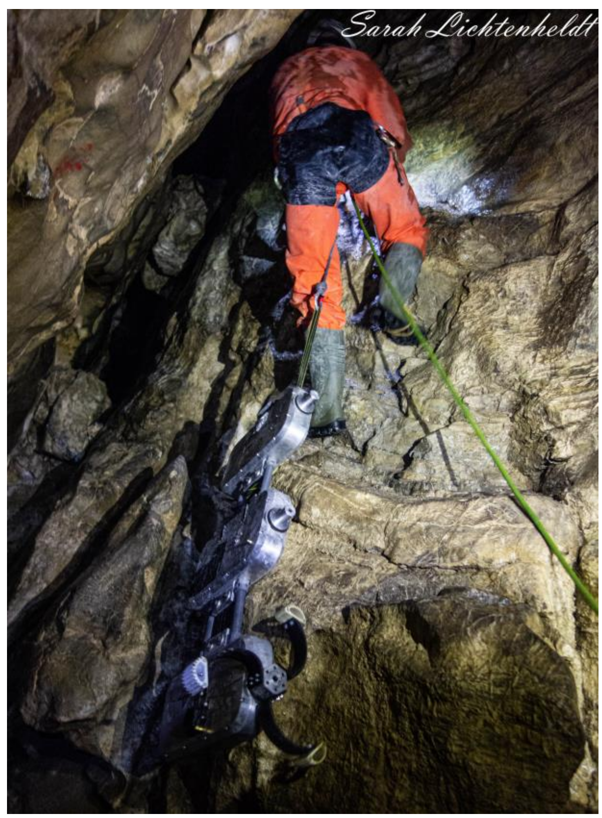


**Figure 2***:* Transport of the rover on rope through pits, photo courtesy of Sarah Lichtenheldt

**Preliminary testing** Before conducting tests in vulnerable cave environment, pre-tests have been performed in a testbed that is built as an on-surface lave tube equivalent. It features break down structures made of basaltic rock, as well as slopes of 30° and several step-type obstacles. The testbed mainly aims at testing the required obstacle traversability and robustness of the rover before heading to expedition terrain. An additional test opportunity, in particular drop test in craters, has arisen by the involvement of the Scout rover in the Arches analog mission on Mt. Etna.

**Cave test preparations** included finding a suitable spot to test the rover while not disturbing the cave fauna. As an additional fact, a cave with intermediate difficulty level would be beneficial to include non-speleologist staff for the tests. In order to also keep transportation effort at a minimum, a local limestone cave, surveyed by the main author, was chosen. The terrain in the main gallery is fairly similar to “Aa” lava tubes, despite the small river flowing through it.

**Figure 3**: *Scout rover driving through terrain of typical roughness along its cave path , photo courtesy of Sarah Lichtenheldt*

In order to deploy the rover at the test spot, it had to be carried to the cave and to the main gallery due to cave conservation considerations. Hence, it needed to be carried on rope in some short pits.

**Test setup:** The rover was brought to the end of a bigger water passage, locating the control center in the same chamber. The intended path in the cave led through a narrow river passage, just as wide as the rover and thereafter over several steps of ~40cm each. Surpassing this next chamber another stepped narrow passage had to be overcome. The overall distance in the cave is roughly 50m. The rover was teleoperated from the starting chamber throughout the whole test using the onboard camera and lights of the rover.

**Results:** Setting up took a bit longer than expected, due to the lack of simple conveniences (e.g. tables) that would have simply been too heavy or too big to take them for the tests. The rover itself coped with the obstacles pretty well. In the narrow passages, the wide angle of the used onboard camera allowed to fluently navigate the rover. Surpassing the obstacles was also fluent, while turning on larger boulders slowed the overall progress. The biggest surprise was, that even though the rover went around several turns and through narrow passages, the signal reception was more than sufficient, even without the use of relay stations.

The end of the test was solely due to a depleted laptop battery on the control side, which did not seem to cope with the temperatures and humidity very well. A spare was not available due to weight limitations.

As a conclusion, we draw that preparation is vital in terms of the rover, practicing anticipated obstacles, but also for things as simple as a spare battery of a laptop.

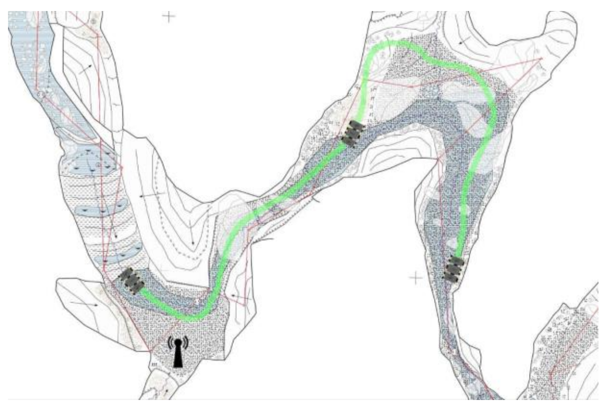

**Figure 4**: *Path of the rover through the cave, the antenna symbol denotes the operation station, while the green path is the track of the rover, map courtesy of Dr. R. Lichtenheldt*

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**References:** [1] Marbach G. and Tourte B. (2002) Alpine Caving Techniques [2] Lichtenheldt R. et al. (2021) *A MISSION CONCEPT FOR LAVA TUBE EXPLORATION ON MARS AND MOON – THE DLR SCOUT ROVER. 52nd LPSC,* Abstract #1443. [3] Stubbig L., Lichtenheldt R., Becker F., Zimmermann K. (2017), Il. Sci. Coll. 59