GLOBETROTTER: AN AIRBAG HOPPER FOR MARS SURFACE AND PIT/CAVE EXPLORATION.
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Summary: GlobeTrotter is a concept for a universal airbag-based robotic hopper for rapid, robust, and low-cost exploration of the surface and subsurface (pits, caves) of the Moon, Mars, Phobos, Deimos, and other small bodies. This paper presents an application of GlobeTrotter to Mars exploration, in particular as a versatile scouting capability in support of planning future human Mars exploration.

Introduction: To date, less than 0.0001\% of the 144.8 million km\textsuperscript{2} of Mars’ area has been explored from the surface. Vast tracks of Martian highlands and lowlands, including discrete regions and features such as impact basins and craters, canyons, giant volcanoes, pits and caves, and circumpolar terrain, remain unexplored from ground level. In efforts to minimize mission risk, surface landing sites accessed to date have been restricted to areas that are low in altitude, topographically benign at large scales (hm to km), and also relatively smooth at small scales (m to dm). While such mission constraints are appropriate for the earliest stages of robotic planetary reconnaissance, their limiting effects may be increasingly felt as access to sites presenting greater scientific interest but also greater challenges to wheeled roving, is desired.

The limits of conventional rover approaches to surface exploration are particularly clear when considering the growing need to explore steep-walled and rough-terrained features such as canyons, valleys, graben, fresh craters, and pits, all of which are among high-priority and still unexplored targets on Mars. Chaotic terrain, deflated terrain, dunes fields, hummocky terrain, and other uneven surfaces are generally considered hazardous and are usually avoided; yet they are considered to be of great scientific interest to explore in-situ as well.

While aircraft such as fixed wing airplanes, rotorcraft, and thrustered drones \cite{1} are anticipated to have an important role to play in Mars exploration in future, a more robust, rapid, low-risk, low-cost, and “all-terrain” approach to robotic ground and underground exploration is needed.

Programmatically, the current pace (in terms of average linear mileage per year) at which the surface of Mars is being explored also appears slow in contrast to NASA’s driving goal of achieving human missions to the surface of Mars by the 2040s. It is anticipated that there will soon be a need to efficiently scout out and validate, with limited mission development time and at reasonable cost, a relatively large number of landing site (LS) and exploration zone (EZ) options, well in advance of the first human landed mission.

Figure 1. GlobeTrotter on Mars.

New Approach: GlobeTrotter is an airbag-based robotic vehicle that could robustly and quickly explore vast areas of Mars via thrustered “leaps and bounds”, tolerant to high terrain roughness, and using slopes for controlled tumbles downhill (Fig.1). The approach emphasizes areal coverage (range) and access to extreme terrain (trafficability) while offering diverse science focus options (mission versatility). GlobeTrotter could also drop into pits/caves, hop around inside, and fly out of them again (Fig. 2).

Payload: GlobeTrotter’s payload, while limited in mass, volume and power, will enable missions of compelling scientific merit. Core instruments include:
- Color Imaging System (CIS), a multidirectional array of small RGB color cameras for science (geology, atmosphere), H\textsubscript{2}O-ice prospecting, navigation, and hazard avoidance, with LEDs to image shadowed areas - including caves - and optionally at night.
- Neutron Detector (ND) to measure regolith bulk composition and hydrogen abundances at spatial resolutions of 1-10 m for science (geology) and resource prospecting (OH / H\textsubscript{2}O ice).
- Accelerometry to reconstruct attitude, position, and speed vs time, and map slope profiles in-situ.

Depending on mission goals, other low mass/volume/power payloads may be considered.

Pit and Cave Exploration. Pits and caves on Mars present unique opportunities for science and possibly for resources and logistics as well. To date, over two dozen pits and candidate pits have been identified on the flanks of Mars’ giant volcanoes, and are interpreted as likely skylights giving access to lava tubes [e.g., 2]. Subsurface cavities on Mars are of interest to science as they represent near-surface environments that are sheltered from the full brunt of rigors in Mars’ surface environment, in particular from intense UV and higher energy ionizing radiation, micrometeoritic bombardment, wide diurnal temperature variations, dessicating and eroding winds, and to some extent, chemical alteration as well. Caves on Mars might also shelter volatiles accreted over time from exogenous sources (e.g. atmosphere directly, or indirectly via windblown snow), and in the case of caves in volcanic and other
thermally active regions, possibly from endogenous sources as well (e.g. volcanic or geothermal venting). Thus, caves on Mars represent high-value targets for both geology and astrobiology.

Beyond science, the potential that caves on Mars might accrete and harbor H₂O ice also makes them attractive targets as potential resource repositories. Caves are also commonly viewed as natural shelters that future Mars explorers might use, occupy, or settle, but their geotechnical properties and safety remains, at this point, unknown and must first be assessed.

Conventional concepts proposed for exploring pits and caves on the Moon or Mars (e.g. robotic rovers, walkers, danglers, direct landers) all face the major risk of having to interact with poorly known, likely rough terrain, as well as limited dwell times in cold, dark, and comms-denied environments. Globotrotter offers a robust, rapid, low-risk and low-cost approach to systematically exploring pits and caves with high efficiency and reliability (Fig. 2).

**Airbags:** GlobeTrotter’s airbag system may take one of several forms: a single expandable shell, a set of adjoining airbags, or an open airbag lattice. GlobeTrotter builds on NASA’s Mars Pathfinder and Mars Exploration Rover landing system heritage, but with a larger volume to mass ratio and lighter airbag materials robust against rapid leakage, punctures, and rips.

**Power:** GlobeTrotter is electrically solar powered.

**Propulsion:** GlobeTrotter uses gas thrusters for long-range leaps, and selective airbag “cinch & release” cycles for short-range displacements and attitude adjustments. It may also be allowed to tumble freely down gravity gradients. On Mars, thruster gas may be compressed CO₂ extracted from the Martian atmosphere.

**Communications:** Indirect to Earth via Mars orbital relay.


![Figure 2: Globotrotter Subsurface Exploration. Top: Pit crater “Jeanne” near Arsia Mons on Mars. Bottom: Globotrotter can target a pit, survey it via initial exterior over-bounces, drop into it, survey the underlying cave, and fly back out through cave apertures mapped during its entry and surveys.](image-url)