REFERENCE MISSION ARCHITECTURE FOR LUNAR LAVA TUBE RECONNAISSANCE MISSIONS.
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Introduction: The possibility for the existence of lunar lava tubes has been postulated as far back as the 1960's [1]. Basic principles for the existence of specific lunar lava tubes have been observed and a number of lunar subsurface voids have been discovered. The discovery by the science team of the Japanese Kaguya lunar sensing satellite of a "skylight" in the area of the Moon's Marius Hills region of Oceanus Procellarum, and the team's subsequent discovery of two other "lunar pits" at Mare Tranquillitatis, and on the lunar farside at Mare Ingenii are potentially important finds for the existence of intact lunar lava tubes [2]. An Indian lunar spacecraft, Chandrayaan-1, also detected with its Terrain Mapping Camera a buried, un-collapsed and near horizontal lava tube in the vicinity of Rima Galilaei [3].

The idea of utilizing lunar lava tubes for habitation protection is not new. The benefits of using natural caverns such as lava tubes on the moon as receptacles for habitation structures or as protective shelter has been around since at least 1985, when first proposed by Friedrich Hörz [4]. Most scientific and popular literature on the subject focuses on the benefits of their extremely favorable environmental conditions and the potential for savings of energy and mass in construction of habitation elements if a base were to be located inside a lava tube. However, prior to any emplacement of the first infrastructure elements to establish human activities and industrial operations in a lava tube, development of a mission architecture and technologies essential for the initial reconnaissance missions of site characterization are needed. Development of a mission planning architecture for reconnaissance missions of robotic and eventually human first contact with a planetary lava tube is proposed in order to get some understanding of the operational scenarios, technologies, and human and robotic performance feats associated with the first missions of planetary cave exploration, including techniques of entering and examining the features robotically and by astronauts.

Reconnaissance Mission Architecture: Operationally, major downsides for exploitation of lava tubes for both science investigations and habitability are issues of difficult accessibility to cave entrances or surface openings, and clearing of large amounts of rubble and debris for site preparation and leveling the floor. The recent lunar discoveries cited give some idea of the size and magnitude of the features. It is apparent from all cases observed thus far, traverses down cliffs of great depths of some 34 to 100 meters or more with difficult terrain are required for both robots and humans. Negotiation of steep slopes and the climbing in and out of a hole presents technology challenges for accessibility. Without advanced technologies and techniques for ease of ingress/egress at all stages of development, from reconnaissance for site characterization to infrastructure emplacement, locating a lunar base at the bottom of a pit may not be very economical from an energy point of view, since mass will have to be lowered and raised to the lunar surface.

Accessibility to cave approaches would require increasingly sophisticated ease of ingress/egress technology solutions for robots, crewmembers and ensuing emplacement of infrastructure elements.

The overall goal of establishing a reference mission reconnaissance architecture is to get some understanding of robotic and human first contact with a lunar lava tube for developing the technologies needed to support these activities. Basic scientific understanding of the features are needed, as well as engineering constraints for determing viability of potential human habitation and emplacement of associated infrastructure elements.

References: [1] Haliday, W.R. (1966), *Terrestrial Pseudokarst and the Lunar Topography*, Bulletin of the National Speleological Society, Vol. 28, No.3: 167-170. [2] Haruyama, J., et al. (2010), *New Discoveries of Lunar Holes in Mare Tranquillitatis and Mare Ingenii*, 41st Lunar and Planetary Science Conference. [3] Arya, A.S. (2011), *Detection of potential site for future human habitability on the Moon using Chandrayaan-1 data*. Current Science, Vol. 100, No. 4. [4] Horz, Friedrich, (1985), *Lava Tubes: Potential Shelter for Habitats*, in Lunar Bases and Space Activities of the 21st Century, W.W. Mendell, Editor, Lunar and Planetary Institute.