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ECONOMICAL LUNAR SAMPLE RETURN MISSION WITH SOIL PENETRATION DARTS

Abstract

Lunar exploration involves substantial financial implications due to the extreme environment of the Moon and the specialized equipment needed. Sample return missions, particularly interesting for both the scientific community and the industry, provide valuable insights into specific space environments. As commercial interest in lunar exploration grows, developing cost-effective and sustainable approaches to minimize sample return mission costs is crucial. This paper presents a novel lunar sample return mission architecture utilizing specialized impactors called Soil Penetration Darts (SPDs). This research represents a significant step towards cost-effective and efficient lunar exploration, paving the way for future in-depth studies of the moon and potentially other celestial bodies. The proposed mission consists of an Orbiter and multiple SPDs, each equipped with a modified sample collector capable of gathering soil samples and returning to the orbit. The SPDs, designed as spear-shaped impactors, are deorbited from the Orbiter to impact the lunar surface at high velocities. This approach enables the SPDs to penetrate deeper into the lunar surface than traditional drilling methods by harnessing their orbital velocity. This allows for the collection of both surface and deep-layer soil samples in less time and without additional power requirements. In a significant advancement from previous designs, the new sample collectors of the SPDs are now engineered to autonomously ascend to lunar orbit after sample collection. The explored design achieves this through a combination of auger movement and staged chemical propulsion. Once in orbit, the sample collectors are captured by the Orbiter and subsequently returned to Earth. This innovative mission design addresses the limitations of current lunar exploration missions by enabling deeper and more comprehensive exploration of the moon's surface geology at a reduced cost. The paper discusses the technical challenges associated with this mission concept, including the extreme mechanical and thermal environments generated by impact and the complexities of achieving lunar orbit post-sample collection. The paper presents engineering models, simulations, and optimization strategies employed to address these challenges and validate the performance of the proposed system. Additionally, the economic benefits of this mission design are explored in terms of its ability to perform sample return with less time and energy, and the potential for mass production of these generalized equipment for various potential missions. The paper concludes with a discussion of the additional space-sustainability issues of the mission in terms of space-debris and potential hazards of this concept in a well-developed lunar ecosystem.