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RECYCLING SPACE DEBRIS AS A STEPPING STONE TOWARDS A PERMANENT LUNAR PRESENCE

Abstract

This paper proposes the novel concept of recycling space debris as a means of supplying material resources for the establishment of a permanent Lunar presence while simultaneously cleaning up Earth's orbital environment. This expands the scope of traditional debris mitigation efforts, which focus only on removing debris. As a first step, the paper presents the creation of a space debris database. A novel classification is made to characterize space debris in terms of material resources and reserves usable for recycling. It is concluded that plentiful defunct upper stages currently drift in Geostationary Transfer Orbits (GTO), presenting substantial risk to other space assets. Their high relative metal content and elliptical orbits make these stages prime candidates for an efficient transfer to the Moon using an orbital transfer vehicle. But as various perturbations have shifted the orbits of upper stages in GTO over the years, the orbital transfer alignment is found to be a critical complexity for a recycling mission. Multiple mission scenarios are analysed from debris capture to processing on the Lunar surface. The total energy expenditure across the entire mission is used as a novel tool to characterize and compare these scenarios to one another and to the alternative: a direct material delivery mission featuring ESA's Argonaut lander. By harnessing the unique advantages of electric propulsion, this paper shows that the concept of recycling defunct rocket stages is both feasible and viable. A direct, single-target recycling mission shows potential to require 30% lower energy investment per kg of raw material delivered compared to a standard lander mission. A novel thrust-arcing trajectory solves the alignment problem through flexible steering of the apogee to facilitate a Lunar encounter at minimal performance cost. Factoring in the potential to spread launch energy expenditure through a secondary client in a rideshare configuration results in an increase to over 60% less energy investment per kg. A preliminary analysis shows that even greater efficiencies could potentially be achieved through a continuous mission that returns multiple upper stages.

Ultimately, the novel concept of coupling space debris mitigation with advancing long-term Lunar exploration presented in this paper shows significant potential and warrants further study. Moreover, a comprehensive analysis of the energy cycle highlights the potential for improved energy efficiency over conventional lander missions. Finally, the use of global energy expenditure as a tool for relative analysis shows potential as an adequate means of analyzing space missions featuring distinct segments.