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Post Mission Disposal and Space Debris Removal 1 - SEM (5)

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COST AND BENEFIT ANALYSIS OF ORBITAL DEBRIS REMEDIATION

Abstract

This study presents a comprehensive cost-benefit analysis of various approaches to mitigate the risks posed by orbital debris, including abandoned vehicle stages, non-functional satellites, and fragments of launched materials. Orbital debris can significantly increase the cost of space operations, threaten the safety of astronauts and satellites, limit the ability to launch spacecraft, and potentially render entire orbits unusable. To quantify the benefits of debris remediation, we developed a model to estimate the annual risk in dollars for spacecraft operators, such as human spaceflight and small satellites, caused by debris interactions, including warnings, maneuvers, and collisions.

Using the risk model, we quantified the benefits of neutralizing debris for two remediation scenarios: remediation of the 50 most-concerning large derelict objects in low Earth orbit and remediation of 100,000 pieces of 1-10 cm debris from 450-850 km altitude. We estimated the costs to remediate a single piece of debris for various remediation techniques and applied these per-debris costs to the remediation scenarios to estimate the total cost of using each technique to achieve the scenario benefits. For large debris remediation, we analyzed five techniques, including controlled and uncontrolled reentry, moving debris with lasers or sounding rockets for just-in-time collision avoidance, and recycling debris by converting its material into propellant. For small debris remediation, we analyzed three techniques, including nudging debris with ground-based or space-based lasers to remove debris and using a physical sweeper to impact debris.

Our analysis shows that there are plausible pathways for debris remediation to produce greater benefits than costs on near-term timescales. The most effective methods of remediation for reducing risk are those that nudge large debris away from collisions—rather than de-orbiting the debris—and remove small debris in the 1-10 cm size range. Controlled re-entry of debris may also produce near-term benefits if our low-cost estimate is achieved.

This study is the most rigorous and wide-reaching analysis of debris remediation in the literature, quantifying the negative effects of debris on space operators in terms of dollars. However, our analysis provides only a high-level view of the landscape and relies on simplifying assumptions. We hope to address these limitations in subsequent work by gathering feedback from the space community to prioritize opportunities for further study. Our findings suggest that direct risk analysis measured in dollars, rather than proxies for risk like total mass or number of debris, should be the focus when analyzing orbital debris and its remediation.