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# Failure Mode and Effects Analysis (FMEA) for CubeSat Deorbit Systems: A Comparative Risk Assessment of Drag Sails, Electrodynamic Tethers, and Propulsion Modules

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## Abstract

The rapid proliferation of CubeSats in low-Earth orbit (LEO) has intensified concerns about space debris, requiring reliable end-of-life disposal under both the longstanding 25-year international guideline and the newer 5-year rule now in force for FCC-licensed missions. While previous studies have compared the deorbit performance of drag sails, electrodynamic tethers, and propulsion systems, no systematic analysis has quantified their relative reliability. This study presents a comparative Failure Mode and Effects Analysis (FMEA) of the three primary CubeSat deorbit technologies, generalizing the scoring methodology into an explicit, reproducible set of anchoring rules for severity, occurrence, and detection. A functional decomposition of each system identified failure modes across critical subsystems, each scored to generate a Risk Priority Number (RPN) for quantitative comparison. Results reveal distinct risk profiles: drag sails achieve the highest performance, but concentrate risk in a single-point deployment mechanism and, newly identified in this analysis, in maintaining post-deployment orientation. Electrodynamic tethers show the highest density of serious risks, led by plasma contactor failure (RPN=315) and tether severance (RPN=300). Propulsion systems carry lower average risk due to better detectability, but the highest number of catastrophic-severity failure modes. A Pareto analysis of the underlying risk data shows that the ten highest-RPN failure modes, representing 42% of all identified modes, account for approximately 64% of cumulative risk. These findings give CubeSat developers an evidence-based framework for selecting deorbit technologies based on both performance and reliability, supporting sustainable, compliant space operations.

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## 1. Introduction

The advent of the CubeSat standard has democratized access to space, enabling universities, small companies, and developing nations to conduct low-cost missions for education, Earth observation, and technology demonstration (Aglietti et al., 2020; Alnaqbi et al., 2024). This dramatic increase in launch rates, however, has intensified concerns about

the long-term sustainability of the low-Earth orbit (LEO) environment. With each non-deorbited satellite representing a potential source of catastrophic collisions for decades or centuries, the need for guaranteed end-of-life disposal has become a critical issue for the global space community (Bilén, 2021; Cotten et al., 2017).

To mitigate the increase of space debris, the Inter-Agency Space Debris Coordination Committee

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