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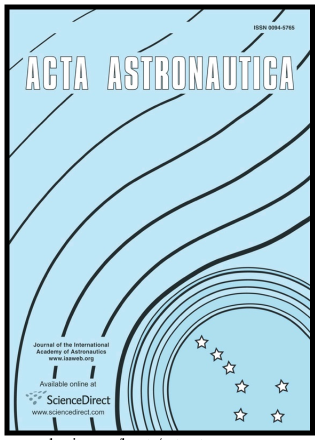

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Ranking upper stages in low Earth orbit for active removal

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Abstract

This paper addresses the problem of ranking the upper stages in orbit in order to evaluate their potential detrimental effects on the debris environment over the long-term, and the relative advantage of having them actively de-orbited. To do so, a new ranking scheme is introduced, applicable to any object in low Earth orbit (LEO) and able to prioritize the target objects potentially most critical for the future preservation of the LEO protected region. Applying the proposed approach, it was found, for instance, that the 22 most massive upper stages abandoned in LEO, at the beginning of 2015, are on the whole equivalent to several hundred average intact objects in sun-synchronous orbit, regarding their latent detrimental effects on the debris environment over the next 200 years. Most of them could therefore be the top priority targets of any worldwide coordinated effort for active removal and the prevention of new collisional debris. The ranking scheme was also applied to other main models of rocket bodies currently in orbit, trying to identify the combinations of orbital elements and upper stage types requiring particular attention.

1. Introduction

Currently, spent upper stages represent more than 42% of the intact objects abandoned in orbit, accounting for 57% of the abandoned mass (and 48% of the total mass, including operational spacecraft). Due to the fact that they belong to a relatively small number of models, compared to spacecraft, and are typically much more symmetric and simple shaped, rocket bodies are ideal candidates for active debris removal missions. Moreover, they are easier and safer to grab, lacking the fragile complement of appendages which characterizes most spacecraft.

In recent years, a popular way to evaluate the latent long-term environmental impact of an orbiting object was to conceive a ranking scheme based on reasonable hypotheses [1] [2] [3] [4] [5] [6] [7] [8]. In this paper, the problem of ranking the upper stages in LEO, in order to evaluate their potential detrimental effects on the debris environment over the long-term, and the relative advantage of having them actively de-orbited, was addressed by applying a new ranking scheme, further developing and extending an approach introduced in [4] and [5]. It is applicable to any object in LEO (payloads included) and able to prioritize the targets potentially most critical for the future preservation of the LEO protected region [9], but its application to rocket bodies, i.e. to homogeneous classes of objects, is much more straightforward, reliable and meaningful.

2. Ranking scheme for abandoned space objects in LEO

Concerning the potential long-term adverse effects on the debris environment, and the relative advantage of performing active de-orbiting, the ranking R of an object in LEO, where a higher ranking value is associated with a higher potential threat, should depend on the probability of catastrophic breakup P_c due to orbital debris collision, on the number of new "effective projectiles" N_p resulting from the breakup, and on the long-term impact on the environment of the resulting debris cloud [3] [5].

Being $F(t)$ the flux of orbital debris able to significantly breakup the target intact object, A the average collisional cross-section of the latter and t the time, the probability of target fragmentation can be expressed by the following relationship [10], taking into account that the cross-section of typical impactors is 2–4 orders of magnitude smaller than A:

$$P_c = 1 - e^{-\int F(t)\cdot A \cdot dt} \quad \textbf{(1)}$$

However, being $F(t) << 1$, Eq. (1) can be approximated by [10]:

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