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Removal targets' classification: How time considerations modify the definition of the index

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Abstract

The growth of the near-Earth debris population since the beginning of human space activities is now a fact commonly admitted by space agencies worldwide. Numerous entities have warned about the danger that debris may have over time. Presently mitigation methods such as imposing post-mission disposal time after launch will no longer be sufficient; remediation processes seem necessary to limit the increase. In particular, this phenomenon is attributed to the generation of fragments due to more and more on-orbit collisions. Therefore, investigations on indexes to select potential removal targets were recently conducted, considering solely objects implicated in a collision course. This study also looks at the multiple fragmentation factors, including time through the altitude at time of impact (due to the behaviour of debris re-entering with time).

The focal point is here to compare different criteria to select removal targets that enable scenarios in best adequacy with the future in question (long term, mid term or short term). Aware of the uncertainty of evolutionary models, this study also incorporates the simulation method as an impactful factor and tries to overcome the potential randomness of the results. Therefore, this paper presents a way to establish a selection criterion the most adequate for the time period focused on.

In order to solve this issue, a "double-check" method is proposed. First, an analytical evolutionary model simulates the environment over 100 years, through 100 Monte-Carlo runs. Then, among the initial population of year 2009, the objects supposed to be at the origin of the debris detected at a given time are tracked back in time into the simulations, using a collision-detecting program. The "given period" above mentioned for the presence of debris is based on a future as such that 2029 be considered a short-term scenario, 2059 a mid-term scenario and 2109 a long-term scenario. This step produces three lists of targets for removal (one for each future), and simulations are run once again, through different scenarios involving the removal of particular listed targets in order to verify the appropriateness of the proposed scenarios. The analysis of the results is based both on the mean of the simulations and on the recurrence considering each run.

Three studies were conducted one for each term, and a fourth one completed the work by establishing comparison between short, mid and long-term periods. As a result, three main criteria could be established: the altitude of the objects, the number of targets necessary to remove, and the phenomenon of chain collisions. According to the future that was investigated, the most adequate criterion appeared to be different, consisting in the number of objects in the long-term analysis or the ranking position at short term (linked to the close-time consideration). As a main conclusion and further perspectives, it should be more efficient to consider the collision-probability and mass

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Abbreviations: ADR, Active Debris Removal; ESA, European Space Agency; Expl., Explosion; GEO, Geostationary Orbit; IADC, Inter-Agency Space Debris Coordination Committee; ID, International Designator; JAXA, Japan Aerospace Exploration Agency; LEGEND, LEO-to-GEO Environment Debris model; LEO, Low-Earth Orbit; MC, Monte-Carlo; NASA, National Aeronautics and Space Administration; NEODEEM, Near-Earth Orbit Debris Environment Evolutionary Model; NORAD, North American Aerospace Defence Command; ODQN, Orbital Debris Quarterly News; PMD, Post-Mission Disposal; R/B, Rocket Body; s/c, spacecraft; UNCOPUOS, United Nations Committee on the Peaceful Uses of Outer Space.

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product together with the time-depending generation of fragments. This would help increasing the precision in the prediction of collision impacts.

Rather than pinpointing specified targets to be removed, the aim of this study is simply to understand the mechanisms at the origin of the population increase around the Earth. Also to demonstrate that a careful definition of selection criteria would enable to adopt a suitable removal process in the period of action or for the goal to be reached.

Keywords: Space debris; Monte-Carlo simulation; Collision fragments; Parentage tracking; ADR

1. Introduction

1.1. Background on the necessity to perform ADR in addition to passivation methods

The growth of the near-Earth space population is a fact commonly admitted and predicted by agencies worldwide and now considered as a threat for future space missions. Until now, major work has been done to encourage the development of passivation methods such as PMD on payloads or rocket upper stages (IADC Steering Group, 2007; UNCOPUOS, 2010). However, in view of the rapid degradation of the space environment, performing remediation processes, like active debris removal, appears necessary (Liou et al., 2013) to complement the efforts of passivation processes; mainly Liou et al. (2010) compared three different scenarios for the evolution of LEO environment: PMD only; combination of PMD and ADR of 2 objects per year; combination of PMD and ADR of 5 objects per year. Their results show that performing only a post mission disposal, even in the best case at a 90% success rate, is not enough to control the growth of the future population (Liou et al., 2013; Liou and Johnson, 2006). Performing a complementary active debris removal appears therefore as a requirement, and the number of objects to be removed also enters into consideration since it is noticeable that the future population is expected to remain stable from a rate of at least five removed objects per year, under the consideration of a very high PMD rate (90%), which is an optimistic scenario, but not necessarily the most realistic one (Liou and Johnson, 2008; Liou, 2011; NASA ODQN, 2014). Many efforts have also been done all over the world to raise similar analyses and conclusions, like in Britain by White and Lewis (2014), Lewis et al. (2012), or to start thinking about feasible and compatible ADR methods, like in Japan by Kim et al. (2010) who proposed to study electrodynamic together technologies.

Now the benefits of ADR have been demonstrated, and since the technology to do so is under development for on-orbit demonstration as explained by Wormnes et al. (2013) or as it can be seen through technology demonstration by entities such as D-Orbit Srl., Astroscale PTE. Ltd., Surrey University (ESA website about e.Deorbit), the importance is then to identify and select the targets that would enable the most efficient removal process in terms of time and number of objects. Therefore, using as a base support the results from these previous researches, the aim of this study is to take consideration of the number of objects to remove, the importance of their on-orbit location, and various parameters presented later in order to point out the characteristics of the objects that should be chosen so as to perform an efficient removal in terms of impact on the future LEO population.

1.2. Preliminary study to underline the impacts of collision events

To choose the appropriated targets, it was first necessary to better understand the lying phenomenon under the predicted change in the evolution of future space environment. To do so, a preliminary study was conducted over a 200-year simulation time. It was divided in three sub-studies, each considering one of the three different PMD rates (30%, 60%, and 90%), in order to focus on the impacts of a combined ADR process. The results were obtained through the mean of one hundred Monte-Carlo simulations, with the assumptions of no explosions, but a continuation of launch traffic (based on a 2005–2013 traffic cycle), and four ADR scenarios: no ADR performed, 2 objects removed per year, 5 objects removed per year, and 8 objects removed per year. If ADR is performed, the removal process starts from year 2025 until the final year 2213. During the projections, space-crafts are assumed to have an 8-year mission lifetime. After this time, if the spacecraft is still present in the near-Earth-orbit environment, its status is moved to drifting object. As for the rocket upper stages, they are left in their target original orbit after payload liberation. Concerning the execution of the PMD inside the model, it is performed only regarding the 25-year rule for all the objects that require it. No other options, such as transfer to graveyard orbits or other processes, are considered. This remark is applicable to all the studies presented in this article when the simulations are performed with the evolutionary model NEODEEM.

The following Figs. 1 and 2 present results only in the case of a 90% PMD success rate, so the best PMD case scenario, in order to fully concentrate on ADR effects. The two other studies, where 30% PMD and 60% PMD rates

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