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Evaluating the environmental criticality of massive objects in LEO for debris mitigation and remediation

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ABSTRACT

Approximately 95% of the mass in Earth orbit is currently concentrated in about 6700 intact objects, of which nearly 80% are abandoned and more than 90% cannot be maneuvered. The intact objects abandoned in low Earth orbit (LEO) above 650 km, i.e. with an average residual lifetime of more than 25 years, represent the main potential mass reservoir for the generation of new detrimental orbital debris in case of mutual collisions with the existing debris environment, taking into account that an 800 g impactor may be sufficient, in principle, to shatter a 1000 kg spacecraft or rocket stage. Since the 1980's, several mitigation measures were promoted and agreed at the international level in order to prevent the occurrence of new breakups in space and put under control the accumulation of mass abandoned in orbit, but unfortunately the level of compliance with such guidelines, requirements or standards is still far from satisfactory. Moreover, the appearance on the scene of space activity of new private and government actors from a growing number of countries makes the proper management of the circumterrestrial space a task of increasing complexity, taking also into account the rapid emerging of new potential applications, disrupting technologies and operational approaches quite different from the past. In this rapidly evolving environment, it might be useful to have a simple and flexible instrument for evaluating the potential criticality for the environment of massive objects placed or abandoned in LEO. With this goal, in the last few years, a particular effort was devoted to the development of various "criticality indexes", then applied for evaluating many families of rocket bodies and selected spacecraft. In this paper, with the underlining ambition to be simple, intuitive and relevant, from an environmental point of view, a couple of the most complete indexes were coherently applied in order to assess the potential criticality of the most massive objects abandoned in LEO. The results obtained are presented here in detail, also highlighting how these ranking approaches might be used both for debris mitigation, for instance to choose an appropriate disposal orbit for either spacecraft or upper stages to be dismissed at the end-of-life, and for debris remediation, as a guide in the selection of the most relevant targets for active debris removal, if and when such missions will become practicable.

1. Introduction

The long-term simulations of the orbital debris environment carried out during the last 40 years have identified the abandoned mass in orbit as the main driver of collisional fragments and impact probability growth over several decades, potentially jeopardizing the practical utilization of some of the most popular orbital regimes, particularly in low Earth orbit (LEO) [1,2]. For this reason, a "25-year rule", i.e. the prescription of limiting to less than 25 years the post-mission orbital presence of spacecraft and orbital stages in LEO, was firstly suggested inside the National Aeronautics and Space Administration (NASA), later on endorsed by the Inter-Agency Space Debris Coordination Committee (IADC), and finally adopted by several national and international standards [3]. The aim of the rule was averting the accumulation of intact spacecraft and orbital stages, in order to retard as much as possible a rapid growth of artificial debris and collision rates triggered by mutual collisions and catastrophic breakups [4,5].

Presently there are approximately 7500 metric tons of mass in orbit around the Earth, of which about 95% concentrated in almost 6700 intact spacecraft and orbital stages [6]. Among them, nearly 80% are abandoned and more than 90% cannot be maneuvered. Those left above ~650 km, i.e. with a typical residual lifetime of more than 25 years, represent the main potential mass reservoir for the generation of new detrimental orbital debris in case of mutual collisions with the existing debris environment, taking into account that an 800 g impactor may be sufficient, in principle and on average, to deeply shatter a 1000 kg

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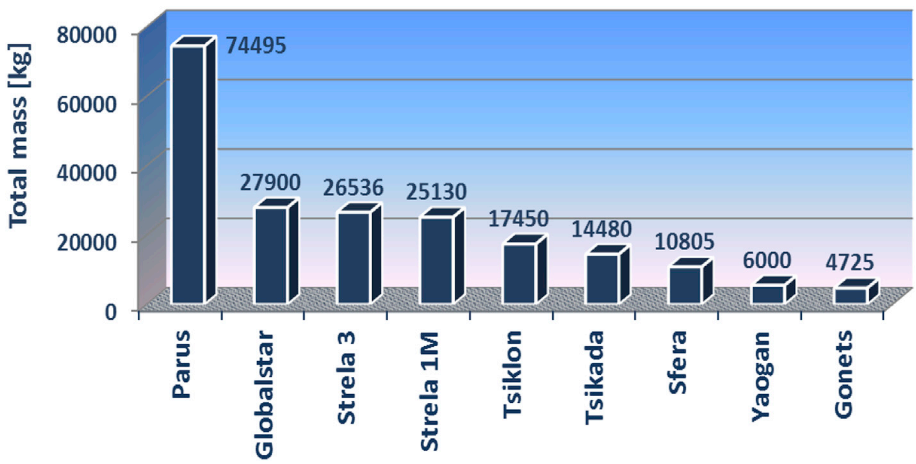

Fig. 1. Constellation satellites in LEO with an individual mass <1000 kg and a mean height >900 km, in order of decreasing total mass.

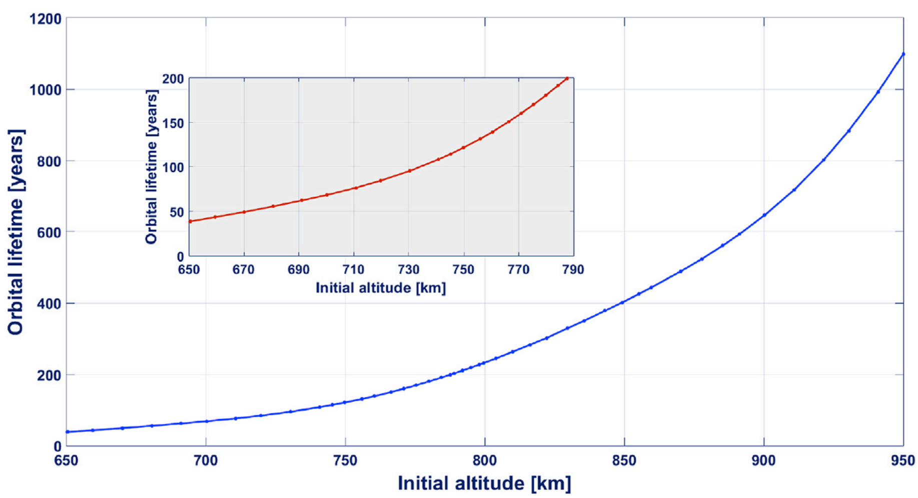

Fig. 2. Mean orbital lifetime, as a function of the initial altitude in nearly circular orbit, of an average intact object.

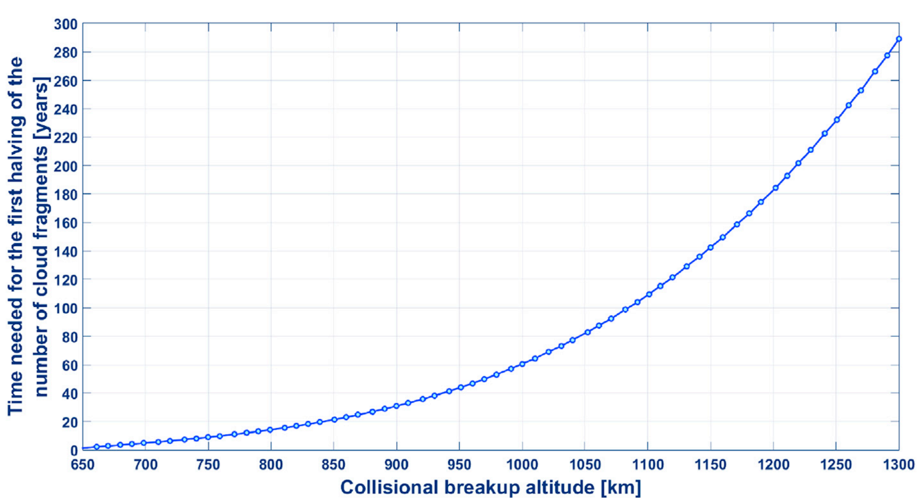

Fig. 3. First halving time of the number of catalogable debris generated by a catastrophic collision (CDCD50), as a function of the breakup altitude in nearly circular orbit.

spacecraft or rocket stage. Just considering the most massive objects abandoned in LEO, the 9000 kg s stages of the Zenit-2 launcher, it has been pointed out that there is a 1/4000 probability per year of a collision involving two of them, leading to an immediate doubling of the cataloged debris population in LEO [7].

A possible approach for gauging the latent long-term environmental impact of an orbiting object, avoiding thousands of complex simulations built on rather uncertain scenario assumptions and forecasts [8], is to formulate a "criticality index" grounded on simplified credible assumptions and characterized by much faster, and easier to implement, computations. An intuitive and simple to understand meaning, if possible, would add further practical value to the definition, which may represent,