Space debris environment propagation through a continuum approach

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1 Introduction

The number of services provided by in-orbit satellites is increasing and, together with that, our exploitation of the space environment. More than thirty thousand objects are currently tracked by the space surveillance network, 73.8% of which are uncontrolled [1]. Long-term simulations of the space environment prove that, even in the absence of future launches, both the debris population and the number of in-orbit collisions are going to increase [1][2][3][4][5]. In this scenario, it is crucial to develop tools that allow the identification of the most critical objects in space. This objective implies performing several simulations, where the orbit of thousands of debris is propagated in time. Therefore, the computational efficiency of such tools is imperative.

This work adopts the continuum approach developed at Politecnico di Milano, and proposed in [6][7][8], to model the evolution of the whole background debris population and to include new potential fragmentations. The modelling of the fragments as a cloud, described through a probability density function, aims to provide the best compromise in terms of accuracy and computational efficiency. A novel collision risk assessment method, which computes the impact rate directly from the fragments' density in the phase space of Keplerian elements, is used to evaluate the collision probability among in-orbit objects.

2 Methods

The continuum approach developed in [6][7][8] and adopted in this work is divided in three main parts: fragmentation density distribution, density propagation, and collision risk assessment. Each of them is here briefly introduced.

Fragmentation density distribution

The initial density distribution is estimated according to the model firstly introduced in [6] and improved in [7]. It adopts the probabilistic reformulation of the NASA Standard Breakup Model [9] to bound the region of the phase space occupied by the fragments ejected by a fragmentation event, and approximates the fragments' distribution through a binning approach. If the grid is fine enough, the bin-wise constant density distribution well resembles the actual debris cloud.

Density propagation

The continuity equation is adopted for the propagation of a density distribution [8] (either a fragmentation cloud or the background debris population). To perform the numerical integration, it is transformed from a partial differential equation into an ordinary differential equation, either via method of characteristics [10] or finite volume method [11]. The dynamics is provided in mean orbital elements.

Collision risk assessment

The impact rate between a fragments' cloud and a target is estimated integrating the flux of fragments over the target cross sectional area, directly from the phase space density in Keplerian elements. The probability of collision is modelled according to a Poisson distribution through an analogy with the gas kinetic theory [12].

3 Discussion

The results of some preliminary simulations are here presented. The 2013 IADC debris population in low-Earth orbit is considered. The proposed continuum approach is adopted to propagate the cloud and to evaluate the effect of a potential new fragmentation to the space debris environment. To this purpose, two fragmentations at two different altitudes are added to the background population. A similar analysis was presented by Duran et al. in [13], but here the density is propagated in the full set of Keplerian elements.

Fig. 1 shows the evolution of the number of fragments over time estimated by the continuum approach, compared to the traditional piece-by-piece propagation, to evaluate the relative error. Instead, **Fig. 2** depicts the spatial density distribution of the background population and of a new fragmentation happening at an altitude of 800 km (a) and 1600 km (b), respectively. It can be immediately inferred how the high-altitude fragmentation would have a more severe effect on the space environment.

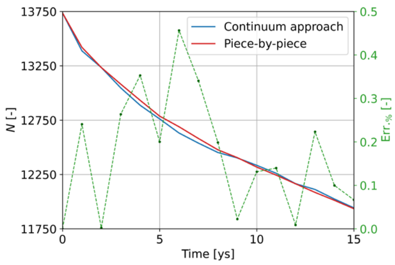
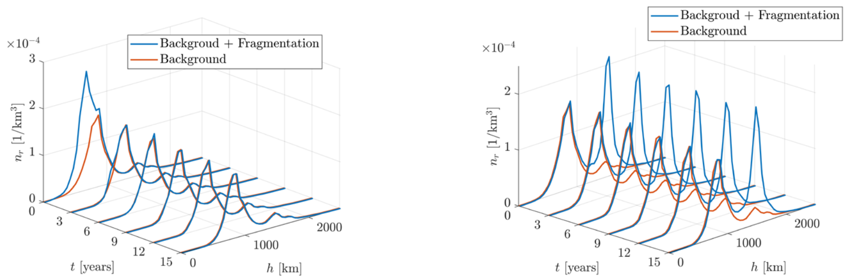


Fig. 1. Debris' number over time estimated by continuum and piece-by piece propagations.



(a) $h = 800$ km (b) $h = 1600$ km

Fig. 2. Spatial density of the debris population over time w/ and w/o fragmentation.

The envisioned simulations will be dedicated to identifying the most critical objects in space from a debris environment point of view. This objective will be achieved adopting the collision risk assessment method previously introduced, and considering the different effect of a potential fragmentation, depending on the fragmentation location.

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