Paper ID: 73762
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20th IAA SYMPOSIUM ON SPACE DEBRIS (A6)
Interactive Presentations - 20th IAA SYMPOSIUM ON SPACE DEBRIS (IP)

Author: Mr. Lorenzo Giudici
Politecnico di Milano, Italy

Dr. Mirko Trisolini
Politecnico di Milano, Italy
Dr. Camilla Colombo
Politecnico di Milano, Italy

PHASE SPACE DESCRIPTION OF THE DEBRIS' CLOUD DYNAMICS THROUGH A CONTINUUM APPROACH

Abstract

It is estimated that almost one million debris greater than 1 cm currently orbit the Earth, the majority of which occupies the Low-Earth Orbital (LEO) region. As a result, the space community has developed several tools for estimating the evolution of clouds of fragments in LEO under the most relevant orbital perturbations (i.e., drag and J2). In recent years, density-based approaches have been investigated, starting from the work by McInnes. Letizia et al. proposed a 2D analytical model for propagating the debris' density under the drag effect. Frey et al. extended the method to deal with density propagation in any dimension and subjected to non-linear dynamics. Nevertheless, the use of a Gaussian Mixture Model (GMM) as interpolation technique does not allow to accommodate forces that lead to bifurcations on a subset of the phase space, as it might be the case of Third Body (3B) perturbation and Solar Radiation Pressure (SRP).

This paper aims to extend the density-based approach to any orbital region, enabling the propagation of clouds of fragments under the whole set of orbital perturbations. Indeed, even though the LEO region is the most crowded, the exponential increase of space debris is also affecting the other orbital regions. According to the ESA's Space Environment Report, out of the nearly 22000 space debris being tracked, approximately 50% occupy orbital regions where SRP and 3B perturbations cannot be neglected, as Medium-Earth (MEO), High-Elliptical (HEO), Geostationary (GEO) or Geostationary Transfer (GTO) Orbits. This objective is achieved combining the Method Of Characteristics (MOC), applied to the continuity equation, and the discretisation of the phase space of Keplerian elements and area-to-mass ratio. Being the interpolation through binning agnostic to the dynamical behaviour of the cloud, it is expected to address the problem encountered by Frey et al., where the branching of fragments caused by SRP and 3B perturbations does not allow the fitting procedure through the GMM to accurately work. The bottleneck of the proposed approach is the computational cost, caused by the discretisation procedure in the multi-dimensional phase space. This problem is faced bounding the domain in Keplerian elements through probabilistic considerations on the way the fragments distribute over the phase space, as consequence of a fragmentation event. The initial density distribution is estimated in the regions probabilistically reachable by the ejected fragments, sampled and propagated through the MOC. The density distributions, at any specified epoch, are eventually recovered through interpolation.