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CONTINUITY EQUATION APPROACH FOR THE ANALYSIS OF THE COLLISION RISK DUE SPACE DEBRIS CLOUDS GENERATED BY A FRAGMENTATION EVENT

Abstract

As the debris density increases, the probability of collisions in space grows. Even a collision involving small objects may produce thousands of fragments due to high orbital velocity and the high energy released in the collision. The propagation of the trajectories of all the objects would be too expensive in terms of computational time, so simplified models have been written to describe the consequences of a collision with a reasonable computational effort. For example, in SDM by Rossi and in DAMAGE by Lewis only some representative objects are propagated to describe the evolution of the cloud formed by a fragmentation.

In this work, the consequences of a collision are simulated focusing on the description of the behaviour of the fragments cloud as a whole and applying the continuity equation: a debris cloud in Low Earth Orbit (LEO) is modelled as fluid, whose spatial density varies with time, under the effect of Earth gravity and atmospheric drag. Introducing some simplifying assumption, such as an exponential model of the atmosphere and the hypothesis of limited eccentricity for fragment orbits, an analytical expression for the cloud density evolution in time is derived.

This novel approach enables the analysis of a large number of potential fragmentation scenarios that would be time-limited with current numerical methods that rely on the integration of the all the fragment trajectories through semi-analytical expression of the dynamics. Moreover, compared to the approaches where only some representative objects are propagated this method operates directly on the objects spatial density, which is then used to compute the collision probability.

By applying the proposed method, results will be shown considering several different collisions scenarios, considering the fragmentation of satellites at different altitudes and inclinations. In this way, it is possible to identify orbiting objects that, in case of fragmentation, are more likely to generate a debris cloud that can create a hazard to a reference operative satellite in LEO. For each fragmentation event, the evolution of the cloud is propagated to identify intersections with the orbit of the reference satellite. In case, a collision probability is computed, considering the density of the cloud, the velocity of the spacecraft and the time of residence within the cloud. Particular emphasis is given to fragmentation events happening or interfering with polar sun-synchronous orbits.