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EVOLUTION OF FRAGMENTATION CLOUD IN HIGHLY ECCENTRIC ORBIT USING REPRESENTATIVE OBJECTS

Abstract

Many historical on-orbit satellite fragmentations occurred in highly eccentric orbits (HEOs) such as the Molniya type orbit and the geostationary transfer orbit (GTO). Such fragmentations produce debris clouds that interfere with the low Earth orbit (LEO) environment and pose a threat to operational satellites. Objects in HEO undergo complex dynamics due to the influence of perturbations varying as a function mainly of their altitude and area-to-mass ratio. At the perigee, typically below 1000 km, perturbations from atmospheric drag and Earth's oblateness are dominant. Towards the apogee, typically above 15000 km, perturbations from solar radiation pressure and third bodies become relevant.

This paper models the evolution of a fragmentation cloud in HEO under the influence of atmospheric drag, Earth's oblateness, solar radiation pressure (neglecting shading effects) and the gravitational pull of the Sun and the Moon. The interaction of the debris cloud with, and the increased collision risk for, objects residing in LEO is analysed. Semi-analytical techniques coupled with the continuity equation are applied to propagate the cloud; rather than following the evolution of each single fragment, the evolution of the debris spatial density is studied. Previous work, applied to the LEO case, demonstrated that such an approach is very efficient and produces accurate results compared to numerical propagators. To assess the collision risk, two different methods are applied and compared. The first method is based on the kinetic gas theory, the second on geometrical considerations.

The proposed method is applied on a typical HEO upper stage using the standard NASA break-up model to find the distribution right after the fragmentation. The short-, mid- and long-term evolution of the debris cloud is analysed and the increased collision risk for selected satellites is computed. The findings are compared to results from conventional numerical solutions.