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STOCHASTIC MODELING OF HYPERVELOCITY IMPACTS INCLUDING MOMENTUM ENHANCEMENT IN ATTITUDE PROPAGATION OF SPACE DEBRIS

Abstract

Bombardment of small orbital debris and micrometeoroids on active and inoperative satellites is becoming an increasing threat to space operations and has significant consequences on space missions. Concerns with orbital debris have led agencies to start developing debris removal missions, known as Active Debris Removal (ADR), and knowing a target's rotational parameters ahead of time is crucial to the eventual success of such a mission. While many of the environmental factors influencing an object's rotational motion in space have been extensively studied, the effect of bombardment of debris and meteoroids on spacecraft attitude propagation, on the other hand, is a research area that is still in its infancy. These hypervelocity impacts, occurring at speeds up to 60 km per second, will lead to disturbances in attitude due to a transfer of momentum from the impactor to the target. Furthermore, at such high velocities, the particles ejected during crater formation provide an additional momentum transfer, an effect known as momentum enhancement.

The method proposed here enables the inclusion of hypervelocity impacts with momentum enhancement into spacecraft attitude propagation models by considering the transfer of angular momentum from collisions as a stochastic jump process known as a compound Poisson process. The differential equation for attitude motion then becomes a stochastic differential equation (SDE) and is solved in a Monte Carlo simulation by generating independent sets of randomly generated collisions. These collisions can be obtained using impact fluxes converted into probability density functions from European Space Agency's (ESA) Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) model describing the debris and meteoroid population around Earth. The momentum enhancement contribution from ejecta is calculated for every collision by considering the velocity, mass and direction distribution of the ejecting particles from a model developed for ESA defining the characteristics of such ejecta. In order to assess the importance of these collisions on attitude propagation, the developed model is applied to two categories of space debris: the defunct European environmental satellite Envisat and a high area-to-mass ratio (HAMR) object thought to be multi-layer insulation material shed off old satellites.