Generalized Collision Flux Approximation for In-situ Measurements

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ABSTRACT

Space debris have been jeopardizing the lives of many spacecraft on the Earth orbits since the start of the space age. Debris with size less than 2 mm is called sub-millimeter debris. They have enough energy to cause a fatal damage on a spacecraft, but cannot be tracked from the ground [1]. Kyushu University has initiated the development of the in-situ measurement satellite, called IDEA, the project for In-situ Debris Environmental Awareness, to have a better understanding of the sub-millimeter-size debris environment. In order to investigate the natures of orbital planes on which debris may impact with the measurement satellite, the previous study has developed a collision flux model, torus model, to estimate the collision flux of debris into the measurement satellites, assuming both debris and measurement satellites are on circular orbits [2]. This paper generalizes the previous modelling to more practical modelling that is applicable to elliptical orbits.

First, this paper investigates the nature of an orbit on which a piece of debris that may be detected by a measurement satellite on an elliptical orbit, using Spherical Finite Model (SFM) developed by European Space Agency (ESA). The numerical example shows that around 90% of debris that may be detected by the measurement satellite on the elliptical orbit are moving on near-circular orbit. This result allows the assumption that the most of debris are on circular orbits, whereas the measurement satellite on the elliptical orbit. Second, two new collision flux models, torus model and ring model, that are applicable to elliptical orbits are introduced. In estimating collision flux, the probability of the existence of a satellite and debris inside cell must be calculated. Both models put the cell along the debris orbit. Torus model uses the geometric relation between the torus and measurement satellites. By finding the intersection points, the probability of the measurement satellite within torus can be estimated. On the other hand, ring model estimates the collision flux by calculating the regions of the intersection analytically.

The effectiveness of the proposed models is verified with numerical examples using SFM. Although the results show that the two models match well, higher computational time is required for the torus model due to the nature of the numerical simulation by Newton's method. Therefore, the ring model is more feasible for the collision flux estimation. Third, this paper builds theories of environmental model that estimates the distribution of sub-millimeter-size debris by using in-situ measurements by applying the nature to the algorithm of the particle filter. Particle filters require a likelihood, which represents a probability that observation data is available in the estimated state of the system. The likelihood function is calculated by the ring model. Finally, the proposed model using the particle filter is verified by numerical simulations using MASTER-2009.

Reference

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