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PERIODIC DEDUCTION METHOD FOR LOW EARTH ORBIT SPACECRAFT BREAKUP DEBRIS POPULATION

Abstract

With the increase in space activities, the amount of space debris continues to grow. However, debris with characteristic sizes in the range of 1–10 cm cannot be directly observed for early warning, posing an escalating threat to space operations worldwide. Therefore, there is an urgent need for a method to predict the distribution of such debris. This paper proposes a semi-analytical periodic deduction method for the orbital distribution of space debris. Recognizing that debris of different sizes resulting from the same spacecraft breakup exhibits certain correlations, this method uses the observable large debris from a breakup to infer the evolutionary distribution of unobservable smaller debris.

In the case of the evolution of low-Earth orbit space debris, the main perturbing forces are the Earth's J_2 oblateness perturbation and atmospheric drag. Rather than focusing on the detailed motion of individual fragments, the paper adopts a probabilistic statistical approach to describe the overall distribution of the debris cloud in orbital radius. Combining NASA's standard breakup model and orbital perturbation equations, a numerical simulation system is established to predict debris evolution. Using direct numerical simulation and the periodic deduction method seperately, reference and inferred values for the spatial distribution of small debris are obtained, and their similarity is evaluated using JS divergence. The findings indicate that the periodic deduction method achieves a high level of accuracy in predicting debris distribution.

Further, using two-line element (TLE) data from the February 10, 2009, collision between Iridium 33 and Cosmos 2251, the evolution of smaller debris is inferred over a two-year period using the orbital data of larger debris. The inferred distribution is compared with the observed data, and the JS divergence between the inferred and actual distributions remains below 0.03 throughout. This demonstrates the effectiveness of the proposed method when tested against real-world data.

This paper proposes a semi-analytical periodic deduction method that uses observable large debris orbital data to predict the spatial distribution of unobservable small debris. The effectiveness of the method was validated through numerical simulations and real-world data. This work lays a foundation for future use of observable large debris orbital data to infer the evolution of unobservable small debris and contributes to future space environment management.