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# COLLISION RISK ASSESSMENT FOR CONSTELLATION SATELLITES BASED ON A MULTIDISCIPLINARY SPACE DEBRIS EVOLUTION MODEL

**Abstract**

In recent years, the rapid growth of human space activities, especially the deployment of mega constellations, has worsened the space debris environment. Therefore, accurate and efficient prediction of space debris evolution, along with reliable collision risk assessments for spacecraft, is essential to ensure the safe execution of human space activities.

The space debris environment evolution model can be categorized into two types: micro and macro. The microscopic models track the individual objects and use the Monte Carlo method to form debris events, requiring significant computational resources and time. The macroscopic models utilize debris count or density variables and employ differential equations to describe debris evolution. Macroscopic models offer significant efficiency in the context of constellations and have become a widely adopted and continuously evolving approach.

However, the accuracy of macroscopic models is limited by overly simplistic spatial segmentation, often relying solely on altitude. Additionally, the perturbation models they employ are simplified, considering only atmospheric drag while neglecting Earth's nonspherical perturbations. Moreover, previous models often treat different types of space objects independently, overlooking the interactions among objects.

The spacecraft collision risk assessment is based on the collision probability algorithm. However, the previous algorithms rely on predictions from microscopic debris evolution models, which also require substantial computational resources. To date, no efficient collision probability algorithms have been developed based on macroscopic models.

Focusing on the above issues, this paper innovatively applies multidisciplinary approaches to the macroscopic space debris evolution model, and subsequently develops a collision probability algorithm, yielding three key contributions:

1) A three-dimensional ($a$, $i$, $\Omega$) space debris environment evolution model is established, incorporating multidisciplinary approaches. It uses a topological network to structure the relationships among space objects, integrates fluid mechanics and spacecraft dynamics to describe the source and sink mechanisms under atmospheric drag and J2 perturbation, and employs AI-based methods replacing traditional Monte Carlo simulations for breakup modeling.

2) Leveraging Kessler's collision probability theory, a spacecraft risk assessment algorithm is developed by integrating the space object flux outputs from the space debris environment evolution model with the

size and material characteristics of various space objects.

3) A constellation activity model is constructed based on actual mega constellation plans. Using the aforementioned model, this paper analyzes the collision risks associated with the constellation satellites during both their operational and deorbit processes.