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SIMULATING HYPERVELOCITY IMPACT WITH A DISCRETE ELEMENT APPROACH

Abstract

Fragmentation is a key phenomenon characterizing hypervelocity impact (HVI). It is of particular interest in the study of space debris, as every fragment generated by a hypervelocity impact contributes to the overall space debris population. Numerical simulations are a popular and practical approach to understanding HVI, and a variety of methods are commonly used, each with its own set of strengths and weaknesses. Besides investigating HVI effects on component level, numerical simulations of complete spacecraft fragmentations contribute to analyzing impact-induced spacecraft failures and their effects on the orbital environment. However, large-scale simulation of spacecraft demand accurate and efficient simulation methods.

Numerical simulations can be separated into two broad categories based on their underlying theory, continuum based methods and discrete methods. Continuum based methods include finite element methods (FEM), Eulerian methods, and Smooth Particle Hydrodynamics (SPH), all of which are routinely used to simulate HVI scenarios. Yet due to their shared theoretical basis in continuum theory, they all have some difficulty accurately representing the types of extreme fragmentation events seen in HVIs encountered in orbit. A separate family of simulation methods, avoiding continuum theory completely, is based on the interaction of many discrete particles. Common examples include the Discrete Element Method and Molecular Dynamics.

Previous work has shown the suitability of a discrete element based approach for simulating HVI, especially its suitability for accurately modeling fragmentation. In this paper, we present new developments to our discrete element model, the aim of which is to provide a practical numerical method to simulate on-orbit fragmentations. As previous work showed the model's ability to accurately simulate HVI fragmentation at very high-impact velocities, our current focus is predominantly on improving the model's behavior at the lower ranges of HVI where the extreme shock pressures are lower and material strength becomes increasingly dominant in the fragmentation process. We achieve this by updating our discrete element model's bonding structure to more accurately reproduce a continuum material. We also examine the modeling of secondary fragment impacts which are highly relevant when considering HVIs into complex satellite structures. The materials models used are also updated to represent increasingly common satellite materials such as carbon fiber reinforced polymers (CFRP). Validation of the numerical model is presented with a combination of in-house HVI experiments and comparison with results published in literature.