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# Simulating Hypervelocity Impact Phenomena with Discrete Elements

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**Abstract**

In this paper, we develop and assess a numerical model for simulating hypervelocity impacts (HVI) with a Discrete Element Method (DEM). The model consists of discrete spheres interacting via simple potentials. We determine the material parameters empirically by comparing them to recent HVI experiments. Using this model, we simulate HVI of aluminum spheres on thin aluminum bumper plates over a wide range of impact velocities and geometries. We perform quantitative comparisons between our simulations and experiments performed at our institute and taken from literature. When evaluating the model's suitability, we find good correspondence between simulation and experiment when the impact conditions lead to strong shock waves propagating through the material. Finally, we perform a comprehensive parameter study to evaluate the validity and limits of our model.


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*Keywords:* Discrete element method; Hypervelocity impact; Debris cloud; Fragmentation; Numerical simulation

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## 1. Introduction

With the growing number of space launches and the increasing buildup of space debris in orbit, the risk of hypervelocity impacts (HVI) on operational satellites is ever increasing [1]. Assessing the risk of future collision events requires the ability to model and predict the dynamics of HVI and the resulting fragmentation. Novel applications of numerical simulation techniques is one way of improving our understanding of the underlying phenomena of HVI.

HVI often involve extreme material deformation and fragmentation, posing challenges for Finite Element based methods traditionally used to model solids. For this reason, meshless methods, such as Smooth Particle Hydrodynamics (SPH) [2], [3], are widely used for HVI simulations [4]–[6]. However, SPH does encounter several difficulties in engineering problems such as the tensile instability problem and the difficulty in loading essential boundary condition that may be important for impact phenomena [7]. Although formulations and algorithms have been successfully implemented in SPH which help to overcome some of these limitations [8], the source of the problems still remains.

A completely different method for simulating materials undergoing HVI is by using a discrete instead of a continuum approach. One such method is the Discrete Element Method (DEM) [9] which approximates a material as a collection of Newtonian particles. DEM has been applied to variety of impact problems in brittle materials ranging from low to mid velocities [10]–[12] because of its natural transition between solid and fragmented particulate state. In this paper, we explore the suitability of DEM for simulating HVI into ductile materials such as aluminum. We make some simplifications to traditional DEM by neglecting dissipation in the form of friction and damping. We evaluate our model within a wide range of impact conditions to determine its suitability for numerical computation of HVI phenomena.

## 2. Model

In our simulations, we use mono-disperse spheres as basic discrete elements and calculate their interactions using attractive and repulsive potentials. In developing the simulation model [13], we begin with the simplest possible working model before adding more complexity. This simplifies the investigation of the complex interactions between material parameters. Because HVI creates strong shock pressures in a material, we make the assumption that material strength plays only a secondary role in the impact simulation. This allows us to use a very simple model for the

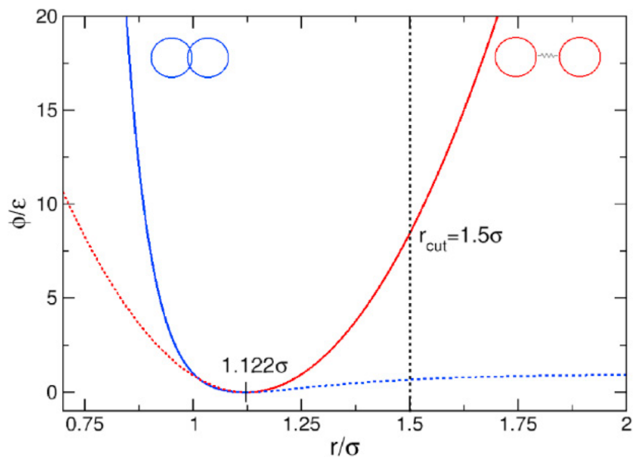


Figure 1: The solid blue line (left side) is the Lennard-Jones potential responsible for repulsive forces and the solid red line (right side) represents the spring potential responsible for cohesive forces. The combined blue and red solid lines govern the forces acting on each particle pair; the dotted lines are excluded.