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Calculating the momentum enhancement factor for asteroid deflection studies

Tamra Heberling*, Galen Gisler, Catherine Plesko, Robert Weaver

Los Alamos National Laboratory, XTD Division, Los Alamos, NM, 87544, USA

Abstract

The possibility of kinetic-impact deflection of threatening near-Earth asteroids will be tested for the first time in the proposed AIDA (Asteroid Impact Deflection Assessment) mission, involving NASAs DART (Double Asteroid Redirection Test). The impact of the DART spacecraft onto the secondary of the binary asteroid 65803 Didymos at a speed of 5 to 7 km/s is expected to alter the mutual orbit by an observable amount. The velocity transferred to the secondary depends largely on the momentum enhancement factor, typically referred to as beta. We use two hydrocodes developed at Los Alamos, RAGE and PAGOSA, to calculate an approximate value for beta in laboratory-scale benchmark experiments. Convergence studies comparing the two codes show the importance of mesh size in estimating this crucial parameter.

Keywords: Momentum Enhancement, Beta, Eulerian Hydrocode, Simulation, Convergence;

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1. Introduction

The threat of asteroid impact into Earth has inspired many scientists to research deflection strategies. One of the most accurate methods is kinetic-impact deflection which will be tested for the first time in the AIDA mission [1]. Kinetic-impact deflection occurs when a spacecraft impacts the asteroid to alter the asteroid's orbit over a large period of time. When the spacecraft impacts the asteroid, the ejecta thrown from the crater can provide an extra boost to aid in deflection. This is referred to as the momentum enhancement factor, beta. Beta plays a large role in deflection strategies and understanding how beta is calculated is of utmost importance. How different aspects of the

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* Corresponding author. Tel.: +1-505-667-6634;
E-mail address: theberling@lanl.gov

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asteroid such as material composition, strength, and damage, affect the calculated value of beta is an open question that is currently being studied with the AIDA benchmark experiments. Beta is calculated using the formula given in Equation (1) where m is the mass of the impactor, M is the mass of the asteroid, $\boldsymbol{v_A}$ is the velocity of the asteroid and $\boldsymbol{v_I}$ is the velocity of the impactor.

$$\beta = \frac{\Delta(M\boldsymbol{v_A})}{m\boldsymbol{v_I}} \tag{1}$$

Beta scales the deflection velocity, $\Delta\vec{v}$, linearly, as shown in the Equation (2).

$$\Delta\boldsymbol{v} = \beta\frac{m}{m+M}(\boldsymbol{v_I} - \boldsymbol{v_A}) \tag{2}$$

Therefore, changes in beta can have large effects on kinetic impact deflection strategies.

2. PAGOSA and RAGE Hydrocode Simulations

To calculate beta, we first simulated hypervelocity impacts using two Los Alamos National Laboratory (LANL) hydrocodes, RAGE and PAGOSA. While RAGE [2,3] has been used for hypervelocity impact simulations for many years this is a new application for the multimaterial hydrodynamics computer program PAGOSA [4]. PAGOSA is a massively parallel code that is routinely used at LANL to simulate the 3D dynamic behavior of materials subjected to high-strain rates, like those produced by hypervelocity impacts. Both RAGE and PAGOSA have adaptive time steps, a p-alpha porosity model, multiple strength models, and both SESAME and analytical EOS capabilities. The biggest difference that we would like to highlight is that RAGE commonly uses adaptive mesh refinement (AMR) capabilities while PAGOSA uses a fixed grid mesh throughout the entire simulation. Therefore, RAGE has the ability to refine the mesh to a small size near material interfaces, and places of high pressure and temperature. The fixed grid can occasionally cause larger run times for PAGOSA, but it avoids any unwelcome dezoning effects.

To investigate the calculation of beta, we began with the first benchmark test as defined by the DART project [5], a hypervelocity impact at 5 km/s of a 0.635 cm diameter aluminum sphere on an aluminum half space. To get a baseline with which to compare future runs, we simulated this calculation with no strength, no porosity, and no damage. Both RAGE and PAGOSA calculated the impact using four different mesh cell sizes; 0.25 cm, 0.125 cm, 0.0625 cm, and 0.03125 cm. For PAGOSA, the fixed grid means that each cell is this size throughout the simulation. For RAGE, with AMR capabilities, this cell size is the finest resolution. We are also utilizing identical resolution for both the target and the impactor. All simulations were run as 2D axisymmetric for efficiency. The impact crater in RAGE at 300 µs is shown in Figure 1 for three different resolutions; 0.125 cm, 0.0625 cm, and 0.03125 cm. Each image is colored by the density with red being the highest density and blue being the lowest. As the ejecta continues to move away from the crater, the density decreases. This is caused by the dezoning of the mesh in the AMR causing the target material in the ejecta to mix with the air which decreases the density. This effect is most severe for the lowest mesh resolution. The region affected by the dezoning decreases for the finer mesh resolutions. Figure 2 shows the same crater at 300 µs with the same mesh sizes using PAGOSA. This image is also colored by the density similar to Figure 1.

The fixed grid in PAGOSA allows the ejecta to remain at the same resolution, regardless of the distance it moves from the crater. Therefore, the ejecta looks similar at the top of the simulation as it does when it first disconnects from the crater edge. The refinement of the mesh allows the bigger fragments that are originally shown for mesh size 0.125 cm, to decrease in size and become more of a continuous body for the finer mesh resolutions. Any decrease in density around the edges of the material is caused by mixed cells which contain both the target material and the air. This effect