

☒ Mitigation Techniques & Missions

GPU ACCELERATED 3-D MODELING AND SIMULATION OF A BLENDED KINETIC IMPACT AND NUCLEAR SUBSURFACE EXPLOSION**Brian Kaplinger⁽¹⁾, Pavithra Premaratne⁽¹⁾, Christian Setzer⁽¹⁾, and Bong Wie⁽¹⁾**

⁽¹⁾Asteroid Deflection Research Center, 1200 Howe Hall, Iowa State University, Ames, IA, 50011, +1 515-294-3124, bdkaplin@iastate.edu, pdp@iastate.edu, csetzer@iastate.edu, bongwie@iastate.edu

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This paper develops a modeling and simulation framework for determining mission effectiveness of a two-body Hypervelocity Asteroid Intercept Vehicle (HAIV) [1]. This HAIV concept has been being developed as part of a NASA Innovative Advanced Concepts (NIAC) Phase 1 and 2 studies to overcome key difficulties in coupling energy from nuclear explosives to an asteroid target at high relative velocities of 5 – 30 km/s. It does so by blending the concepts of a kinetic impactor and a nuclear subsurface explosion to create successive impacts that mimic the behavior of a buried explosive, increasing energy coupling by an order of magnitude. To demonstrate this increase in effectiveness, this approach is simulated in a Smoothed Particle Hydrodynamics (SPH) model adapted for high-speed, low-cost, implementation on Graphics Processing Units (GPU).

Initial simulations in [2, 3] used a spherical axisymmetric near-Earth object (NEO) model, with the key limitations being the size of the target and a lack of a range of source energy input. With a new computational approach to the hydrodynamic simulations, we efficiently compute results for a 3-D shape of user-selected characteristics, such as that shown in Figure 1. This will allow us to address much larger targets with increased resolution and a faster turnaround time, so the influence of more composition parameters can be investigated. A nonlinear orbit solver is presented that calculates an impacting trajectory given boundaries of a (a, e, i) sampling space. This approach increases our understanding of what components of the interplanetary environment affect the likelihood of a NEO being

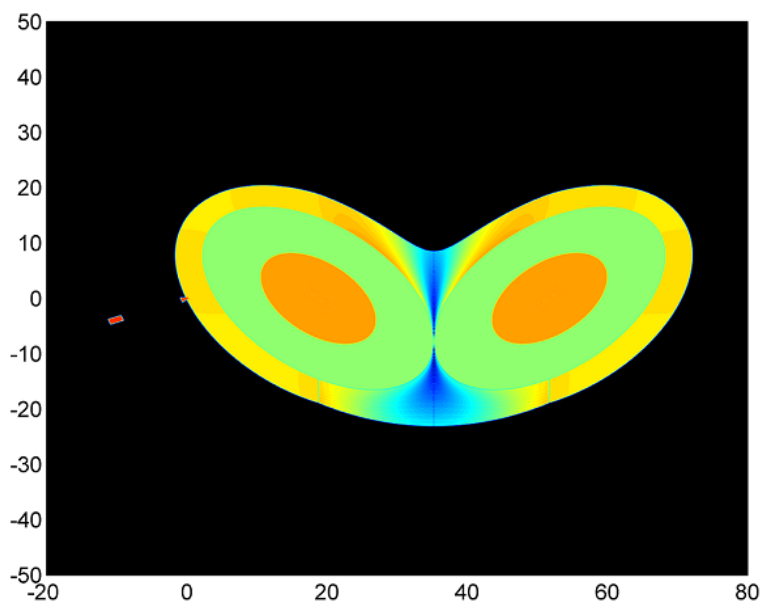


Figure 1. Initial Asymmetric Target Model

on a collision path with the Earth. Dispersion along these orbits is computed to determine mission effectiveness for a variety of possible cases.

New high-throughput neighbor-finding methods are suggested for the particle representation of disrupted NEOs. This approach becomes more effective using the GPU acceleration technology of the current simulation toolkit. In contrast to the Weibull distribution used to seed implicit flaws in brittle materials [2, 3], the current simulation set develops a tensor relationship for material characteristics and orientation, such as that developed in [4]. This allows for more realistic size and shape generation for NEO fragments by treating damage as a local quantity (cracks) rather than a distributed state variable. One of the key limitations is that most proposed neighbor-finding methods for interpolation rely on complex logic and lists not suitable for efficient GPU implementation. Therefore, the addition of the third dimension makes this problem far more complex. A new approach for efficiently computing unions and intersections of integer sets on the GPU is proposed, allowing for neighbor-finding as an update process from previously computed relative relationships. We hope to maintain superlinear scaling of the neighbor computation with problem size, while adapting to fit the limitations of the computational architecture.

GPU acceleration of this new model is up to 400x on a single workstation, continuing a trend of increasing computational complexity while also increasing efficiency. This approach allows us to compute a range of values rather than monolithic single simulations, and is incredibly important for the orbital analysis. Sensitivity to the orbital parameters is a true unknown, since large impacting NEOs have yet to be observed, so computation for a range of these values is a necessity.

Previous work [3, 4] showed that a large amount of data can be processed using GPU simulation. Initial work was focused mostly on prediction of relative impacting mass, but disruption at different times along a given orbit can have a large effect on the resulting shape of debris. The proposed approach looks at the fragmentation model to better address how uncertainty in the NEO breakup affects orbital prediction, particularly in the case of variable time-to-impact. This allows for a more clear set of objectives for mission design. Another new result is the availability of representative 3-D fragment distributions for non-spherical bodies. This will improve the trajectory of the desired hypervelocity intercept mission by allowing full degrees of freedom in choosing the approach asymptote.

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[2] Kaplinger, B. and Wie, B., "Comparison of Fragmentation/Dispersion Models for Asteroid Nuclear Disruption Mission Design," AAS-11-403, AAS/AIAA Astrodynamics Specialist Conference, Girdwood, AK, Aug. 1-4, 2011.

[3] Kaplinger, B. Wie, B., and Dearborn, D., "Nuclear Fragmentation/Dispersion Modeling and Simulation of Hazardous Near-Earth Objects," 2011 IAA Planetary Defense Conference, Bucharest, Romania, May 9-12, 2011. To appear in *Acta Astronautica*.

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