Preliminary Results from Modeling the Kinetic Impact of the DART Spacecraft into Dimorphos

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Abstract

The National Aeronautics and Space Administration (NASA) Double Asteroid Redirection Test (DART) spacecraft successfully impacted Dimorpohos on September 26, 2022. The mission was the first of its kind to test the kinetic impactor deflection method for planetary defense. Prior to impact, the Investigation Team ran a number of simulations of plausible scenarios. Since impact, modeling efforts have included updated shape models of Dimorphos, surface features detected by mission observations, spacecraft mass and velocity, and momentum enhancement and period change. Here, we share preliminary hydrocode modeling results of DART models.

Introduction

Methods: FLAG Hydrocode

- Abritrary Lagrangian–Eulerian finite-volume code that models solids and fluids [1,2]
- Developed and maintained by Los Alamos National Laboratory [2]
- 1–3 spatial dimensions [1,2]
- Variety of meshing strategies including adaptive mesh refinement [1,2,3]
- Variety of material modeling capabilities including tabular and analytic equations of state, constitutive models, and damage/failure models [1,2]

Dimorphos

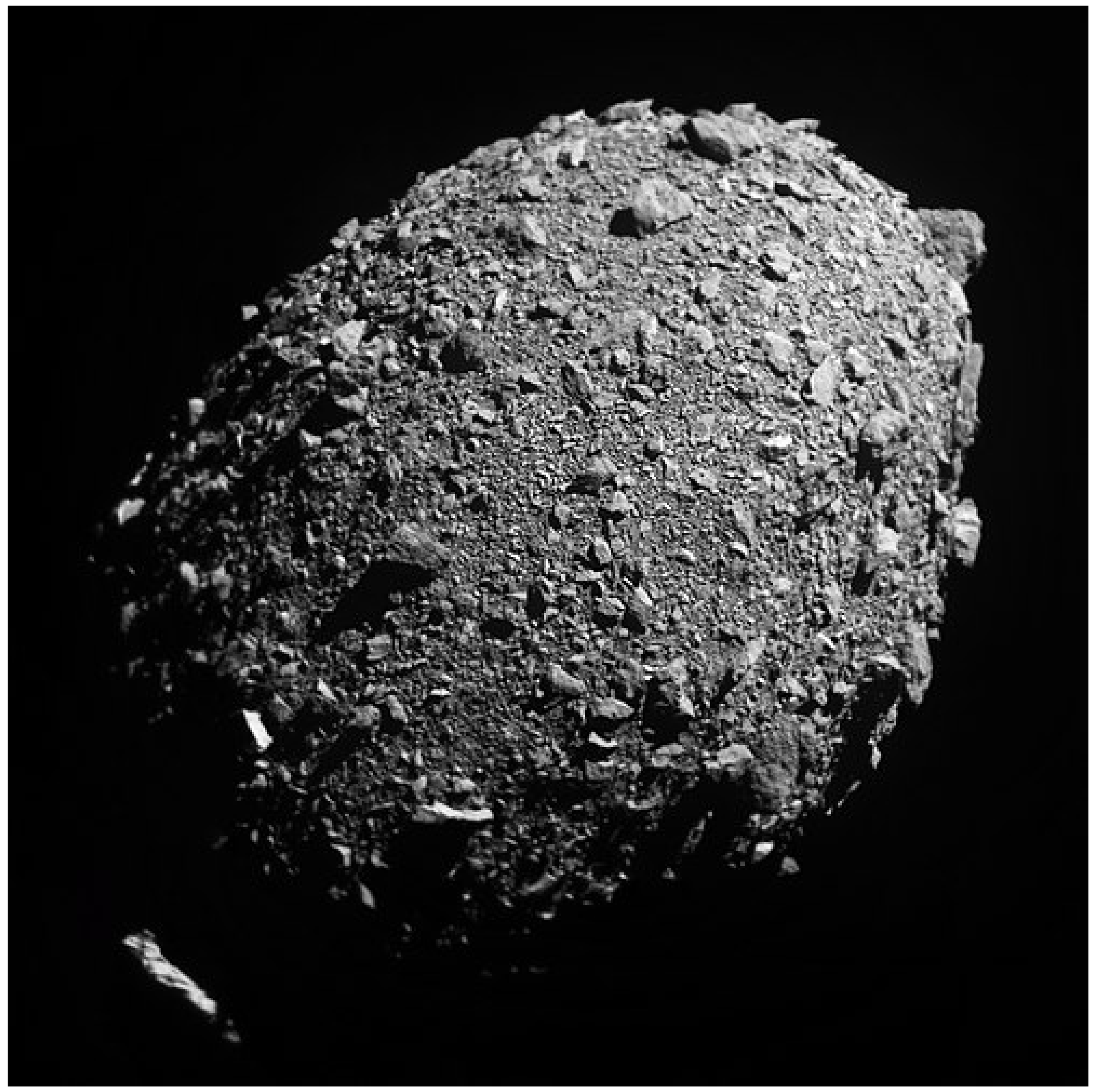
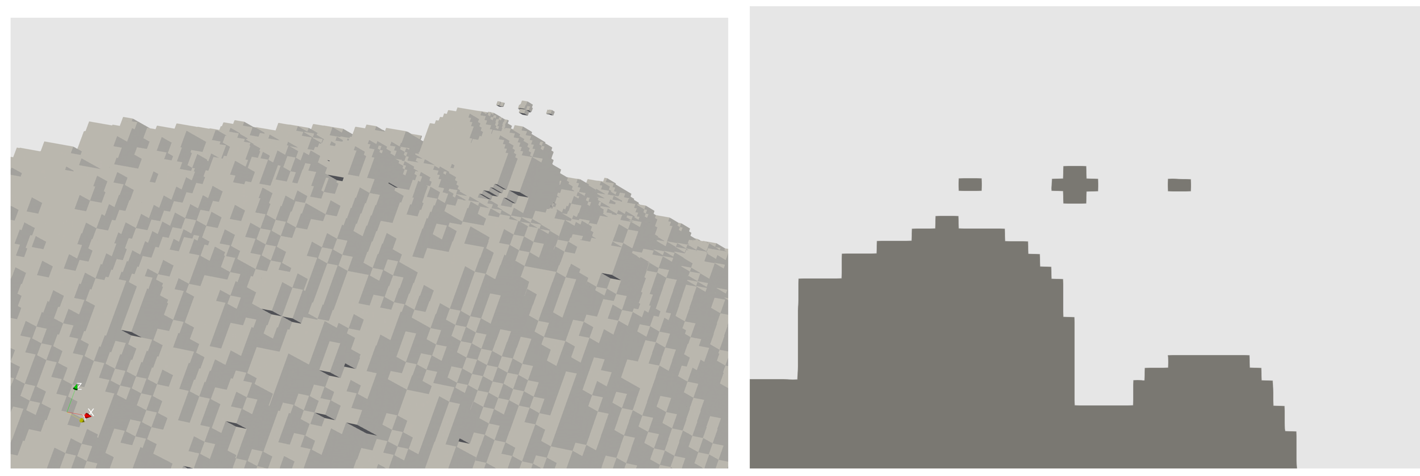


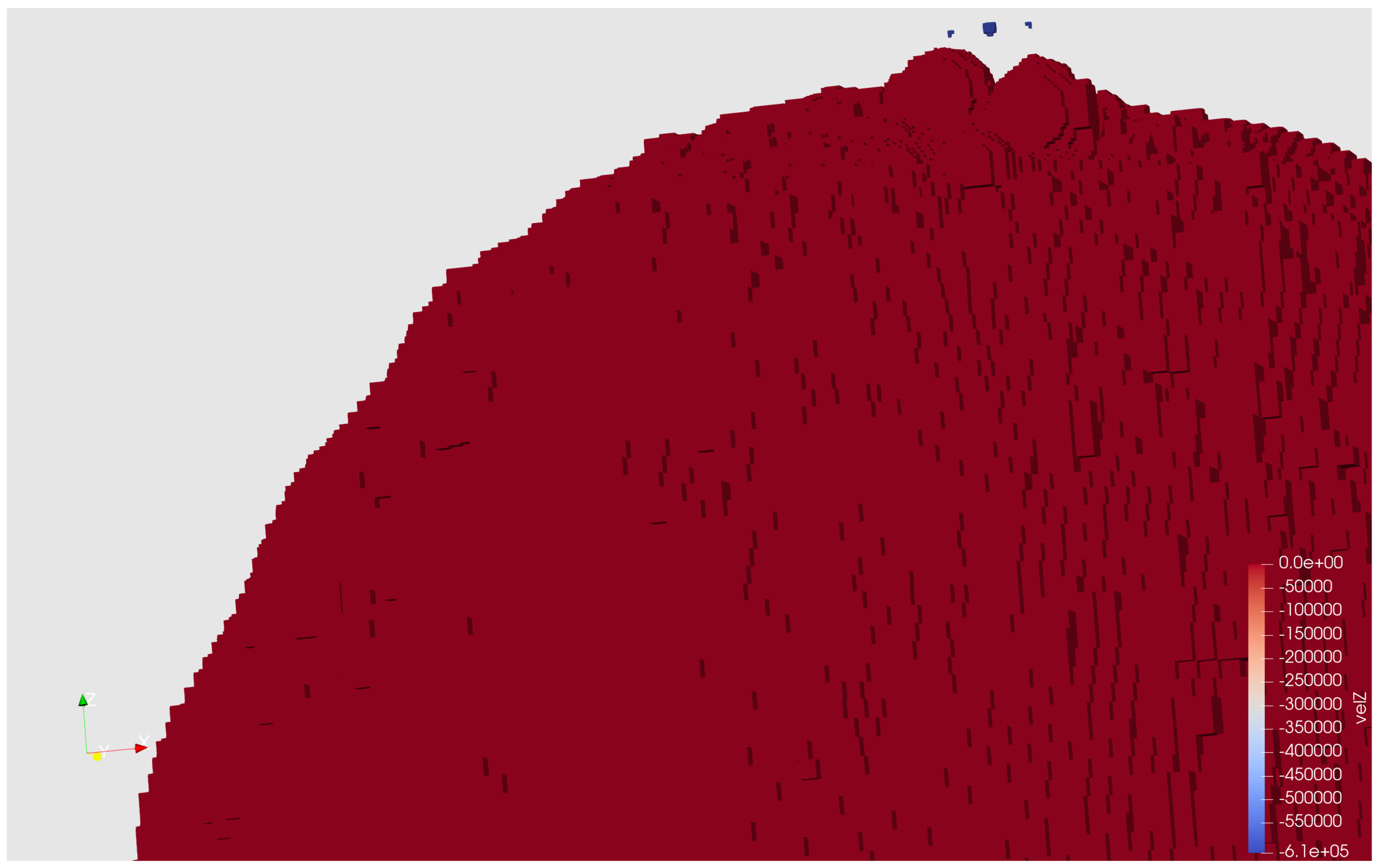
Image of Dimorphos taken moments before impact. Note the surface features, including rough boulders. Such features are key to modeling the DART impact.
Image credit: NASA/Johns Hopkins Applied Physics Laboratory

3D Initializations

We modeled Dimorphos as porous dunite, and we used different material strengths for the boulders and matrix material. Because Dimorphos appeared to have a bouldered surface, we used a rubble-pile configuration for our 3D simulations. Such a configuration is computationally expensive but more representative of the observed surface properties of Dimorphos than a uniform, smooth surface. Preliminary studies from the Investigation Team indicated that modeling the DART spacecraft as 3 colinear spheres, with the center sphere's radius about double the radius of the other spheres, produced results most closely matching those of simulations fully modeling the spacecraft geometry. Thus, we used this same approach to provide a good match to the spacecraft geometry that still allowed for reasonable computational costs. To allow for simulations to run in a reasonable time frame with sufficient memory, we modeled the top half of Dimorphos. Dimorphos was oriented so that the velocity vector of the spacecraft was in the -Z direction.



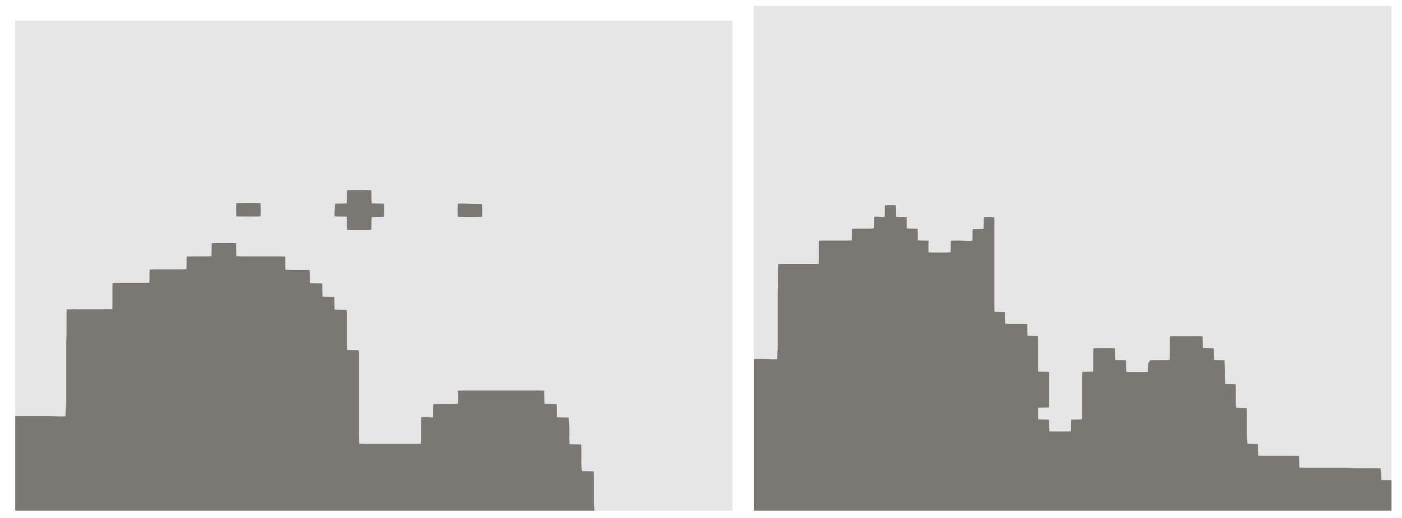
Initialization of simulations with resolution of about 5 cells per projectile radius. Simulations using 10 cppr and 15 cppr are currently running. The left image shows Dimorphos and the DART spacecraft, and the right image shows a 2D slice through the center of the spacecraft, zoomed to show detail. The two boulders present below the spacecraft were modeled from two large boulders observed on Dimorphos prior to impact.



Initialization of DART impact simulations colored by velocity.

3D Results

While our higher-resolution simulations are still ongoing, preliminary results from earlier simulation times show promising trends. As expected, in early simulation time, the momentum enhancement factor β continues to increase until the simulation reaches convergence of β. Simulations less than 0.01 s had β values between 1.1 and 1.3. While these early times cannot provide the same information as later simulation times, the simulations do exhibit expected behavior: β values are increasing with time, as expected, and indicate that momentum from the impact has been imparted to the asteroid. Simulations between 0.01 and 0.05 had β values growing to about 2.3 to 2.5. Again, this trend in earlier times demonstrates the expected result of growing $beta$ values as material begins to be ejected from Dimorphos during the crater formation process.



Images from 2D slices of DART impact models showing (left) initialization and (right) about 0.005 s after impact. Although these early simulation times do not yet show the full effect of the spacecraft's impact, including the ejected material, they do show remnants of the spacecraft post-impact. The two large boulders at the impact site have already begun to deform, and the crater has begun early stages of formation as well.

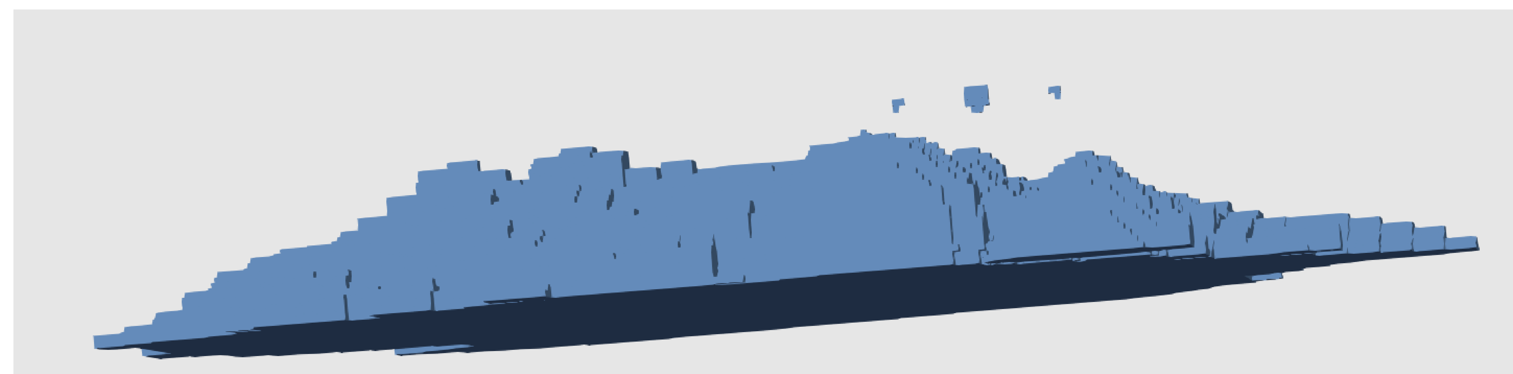


Image of the top approximately 3.75 m of Dimorphos, with the centers of the impactor spheres located about 1.25 m above the highest boulder at initialization. The scale of this image demonstrates the need for meshing techniques to properly resolve the spacecraft while still allowing simulations to be run on fewer than 500 cores.

Conclusions

Preliminary results indicate that mesh resolution affects β values, at least in early time simulations. Conclusions regarding later simulation times will be made once higher-fidelity runs have completed. Modeling the DART spacecraft as 3 colinear spheres allows for deformation of boulders upon impact and is likely sufficient for capturing the important aspects of spacecraft geometry. Higher-fidelity models, including AMR and varied mesh resolution techniques, are needed in order to balance simulation run time with computation cost. Some of these simluations are already running, and we hope to have more updated information before the Planetary Defense Conference as well as in forthcoming publications.

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[3] M. A. Kenamond (2020). Los Alamos National Laboratory Report LA-UR-20-27533.
[*] Authors' Note: Much of this work is currently in manuscripts in progress or recently submitted. Please contact the author at the listed e-mail address for citations for those works once available.