Benchmarking the FLAG Hydrocode for Kinetic Impactor Deflection Simulations

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Abstract

The National Aeronautics and Space Administration (NASA) will test the kinetic impactor method of planetary defense in the forthcoming Double Asteroid Redirection Test (DART) mission. The mission will visit the Didymos binary asteroid system and will impact Dimorphos, the smaller of the two asteroids. Prior to mission launch, it is important to understand how computational modeling tools capture the physics of such an impact, including important properties such as momentum enhancement and period change. A number of hydrocodes have already been benchmarked for the mission using a set of 5 normal impact scenarios as test problems. In this work, we perform these same simulations in the Los Alamos National Laboratory (LANL) FLAG hydrocode.

Introduction

In 2022, the NASA DART mission is scheduled to launch, becoming the first planetary defense mission to test a kinetic impactor for potentially hazardous object (PHO) mitigation. Prior to mission launch, impact modeling simulations are crucial for preparing for eventual spacecraft impact and subsequent data analysis. In this work, we present simulation results in preparation for the DART mission. Our work uses the ALE hydrocode FLAG, developed and maintained by LANL, to simulate high velocity impacts into solid bodies. FLAG has previously been verified and validated for impact cratering simulations (Caldwell *et al*. 2018).

Benchmarking Cases

To benchmark FLAG for the DART mission, we replicated simulations performed by the DART Impact Modelers Working Group (Stickel *et al*. 2020). These simulations involved aluminum and basalt impactors and targets, testing a variety of strength, damage, and porosity models to understand those effects on crater formation and momentum enhancement (β), which measures the post-deflection momentum of an asteroid relative to the initial impactor momentum, a crucial quantity in determining the effectiveness of a kinetic impactor.

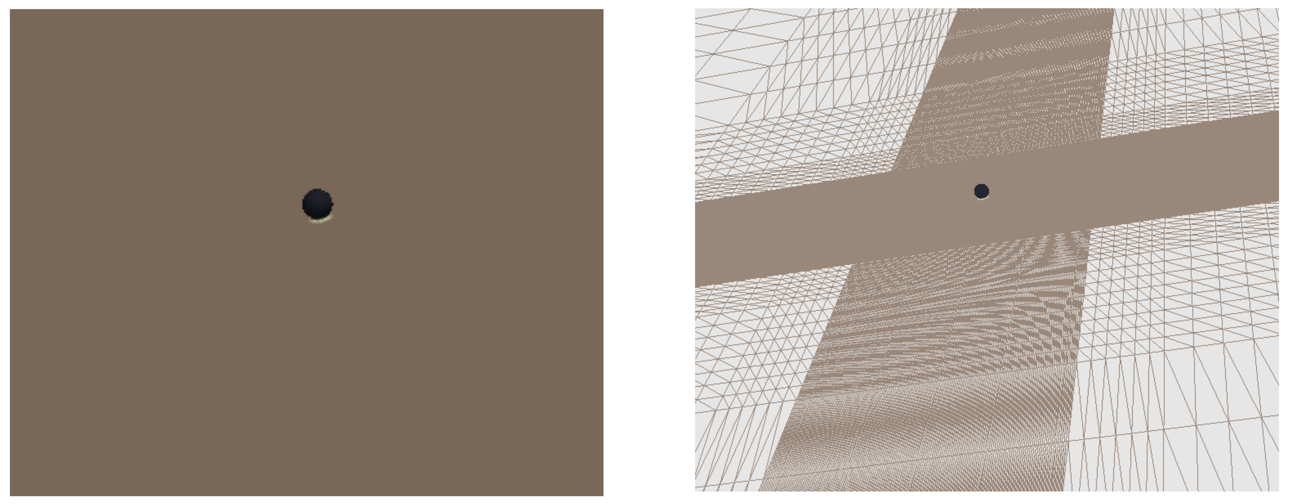

Figure 1. Case 1a at initialization zoomed to show impactor (left) and mesh (right).

Case	Material	Plasticity Model	Damage Model	Porosity Model
1a	Al-6061	None	None	None
1a'	Al-6061	Von Mises	None	None
1b	Basalt	None	None	None
2	Basalt	Von Mises	Johnson-Cook	None
3	Basalt	Von Mises	Johnson-Cook	P-α
4	Basalt	Von Mises	Johnson-Cook	P-α

Table 1. Cases used for benchmarking hydrocodes for the DART mission. Cases 1, 1a', 1b, 2, and 3 had the same geometry of a sphere impacting a target block but differing material properties. Cases 3 and 4 had the same material properties but differed in target geometry, with Case 3 having a target block and Case 4 having a target sphere.

Momentum Enhancement (β) over Time

Strengthless runs resulted in β values that continued to increase over time rather than converging to a value. This behavior is expected for strengthless simulations, while runs with strength should converge to a β value.

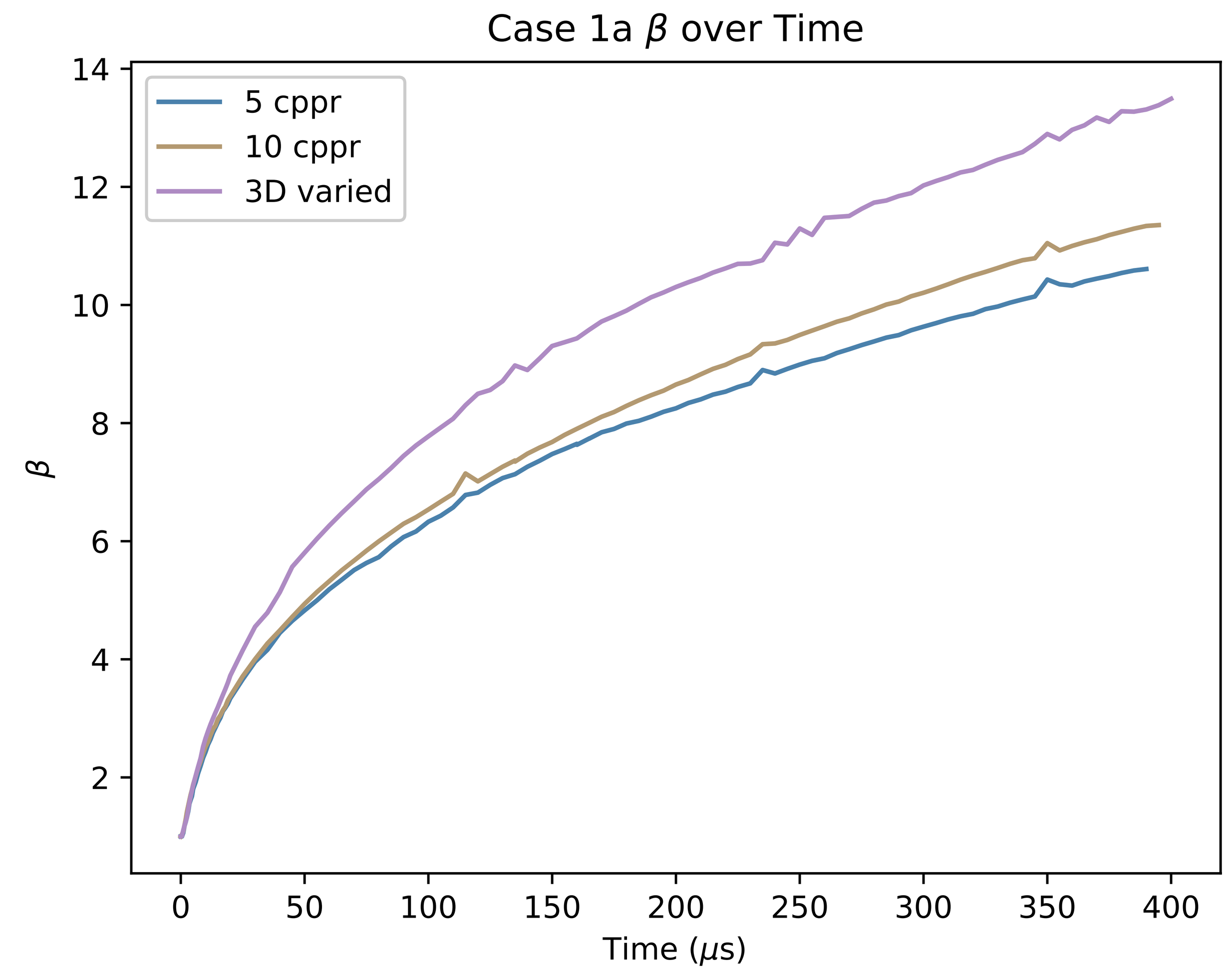

Figure 2. β over time for strengthless Al-6061 impact in 2D and 3D FLAG simulations. Resolution is given in cells per projectile radius (cppr), and the 3D simulation had a varied resolution, most resolved near the point of impact (5 cppr).

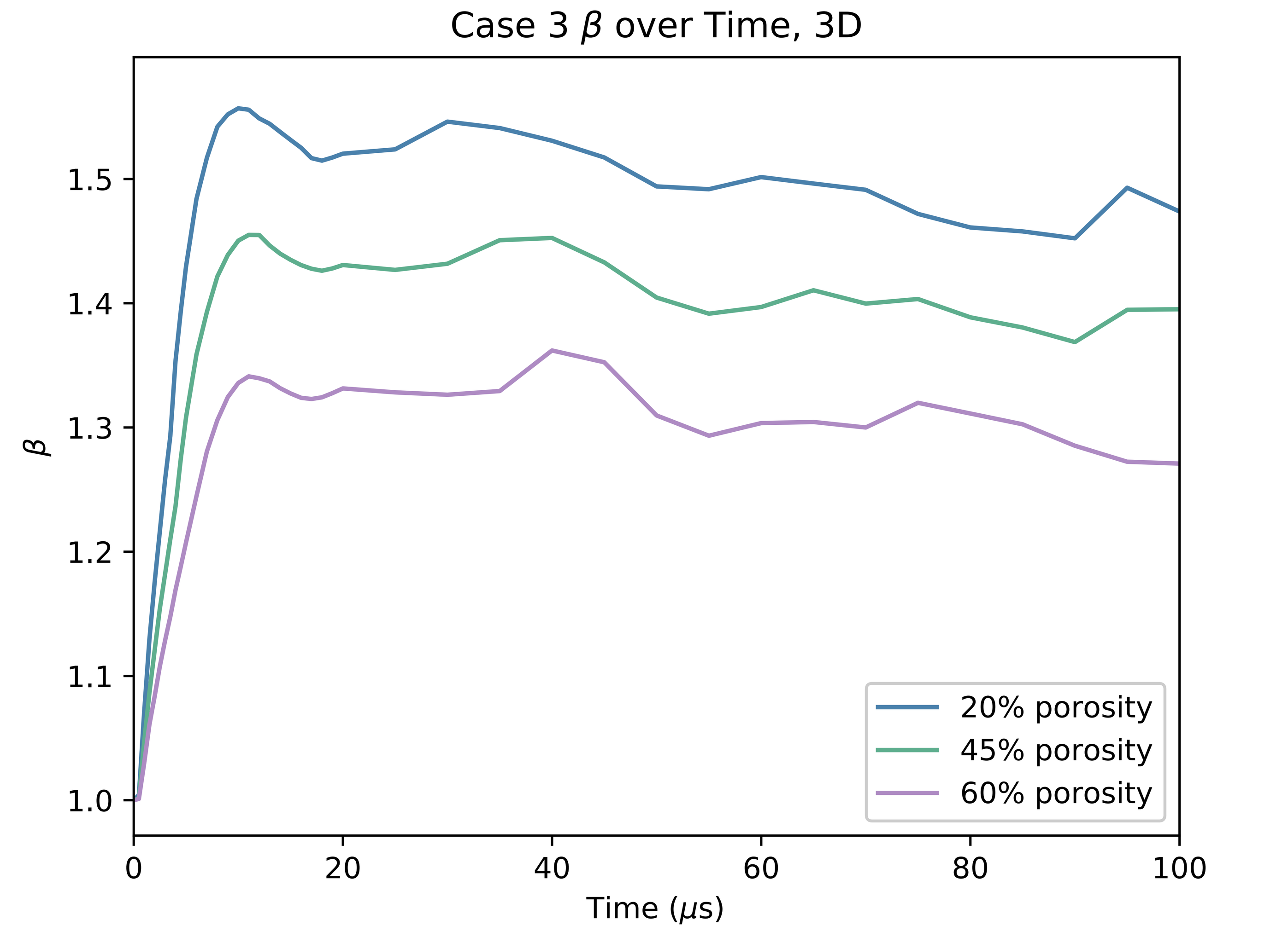

Figure 3. β over time for basalt impact with strength, damage, and target porosity in 3D FLAG simulations. As expected, β does not continue to grow as in strengthless simulations but instead converges over time.

Crater Dimensions over Time

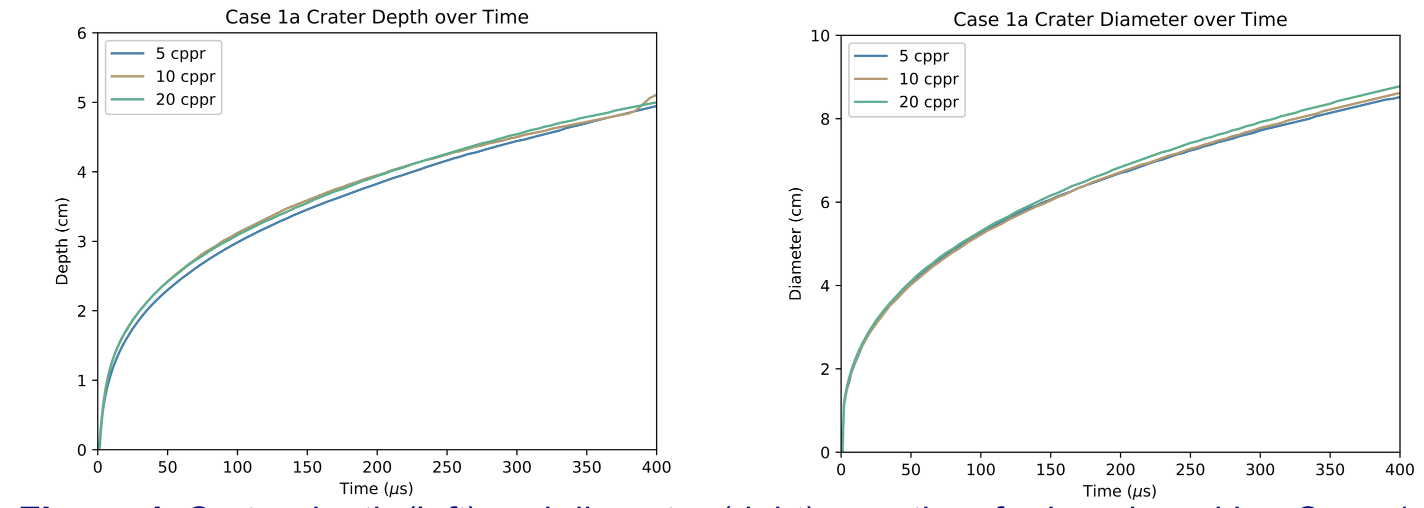

Figure 4. Crater depth (left) and diameter (right) over time for benchmarking Case 1.

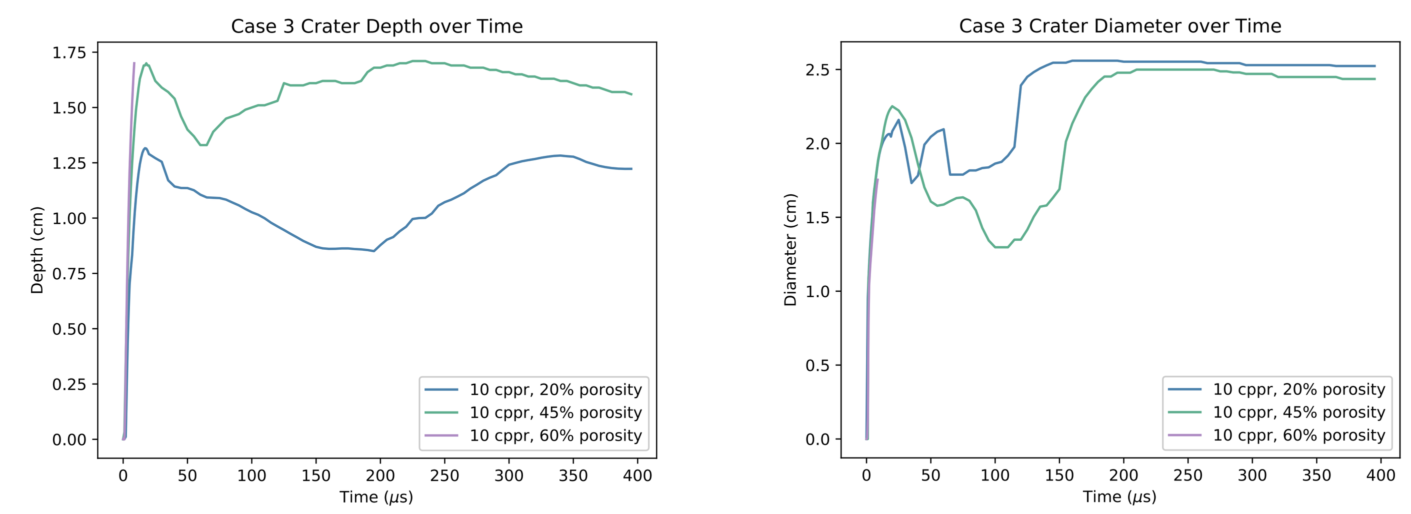

Figure 5. Crater depth (left) and diameter (right) over time for benchmarking Case 3.

Acknowledgments

This work was supported by a Chick Keller Postdoctoral Fellowship from the Center for Space and Earth Science at Los Alamos National Laboratory. Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by Triad National Security, LLC, for the National Nuclear Security Administration of the U.S. Department of Energy under contract 89233218NCA000001.

LA-UR-21-23634

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