CRATERING AND EJECTA FROM THE DART IMPACT – INFLUENCE OF SPACECRAFT GEOMETRY.

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Introduction: On September 26, 2022, the first full-scale demonstration of a kinetic impactor for planetary defense was performed as part of NASA's Double Asteroid Redirection Test (DART) mission. The impact of the ~579kg spacecraft into Dimorphos, the secondary of the (65803) Didymos system, at ~6.14 km/s caused an orbital period change of ~33 minutes [1], resulting in a momentum enhancement factor, or β, of ~3.6 [2].While observations can provide information about the amount of ejecta produced, the change in orbital period, and momentum enhancement factor, numerical simulations are one of the only tools that exist that can provide details of the physics that occurred during the impact and subsequent cratering.

During the DART spacecraft's approach to Dimorphos, the Didymos Reconnaissance and Asteroid Camera for Optical navigation (DRACO) instrument acquired numerous images of Dimorphos and impact site prior to impact [3]. These images show that the surface of Dimorphos is covered in many boulders with no observed regions of fine-grained regolith. Further, from impact site reconstruction, we know that the DART spacecraft impacted such that each of the spacecraft wings impacted onto two separate boulders [3]. These details of the impact geometry are important to understand and recreate the DART impact physics.

Prior to the DART impact, the DART Impact Modeling Working Group (IWG) performed many studies to identify specific characteristics and material properties influence impact cratering and the momentum enhancement factor, β. From these studies, it was identified that material strength and porosity, the rubble pile nature of the asteroid, and spacecraft impactor geometry (shape and angle) were all important aspects which would alter the outcome of the impact [4].

Using hydrodynamic shock physics codes, such as CTH (an impact code developed by Sandia National Laboratory) [5], combined with the observations of surface structure and morphology, it is possible to reconstruct what occurred during the DART impact. These simulations can be used to predict the cratering that could be observed when the European Space Agency (ESA) Hera mission visits the Didymos system in late 2026 [6]. While we must wait for validation of our simulations for the cratering until later this decade, we can compare the ejecta and the β value from the DART impact to determine the plausible impact scenarios and material properties that gave rise to the DART impact outcomes.

Preliminary Results: Based on pre-impact simulations, we know that material strength, porosity and impactor geometry are all important factors in determining cratering and ejecta properties for hypervelocity impacts [4]. Work prior to the DART impact demonstrated that the complex spacecraft geometry can also influence the cratering on the surface and alter how the momentum enhancement and ejecta properties [7]. Building off of that work, we have now taken the exact DART spacecraft velocity and mass to reconstruct the DART impact. Figure 1 displays an image of the initial conditions of the simulation, with the DART spacecraft above a monolithic asteroid surface in the CTH hydrocode.

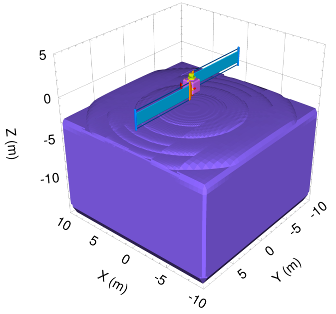

Figure 1: Image of the DART spacecraft impact simulation set-up in CTH. Here, the asteroid is modeled as a monolith, without any boulders.

While we know that the DART spacecraft impacted into a boulder strewn surface, simulations combining the full 3D spacecraft geometry with rubble pile structures is computationally stressing. As such, we begin our initial studies with a monolithic asteroid target. However from previous simulations, we know that rubble piles and boulders decrease the momentum enhancement so any simulations impacting into monoliths would need to be in excess of the observed momentum enhancement [4]. The cratering observed in simulations of monoliths however would not be the same as is observed with boulders. The boulders on the surface impact the crater shapes and volumes in ways that are difficult to predict without the use of numerical simulations.

For our simulations, we make some assumptions on the material properties based on the large amounts of ejecta observed during the impact. The asteroid material is modeled as basalt with a density of 2.3 g/cc (15% porosity) [3]. The strength of the material is low, 1 kPa, and the surface is modeled as a granular material, with a coefficient of internal friction of 0.7. Figure 2 displays an image of the crater at ~100 msec. We can see two side craters surrounding the central large crater. The two side craters are formed from the spacecraft solar panels impacting the surface. The spacecraft bus contains ~88% of the spacecraft mass, so the central crater is larger than the smaller two side craters. This crater is a transient crater, and as time evolves the two side craters would likely merge into the central crater, as was seen in previous studies [7].

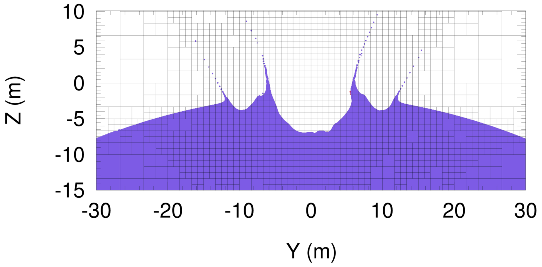

Figure 2: Image of the crater formed during the DART Impact from simulations of a weak asteroid at 100 msec.

We obtain a value for β of ~ 3.6 at 100 msec for the simulation, matching the analytical solution for β reported in [2]; the time evolution of β is shown in Figure 3. At 100 msec, the value for β in the simulation is still evolving and growing. This is not surprising given the low strength of the material but does indicate that for this monolithic target, the final value for β would be in excess of the DART impact value. This suggests good agreement with the value from DART as the boulders present on the surface would reduce the final value for β.

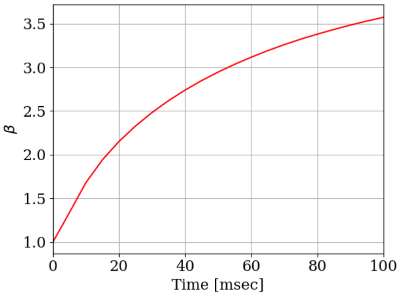

Figure 3: Time evolution of β for impact simulation of the DART impact into a weak asteroid.

Summary and Future Work: Here, we present initial simulations of a weak asteroid target being impacted by the full spacecraft geometry of the DART impact. Although these simulations are of a monolithic surface, we plan to extend these to include both boulders on the surface and rubble pile geometries, impacting with the full DART spacecraft geometry. This will allow for us to acquire predictions for the crater and β with a realistic simulation of the full DART impact. We will further compare these runs to both other simulation codes to understand the sensitivities to our model parameters and to observational estimates of β and ejecta mass.

It is important to note that while the material properties here were chosen because they had good agreement with the DART impact for a monolithic asteroid, it is likely that the range of material properties that reproduces observations from the DART impact will be quite broad. Based on the value of β obtained, the strongest material properties (strengths > 1 MPa) can be ruled out as possible initial conditions, however weak to moderately strong asteroid materials are not currently excluded from the range of possible material properties. Until the ESA Hera mission, we will be unable to say precisely what the crater formed from the DART impact looks like but these simulations can provide us with initial knowledge and estimates of what we could expect to see when Hera visits Dimorphos in 2026.

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References: [1] C. Thomas et al. (in revision) [2] A. Cheng et al. (under review). [3] R. T. Daly et al. (in revision). [4] A. M. Stickle et al. (2022) *PSJ, 3,* 248. [5] J. M. McGlaun et al. (1990) *IJIE*, 10 351-360. [6] P. Michel et al. (2022) *PSJ, 3,* 160. [7] J. M. Owen et al. (2022) *PSJ, 3,* 218.