NUMERICAL MODELLING OF THE DART IMPACT AND THE IMPORTANCE OF THE HERA MISSION S. D. Raducan[1], T. M. Davison[1], G. S. Collins[1]. [1]Impacts and Astromaterials Research Centre, Department of Earth Science and Engineering, Imperial College London, London, SW7 2AZ, United Kingdom (E-mail: s.raducan16@imperial.ac.uk).

Introduction: Earth is continuously impacted by space debris and small asteroids, and, while large asteroid impacts are uncommon, they could produce a severe natural hazard. NASA's Double Asteroid Redirection Test (DART), set to launch in 2021 [1], aims to be the first mission to test a controlled deflection of a Near-Earth binary asteroid, by impacting the smaller component of the 65803 Didymos asteroid system [2, 3]. The impact will thereby alter the binary orbit period by an amount detectable from Earth [1].

In high velocity impact events the change in momentum of the asteroid ΔP can be amplified by the momentum of crater ejecta that exceeds the escape velocity, which is often expressed in terms of an empirical value, $\beta = \Delta P/(mU)$, where mU is the impactor momentum [4]. The DART mission, together with Earth based measurement, will measure the deflection of the Didymos secondary–Didymoon–and hence, β. However, the amount by which crater ejecta enhances asteroid deflection–that is, the normalised momentum of the crater ejecta that escapes the gravitational attraction of the target body ($\beta - 1$)–has been found to vary significantly depending on the target asteroid's properties and composition [5]. Thus, without knowledge of the surface properties of the Didymos secondary, a measurement of β alone is not sufficient for the purpose of numerical model validation.

For a better constraint of Didymoon's target properties, ESA is planning a rendezvous mission, Hera [1, 6], that has a 2023 planned launch and will arrive at Didymoon several years after the DART impact. The spacecraft will enable us to perform detailed characterisation of the Didymoon volume and surface properties, as well as measure the DART impact outcome, such as change in the binary system orbit or the volume and morphology of the DART impact crater. Here, we discuss the measurements made by Hera that should enable us to infer the asteroid surface material properties from the DART impact crater morphology.

Numerical Model: We used the iSALE shock physics code [7, 8] to numerically model the DART impact in two and three dimensions. The DART spacecraft structure was modelled as a porous aluminium sphere, impacting a basalt target at 7 km/s.

Didymoon is too small and distant from the Earth to be individually resolved and no spacecraft has visited it, yet, so the material properties and the internal structure are unknown. However, observational studies [3, 6] suggest that Didymos is an S-type silicaceous asteroid system, and therefore the target asteroid material was considered to be made of weak porous basalt, which is a good approximation of the compositional structure of most asteroids. To study the target material response to a possible impact, we considered three distinct target scenarios:
a) a homogeneous porous half-space;
b) layered targets with a porous weak upper layer overlying a stronger bedrock layer;
c) targets in which porosity decreases with depth
For each of these target scenarios we systematically varied the target material properties (e.g. the cohesional strength, porosity or coefficient of internal friction, the layer thickness or the porosity gradient profile) and determined the crater morphology and the momentum carried away by the ejecta, $\beta - 1$.

Momentum enhancement: In all of our numerical simulations, asteroid deflection was amplified by the impact ejecta, i.e. $\beta - 1 > 0$. Consistent with previous work [4, 9–11], we found that the amount by which the deflection was amplified depended strongly on the target properties. We first modelled impacts into porous half-space targets, with a cohesional strength of the damaged material, Y_0, between 0.1 and 100 kPa. We found that the amount of momentum transferred from the impactor is highly sensitive to Y_0: the weaker the target, the more deflection occurs (Fig. 1). For a porous half-space target DART scenario, $\beta - 1$ can vary between 0.5 and 3.5.

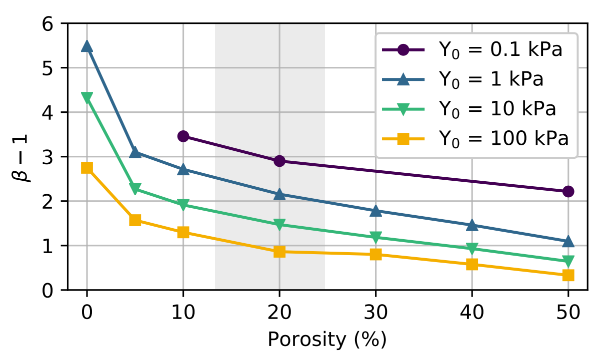

Figure 1: Total ejected momentum in the z direction ($\beta - 1$) for four different cohesions and different porosities of the target. The grey shaded region is the current estimate of the porosity of Didymos system [12].

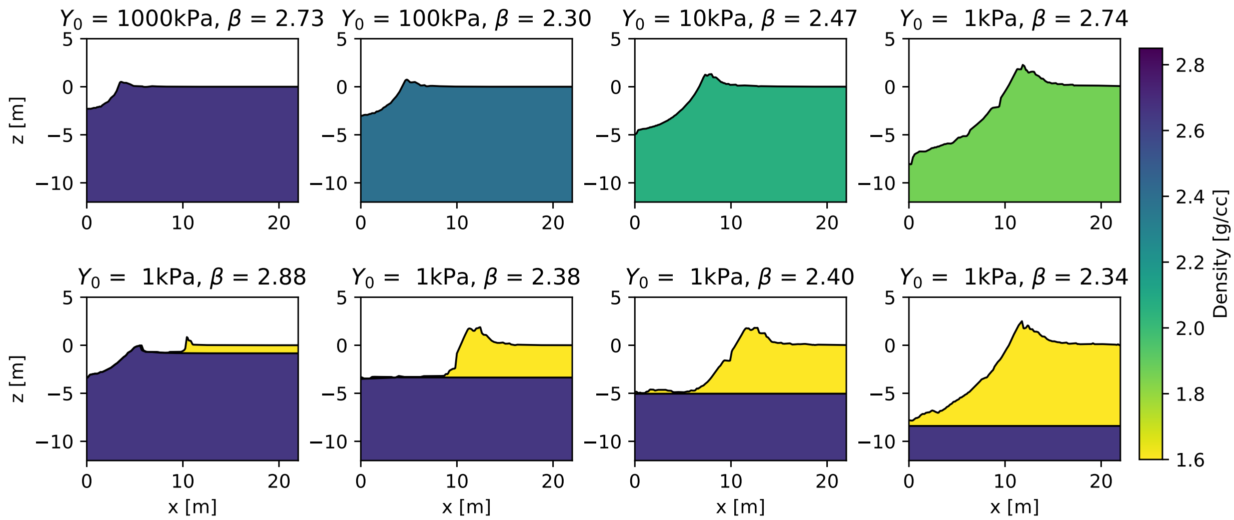

Figure 2: Crater morphologies for eight impacts into targets with different properties that produce a similar total ejected momentum ($2.3 < \beta < 2.9$).

The DART mission will not be able to measure the cohesive strength of the target before the impact or to select the impact site. Therefore, DART could impact a strong boulder (e.g., as seen on the recent images of Bennu and Ryugu), which might result in almost no momentum enhancement. On the other hand, DART could hit a smooth, very weak terrain, with a cohesion Y_0 even lower than our investigated range, which might provide a very large deflection of the asteroid. The porosity of the surface material was found to also influence the deflection, but not to the extent of the cohesive strength. An increase in porosity of 10% can decrease $\beta - 1$ by up to 0.5, for a given target material.

Crater morphology: We found that similar deflection (i.e., similar β values), can be achieved by impacting targets with very different material properties or structures. However, these impacts produce different crater morphologies (Fig. 2). For example, our simulations suggest an impact into a strong 10 MPa homogeneous non-porous surface results in the same momentum enhancement as an impact into a weak 1 kPa, 50% porous surface ($\beta \approx 2.7$). However, these two impacts produce craters that differ considerably in size, with diameters of $\approx$ 6.5 m and 20.5 m, respectively. Another factor that can introduce non-uniqueness is target layering (Fig. 2). Impacts that result in similar values of β can result in different crater morphologies, depending on the pre-impact upper layer thickness [e.g. 13]. The Hera mission will be able acquire high-resolution images and measurements of the DART impact crater which will hopefully allow the asteroid's near-surface properties and structure to be inferred and provide robust validation of impact simulations. Such validation would greatly increase confidence in the numerical predictions of kinetic impact deflection.

Conclusion: We found that for impacts on small asteroid surfaces β is most sensitive to the cohesion of the target. For a homogeneous porous Didymoon, the expected enhancement resulting from the DART impact is $\beta - 1$ between about 1 and 3, implying a momentum multiplication factor of between 2 and 4. By measuring the DART crater, the Hera mission will be vital for validating the predictive capabilities of numerical models of asteroid deflection.

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