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Kinetic impactor technique: Benchmark and Validation Studies with iSALE and SPH

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Introduction: NASA's Double Asteroid Redirection Test (DART) will impact the secondary of the 65803 Didymos system, Dimorphos, at the end of October 2022 [1]. The impact will cause a measurable change in the orbital period of the binary. ESA's Hera mission [2] will arrive at the Didymos system several years after the DART impact and will characterise the binary system in detail, particularly the small moon and the crater produced by DART on its surface.

The aim of this work, which was generated in the context of the NEO-MAPP project, is to model the collision of the DART kinetic impactor with Dimorphos and to provide quantitative and reliable predictions regarding the outcome of the impact with respect to parameters that are measurable by spaceborne and in-situ instrumentation provided by the Hera mission. We model the impact using two different codes: iSALE-2D/-3D & Bern SPH. In order to improve the reliability of results from numerical modelling, accurate validation tests against laboratory experiments are required.

Method: iSALE-2D/-3D [3, 4] is a grid-based arbitrary Eulerian and/or Lagrangian (ALE) code and is best suited to study the crater formation and the propagation of shock wave from a high velocity impact. On the other hand, Bern's grid-free Smooth Particle Hydrodynamics (SPH) [5, 6] is most appropriate to study the ejection of material and processes where the entire target body is involved. In iSALE the porosity compaction behaviour of the target material is modelled using the ε-α model, while SPH uses the P-α model. In this study, we employ the Drucker-Prager and the Lundborg rheology models to describe the strength of the material. For both codes, the ejection behaviour is analysed as described in [7,8] and was used to determine the momentum transferred onto the target (momentum enhancement factor β= transferred momentum / impactor momentum). This approach was used previously for systematic material studies [9] and benchmarking studies [10]. Despite the fact that all codes in principle solve similar forms of conservation equations and use similar constitutive models, different numerical schemes tend to produce more or less varying results. Here, we present first results of a new validation study that extends the range of tested target materials to glass beads and regolith simulant (i.e., smaller or larger coefficient of friction, respectively, and larger cohesion for regolith simulant), and compare against results from a recent laboratory study [11], where PVC projectiles with a mass of ~25 mg were accelerated to velocities of 1-2 km/s. We also continue the benchmarking work done by the Hera impact working group [12] to detect, assess and remove deviations between two different numerical schemes, iSALE (in 2D and 3D) and Bern SPH.

Validation Results: We have simulated the crater formation in glass beads and regolith simulant with iSALE at impact speeds of 2.4 km/s and 2.2 km/s, respectively. The glass beads target was modelled using a Drucker-Prager criterion with a coefficient of internal friction, f = 0.5 and an initial porosity of 35%. The regolith simulant used f ~ 0.8 and an initial porosity of 42%. We determine β-values of 2.9 and 1.4, which agree to experimentally determined values of 2.7 and 1.3, respectively. In the glass beads target laboratory experiment, at ~0.5-1 ms after the impact, the ejecta curtain made an angle of 50-60°. In the case of the regolith simulant, at ~0.5 ms after the impact, the ejecta curtain angle was 30-40°. From our numerical models, we determined ejecta curtain angles 0.5 ms after the impact as 48° (glass beads) and 30° (regolith, Fig. 1). Both results agree with the lower bound of the experimental constraints.

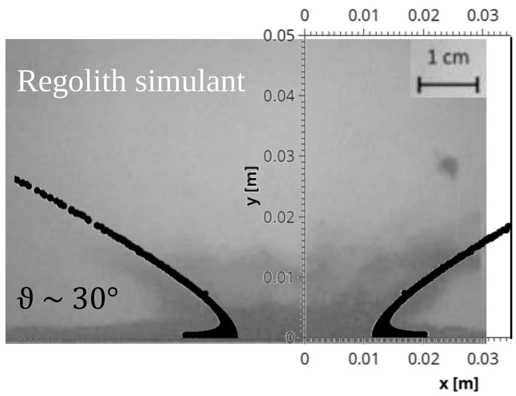

Figure 1: Experimental (background) and modelled (black) ejecta curtain for regolith simulant at 2.2 km/s impact velocity 0.5 ms after impact.

Benchmark Results: The first benchmark study focuses on the influence of target porosity on the efficiency of the momentum transfer from the DART impact, β, for materials similar to the regolith from the experiments. The 500 kg aluminium spherical projectile impacts targets with varying porosities between 20 and 50%, and cohesions from 1 to 100 kPa at a velocity of 6 km/s. The second benchmark study focuses on the influence of the impact angle on β for the 20% porosity case with 10 kPa cohesion at an impact velocity of 7 km/s.

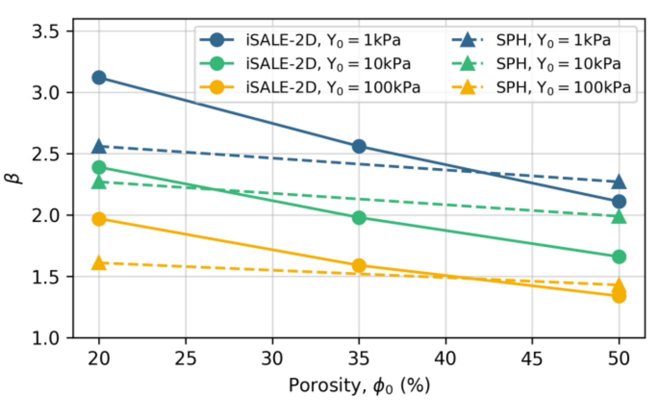

Figure 2: Momentum enhancement factor β for simulations done with iSALE and SPH for different target properties.

In general, we find good agreement between the results derived with iSALE and SPH (Fig. 2). However, for a porosity of 20% and a cohesion of 1 kPa or 100 kPa, SPH gives ~20% smaller values than iSALE, while it exceeds the values for 10 kPa cohesion and 50% porosity by ~25%. For both codes, we used crush curves which are consistent with the quasi-static crush curves of lunar regolith. The differences in β might relate to code specific or user defined parameters, which have no direct correlation between the codes.

Varying the impact angle for a specific impact scenario and set of target properties shows a remarkably good agreement between the two codes (Fig. 3).

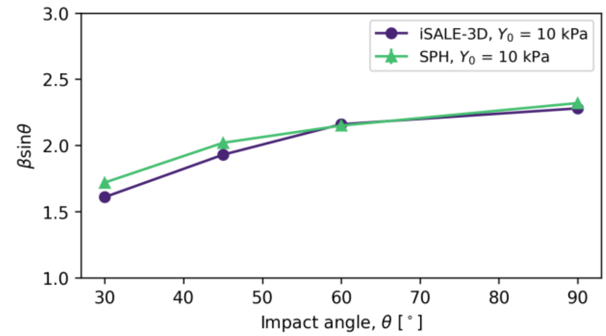

Figure 3: Momentum change in the orbital velocity direction ($M\Delta v/mU$ ~ $\beta sin(\theta)$) for simulations done with iSALE-3D and SPH for impact angles from 30-90° for a 20% porous, cohesive target (U = 7 km/s).

Summary: Our joint modelling and experimental approach to study the efficiency of a kinetic impactor to deflect an asteroid shows that there is generally a good agreement between different numerical approaches and experimental work on estimating crater size and ejection parameters. The benchmark studies show that the grid based iSALE (-2D/-3D) and the meshless SPH produce similar results when similar impact conditions are considered. In a next step, we will investigate the cause of the observed small deviations between different modelling schemes, and we expand our study to further materials and impact regimes.

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