Momentum Enhancement and 3D Visualization of the DART Kinetic Impact.
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Abstract: We study deflecting sub-kilometer sized potentially hazardous asteroids that may collide with Earth by deploying a kinetic impactor. The momentum delivered by the impact of a spacecraft may sufficiently alter the asteroid's orbit and henceforth avoid an impact with our home world. While near-Earth asteroids of this size are difficult to observe, they are believed to be very common and to consist of a wide variety of materials with varying bulk densities.

Apart from directly transferring momentum from the projectile to the target, post-impact effects of a kinetic impact will cause material to be ejected from the impact site. This material will carry additional momentum and hence increase the target's momentum after the impact, translating to a momentum transfer efficiency $\beta > 1$ which is only weakly constrained due to the unknown target material and porosity. In an effort to constrain this β factor, we study the impact of a spacecraft onto an asteroid similar in size to the secondary body "Didymoon" of the binary near-Earth asteroid (65803) Didymos, the target of NASA's Double Asteroid Redirection Test (DART[1]) and ESA's Hera[2] mission concepts.

We present results from simulations with our own 3D smooth particle hydrodynamics (SPH) hypervelocity impact code. Depending on the impact angle and target porosity, we find β factors between 1.15 and 1.93, which is compatible with results obtained in a previous study and by others using various methods. Real-time analysis of the simulated impact process and the resulting surface features will allow us to align simulation results with observations of the ESA Hera mission, further constraining material and porosity parameters of the mission target.

Method and Simulations:

Impact simulations. We deploy our 3D smooth particle hydrodynamics (SPH) hypervelocity impact code (e.g., [10, 12, 5]) that implements elasto-plastic continuum mechanics, a fragmentation model for fracture and brittle failure [4, 1], and the P - α porosity model [7]. A tensorial correction as outlined in [11] warrants first-order consistency.

In the impact simulations, we resolve each scenario in 1M SPH particles. The physical system underlying the simulations is based on a rocky cuboid section of Didymoons's surface corrected for a surface curvature corresponding to an assumed target diameter of 160 m. This results in a resolution of about 50 cm in the simulation scenarios. Target porosities range from 0 % (competent rock) to 75 %. The projectile is modeled as a single aluminum SPH particle with a mass of 500 kg that hits Didymoon at 6 km s^{-1} and impact angles of 0° (head-on) and 45°, respectively.

The total momentum carried away to infinity by escaping ejecta enhances the momentum transferred to the target by a factor β. We calculate this β factor post-simulation as described in [9].

Impact visualization. The simulation results (point cloud data) are visualized using the Aardvark open-source platform for visual computing, real-time graphics, and visualization developed at VRVis. Aardvark is able to handle large simulation datasets in the terabyte-scale.

Results and Conclusions: Figure 1 shows the simulated domain of the target along with the impact ejecta at 0.4 s after the impact. The velocity components in xyz direction are rgb color coded: with the impact site being in the xz-plane, green corresponds to the velocity component perpendicular to the target's surface.

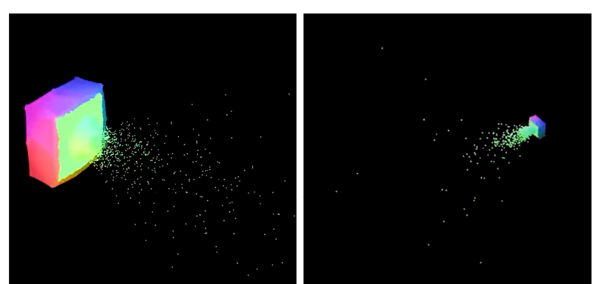

Figure 1: Simulation showing a patch of Didymoon's surface with ejected material 0.4 s post-impact as seen from two different viewing angles. See text for details.

Table 1 lists the β factors resulting from different assumed target porosities and impact angles. The results

[1] https://www.nasa.gov/planetarydefense/dart

[2] https://www.esa.int/Safety_Security/Hera

suggest a systematically smaller momentum enhancement factor for increasingly porous target material. Our results are compatible with independent studies that predict the momentum transfer efficiency using different methods such as scaling models [2, 3, 6] and a different SPH impact code [8] (see Fig. 2).

Table 1: Results for various impact configurations and porosities of the target.

Impact angle	Target porosity	β factor
Head-on (0°)	0 %	1.93
Head-on (0°)	20 %	1.52
Head-on (0°)	50 %	1.27
Head-on (0°)	75 %	1.15
45°	0 %	1.79
45°	20 %	1.70
45°	50 %	1.49
45°	75 %	1.31

With Hera surveys of the vicinity of the DART crater down to an expected resolution of 10 cm and comparing these observations to VRVis-powered visualizations of the simulation outputs, we expect to constrain Didymoon's material, porosity, and internal structure. Once the final mission parameters of DART are available, we plan to run higher-resolution simulations down to the survey-resolution of 10 cm.

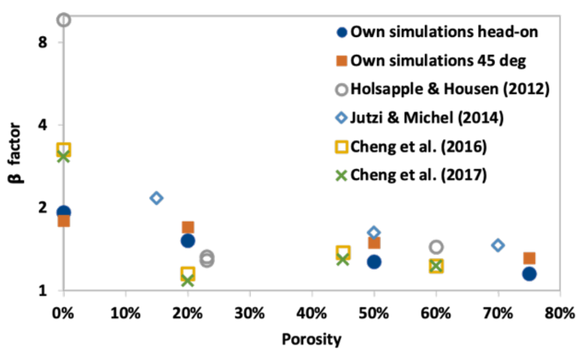

Figure 2: Comparison with existing results (β corrected for impact velocity v_p: β-1 ~ $v_p^{3\mu-1}$, [6]). References: [6] Holsapple & Housen (2012), [8] Jutzi & Michel (2014), [3] Cheng et al. (2016), [2] Cheng et al. (2017).

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