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Recent Results from the Hera Impact Simulation Group: Benchmarking of Shock Physics Codes

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Abstract

We use different numerical approaches (SPH vs. ALE) to benchmark the outcome of impact simulations. We use different target properties and apply our results to the DART impact event.

1. Introduction

In September 2022, NASA is going to impact the moon of the binary asteroid Didymos with the DART space craft to demonstrate the "kinetic impactor" asteroid deflection technique. Hera is ESA's contribution to this international cooperation and is planned to be launched in 2023/2024, aiming at a detailed characterisation of the binary system, the small moon, and the crater produced by DART. The HERA impact simulation working group combines experimental and numerical experience in order to improve predictions on the resulting crater morphology and morphometry, the ejection and deposition of material, and the momentum transfer. The most important factors that influence the results of crater simulations for the DART cratering event are the target properties of the asteroid (mainly porosity and strength). Therefore, our study focuses on determining how the variation of these parameters over a realistic range might affect the impact process. In addition, we have carried out a benchmark study with different shock physics codes.

2. Method

We use grid based shock physics codes (iSALE [1,2,3], HESIONE [4], RADIOSS) and particle based codes (SPH [5,6,7]), which include strength and failure parametrisations [e.g. 2, 8] and porosity-compaction models [e.g. 3, 9, 10,11]. In our study, we use two test cases. First, we simulate the impact of an aluminium sphere (6.35 mm) with a velocity of 5 km/s on an aluminium target, which is assumed to i) be strengthless, ii) have a Von-Mises strength of 275 MPa [12]. We use a Tillotson equation of state (EoS) or a Mie-Grüneisen EoS. In the second scenario, modelling constraints were limited to the impactor mass (500 kg) and the impact velocity (6 km/s), whereas target properties (which are unknown), and setup geometry and resolution rely upon each modeller's choice. For the second scenario, we compare results on the momentum multiplication factor β, derived from the properties of the ejected material, using iSALE and SPH. Models computed with iSALE applied a Tillotson EoS for basalt and a Lundborg strength (User 1), or an ANEOS for basalt and a Drucker-Prager strength (User 2). User 2 also included a two layered setup with a 50% porosity layer on top of a 30% porosity layer. SPH codes used a Drucker-Prager strength and a Tillotson EoS.

3. Results

Results for the test case 1 are in overall agreement with respect to the derived crater diameters D and depths d for both assumed strength cases (Figure 1). In the strengthless case, D and d differ by 1% and 2%, respectively, comparing HESIONE and iSALE. In the constant strength case, where results from three codes are considered, the deviation increases to ~4%.

For the second scenario, we compare resulting values for β as a function of target strength (Figure 2, top panel) and the target porosity (Figure 2, bottom panel). With an increase of the material strength (coefficient of friction as well as cohesion Y_0), β has shown to decrease. Furthermore, β decreases with increasing porosity. The increase of porosity from 20% to 50% leads to a decrease of β in about as much as an increase of the cohesion from 1 kPa to 100 kPa. Differences in the results from different users for similar target properties show deviations on the order of 2% - 5% in β. The deviation that comes from the usage of different codes is a little larger, 5%-11%.

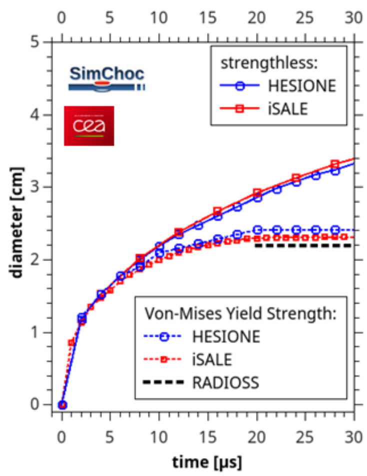

Figure 1: Resulting Diameters for scenario 1.

4. Discussion and Conclusion

The agreement of the results from different codes falls into the range of previous benchmark studies [12,13]. Sources of uncertainties include: i) differences in the numerical approach (e.g. ALE vs. SPH); ii) different material models (EoS, strength, fracturing); iii) user-specific differences in the set-up and analysis. Independent of the methodological approach all studies agree that a detailed knowledge of the petrophysical properties (strength, density, porosity) are essential to provide reliable estimates on the outcome of the DART deflection experiment. Furthermore, our results show that, besides β, further constraints like e.g. the crater morphology are needed to enhance the reliability of the remote characterisation of the material properties.

Acknowledgements

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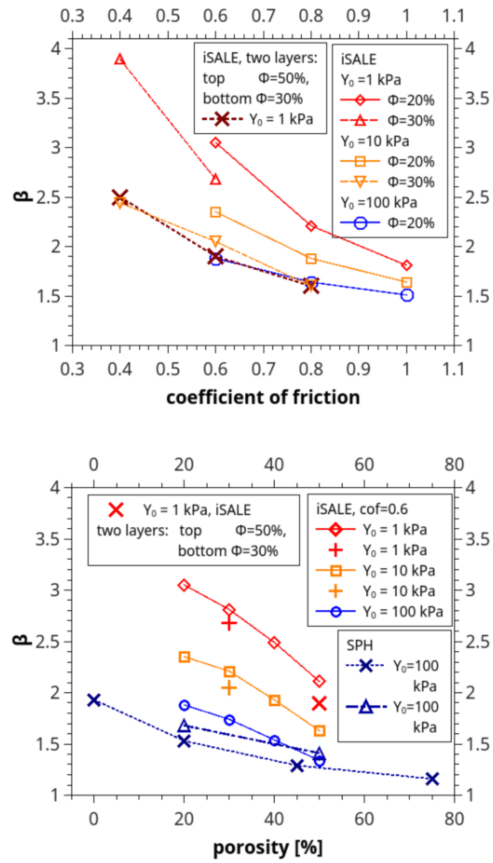

Figure 2: Resulting β for scenario 2 for various coefficients of friction (top) and porosities (bottom) from different users and codes. Results from User 1 are shown by ◊, □ and ○ symbols. Results from User 2 are shown as red ▲, and + or x (brown, red, orange). Results from Users 3 and 4 are shown as blue ▲and x, respectively.

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