IMPACT SIMULATION BENCHMARKING FOR THE DOUBLE ASTEROID REDIRECT TEST (DART).

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The AIDA/DART mission: The Asteroid Impact Deflection Assessment (AIDA) mission is a joint ESA-NASA concept, currently in Phase-A with NASA and Phase-A/B1 with ESA. The mission is composed of two independent, but mutually supportive elements: the ESA-led Asteroid Impact Monitor (AIM) will rendezvous with the 68503 Didymos system in 2022 and characterize the secondary body. The NASA-led Double Asteroid Redirect Test (DART) spacecraft will impact the secondary of the Didymos sytem (here informally called "Didymoon") in late September 2022 to test the effectiveness of a kinetic impactor for planetary defense. DART represents the first full-scale test of a kinetic impactor. The DART spacecraft is approximately 2m × 2m × 2m and 300 kg and will impact Didymoon at ~7 km/s. The deflection of the moon will be measured by the AIM spacecraft and from ground-based observations by measuring the change in Didymoon's orbital period.

The momentum enhancement of Didymoon from the DART spacecraft is parameterized by β and depends on the initial spacecraft momentum ($p_{\text{spacecraft}}$) and the momentum of ejecta excavated during crater formation (p_{ejecta}): $\beta=1+(p_{\text{ejecta}}/p_{\text{spacecraft}})$, with momenta tracked in the direction of intended deflection.

Impact Code Benchmarking: In support of the AIDA mission concept, an international working group was formed to better understand the range of possible outcomes of the DART impact. Impact modeling is one of the primary tools to be used to interpret the results of the kinetic impact deflection, to infer the physical properties of the target asteroid, and to advance our understanding of impact processes on asteroids. Several types of numerical methods can be used to model the DART impact, all of which differ in their fundamental approach to solving flow equations as well as modeling of material properties and responses to impact stresses. An initial benchmarking campaign was established to compare the results of simplified test cases across a variety of hydrocodes. The five numerical schemes used in this campaign are outlined below. Though some of these codes were benchmarked against each other using simple test cases of strengthless metal targets by [1], updated implementations and material models are included here.

Trial Problems. To enable comparison between codes, five initial test cases were sent to each team performing simulations. These cases cover impact into both aluminum and basalt targets and were designed to isolate the effects of geometry (impacts into a half-space versus a sphere), material strength, and porosity. All simulations utilize a Tillotson EOS, with properties for basalt taken from [21]. Comparisons between models include metrics such as crater size, ejecta velocity, and damage growth as well as measurements of β.

AUTODYN. Ansys' AUTODYN code can be used in many different forms [2]. In regions of high deformation, Lagrangian elements are transformed into SPH particles with Lagrangian contacts. For aluminum impacts, both Lagrangian and Smooth Particle Hydrodynamics (SPH) methodologies were employed. When impacts into basalt are considered, SPH is used to simulate fracturing. The Johnson-Cook model was used to simulate aluminum and a von Mises strength model was used for basalt.

CTH. CTH is a 2-step Eulerian code developed by Sandia National Laboratories [3]. The code has the ability to consider multiple materials and rheologies using a wide variety of material models and equations of state (EOS). Here, the aluminum was represented using a SESAME EOS. Basalt material utilized a pressure-dependent yield surface coupled to a Johnson-Cook fracture model to track subsurface damage [4], a SESAME EOS, and an p-α porosity model using a crush curve for pumice from [5]. Adaptive Mesh Refinement (AMR) [6] allows for high resolution over the areas of interest while minimizing computational time.

iSALE. The iSALE-2D shock physics code [7] is based on the SALE hydrocode solution algorithm [8]. To simulate hypervelocity impact processes in solid materials SALE was modified to include an elasto-plastic constitutive model, fragmentation models, various EOS, and multiple materials [9-10]. More recent improvements include a modified strength model [11] and a porosity compaction model [7,12].

Uintah. Uintah is a public domain code that uses the Material Point Method (MPM), a quasi-meshless numerical method [13-14]. In MPM, a continuum is discretized into a set of Lagrangian material points that carry history-dependent material information which is used to compute the stresses at the material point.

Stresses are then projected from the material points to a background grid where the equations of motion are solved. The mapping scheme avoids mesh distortion issues while material variables are tracked through the complete deformation history. Tonge et al. [15] describe the material models specific for damage in brittle materials that are appropriate for these studies, including micromechanics-based fracture and damage growth, and granular viscoplastic flow.

Adaptive SPH. Smooth Particle Hydrodynamics [e.g., 16] is a type of meshless computational scheme that is well-suited to track ejecta while avoiding mesh entanglement issues. Adaptive SPH (ASPH) is an extension of typical SPH methods [17]. ASPH allows the smoothing scale to vary with direction, so that anisotropic displacements can be captured more accurately. ASPH results presented here are calculated using the open source code Spheral, which employs an exactly energy preserving method method designed to capture adiabatic flow and strong shocks [18]. The damage model employs a statistical representation of flaw-activation strains [19-21]. Spheral includes a tensor form of the damage variable, allowing the directionality of damage to be calculated at each node and thus the tracking of deformation mode [22]. For porous materials we use the strain-alpha mode of [7].

Initial Results: Benchmarking between codes is underway, with progressively complicated test cases being simulated. Here, examples of impacts using two different approaches illustrate typical computational results expected from these calculations as well as metrics for comparisons between simulations. Figure 1 shows a Spheral (ASPH) calculation showing damage following an impact and the ejection of material; the measurement of the ejecta is critical for calculations of β. Another way to track ejecta velocity is shown in Figure 2, with results from a similar CTH simulation. Comparisons between methods will allow determination of variability between differing numerical schemes and material models, which will provide confidence for the more complicated numerical simulations required to understand and interpret the DART impact.

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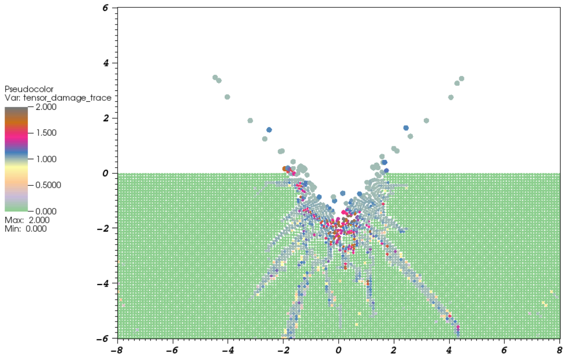

Fig. 1: Simulation results from a Spheral calculation of a 0.635-cm basalt impactor impacting at 5 km/s onto a basalt half-space. The colored contours show the trace of the damage tensor, where 2 (brown/black) is fully damaged.

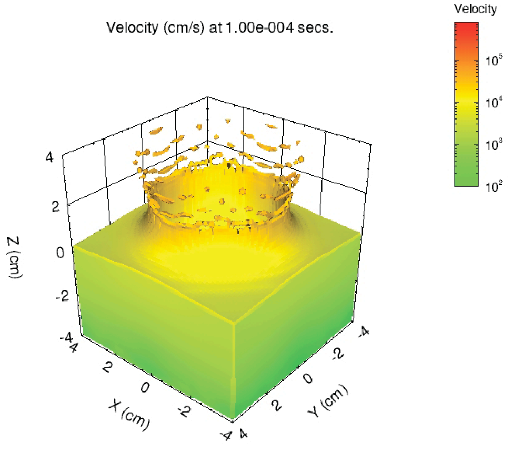

Fig. 2. CTH calculation of a 0.635-cm basalt impactor into a basalt halfspace at 5 km/s. Color show velocity contours, allowing the velocity of ejecta particles to be tracked and quantified.