

HYPOTHETICAL DEFLECTION SCENARIOS FOR A 100-M-DIAMETER DIDYMOS-B-LIKE ASTEROID AND A 200-M-DIAMETER LOW-DENSITY CONTACT BINARY ASTEROID. C. S. Plesko¹, S. A. Becker², C. M. Biwer³, M. E. Boslough², M. L. Harwell¹, L. G. Margolin¹, A. R. Truitt²

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Introduction: LANL has been tasked by the National Nuclear Security Agency (NNSA) to study the mitigation of the impact hazard of asteroids and comets on the Earth as part of an inter-agency agreement (IAA) with NASA. We are modeling deflection or disruption of a potentially hazardous object (PHO) by kinetic impactor, nuclear burst, or a combined nuclear impactor, and developing criteria for the design of a mitigation mission. Kinetic impactors transfer momentum directly through impact and through a target-dependent momentum enhancement from ejecta thrown out of the artificial crater. Nuclear explosive devices (NEDs) impart momentum to the target object by vaporizing target material, and in some cases entraining solid material in the vapor and lofting it away from the body.

Design Reference Asteroids (DRAs): We cannot assume spacecraft reconnaissance data will be available for a specific PHO before a mitigation attempt. The deflection mission would likely be the first spacecraft rendezvous. Spacecraft reconnaissance data is most valuable to us as aggregate information about the diversity of objects we might encounter, particularly information about internal structure, composition, porosity, and the heterogeneity of structure and composition observed for a given object and across dynamical families and spectral types.

DRA2, Didymos B: We are currently considering two models. The first is DRA2, which is modeled after Didymos B, the 100-m-diameter moon of Didymos (Fig. 1) [1]. It is expected to be an LL5 chondritic rubble pile aggregated from mass shed from Didymos, with a bulk density of 2.1 g/cc, including void space and solid components similar to LL5 meteorite densities of 3-4 g/cc.

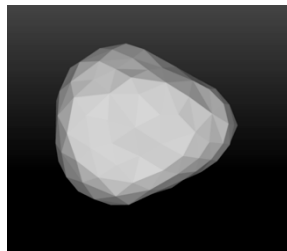


Fig. 1: Didymos B shape model, courtesy the AIDA collaboration. Didymos B is 100 m in diameter.

DRA3 Contact Binary: We are exploring the effects of strong asymmetry on our models using the ROSETTA shape mode for Comet 67P/C-G [2] (Fig. 2).

DRA3 is not modeled on Comet 67P, beyond the shape. The physical properties of the model are those of an LL5 chondrite, similar to DRA2. The DRA3 shape is scaled down from Comet 67P to a maximum radius of 200m. The main axes are approximately 200m x 190 m, with a volume of $1.0 \times 10^6 \text{ m}^3$, a mass of $5.73 \times 10^8 \text{ kg}$, and a bulk density of 0.5 g/cc.

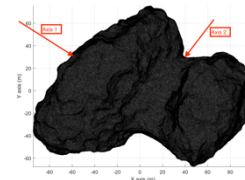


Fig. 2: DRA3 shape model, courtesy Brent Barbee, originally, ESA. The model is scaled down from comet 67P/C-G to 200 m maximum diameter, to simulate a contact binary.

Numerical Methods: We use a variety of numerical methods to model both mitigation scenarios. We start with 1-D analytical scaling estimates based on the work of Holsapple [3]. Once we have an initial prediction for the outcome of each deflection attempt, we carry out higher-fidelity 2-D axi-symmetric hydrocode models using two different numerical methods.

The RAGE Hydrocode. The radiation grid Eulerian (RAGE) code [4], [5] is a compressive Eulerian hydrocode with radiative transfer enabled. It uses continuous adaptive mesh refinement (CAMR) for increased accuracy and computational efficiency. Simulations may be carried out in one, two, or three dimensions, and in Cartesian, cylindrical, or spherical coordinate systems. Elastic-Plastic and Steinberg-Guinan strength models, and a P- α crush model are included for modeling of solids. It includes gray radiation transport for x-ray energy deposition.

The FLAG Hydrocode. FLAG is a well-validated Lagrangian/ALE hydrocode developed and maintained by the Lagrangian Applications project at LANL [6]. It has a wide range of solid mechanics options available to it given the relative ease of implementation of solid mechanics in Lagrangian numerical schemes.

Both codes use the LANL SESAME material property database [7] for equations of state.

Model Results: The figure of merit for these calculations is Holsapple's momentum enhancement factor ($\beta = 1 + |\text{ejecta momentum}|/|\text{impactor momentum}|$) [8].

We also estimate crater depth, diameter, and formation time.

DRA2. We modeled four different kinetic impactor scenarios for DRA2, two each along the semi-major axis, and the semi-minor axis of the target, respectively. The two cases modeled along each axis used different impactors. One impactor was a 177-cm-diameter, 7897 kg aluminum impactor traveling at 8.1 km/s. The other impactor was a 187.4-cm-diameter, 10,350 kg aluminum impactor traveling at 19.5 km/s.

The 7897 kg aluminum impactor, striking dry regolith at 8.1 km/s should make a 125-m-diameter crater in 1000 seconds, and eject 2.6×10^8 kg of ejecta faster than 70 cm/s, predicting a minimum $\beta = 2$, if all escaping ejecta were going just the predicted minimum velocity.

The 10,350 kg aluminum impactor, striking dry regolith at 19.5 km/s should make a 175 m-diameter crater in 200 seconds.

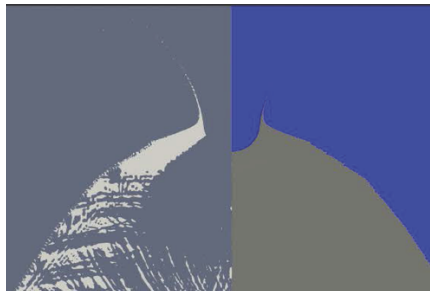


Fig. 3: A crater forming along the semi-major axis of DRA2, from a 7897 kg aluminum impactor striking at 8.1 km/s, FLAG hydrocode model showing $v > v_{\text{esc}}$ on the left, density on the right.

Hydrocode models of the low-velocity case (Fig. 3) that impact along the semi-major axis suggest $5 < \beta < 12$. Hydrocode models of the high-velocity case that impact along the semi-major axis suggest $3 < \beta < 6$.

DRA3. For this object, we will model two kinetic impactors and nuclear stand-off bursts of comparable energy. The first kinetic impactor will be a 321.5 kg aluminum impactor traveling at 4.5 km/s, and the second will be a 1156 kg aluminum impactor traveling at 8.2 km/s. Initial analytical estimates for DRA3 are as follows:

The 321.5 kg aluminum impactor, striking dry regolith at 4.5 km/s should make an 80-m-diameter crater in 500 seconds.

The 1156 kg aluminum impactor, striking dry regolith at 8.2 km/s should make a 150-m-diameter crater in 600 seconds.

Numerical models of these scenarios are in progress, and results will be presented at the meeting.

Conclusions: We present calculations of deflection scenarios for hypothetical 100 m and 200-m-diameter PHOs as part of an inter-agency collaboration between

NNSA and NASA. Our models predict β values greater than 1 and within the ranges measured by laboratory-scale experiments for targets of similar composition [9]

References:

- [1] Hergenrother C. W., et al. *Icarus* 226:663–670, 2014. [2] Preusker, F., et al. *A&A* v. 607 L1, 2017. [3] Holsapple, K. A., *Asteroids III*, pp. 443-462. [4] Gittings M. L. et al., *Comp. Sci. Disc* 1, 2008. [5] Plesko, C. S. Thesis, UCSC, 2009. [6] Burton, D. E. *Advances in the Free-Lagrange Method Including Contributions on Adaptive Gridding and the Smooth Particle Hydrodynamics Method* pp. 7-19. [7] Lyon, S. P., Johnson, LA-UR-92-3407, 1992. [8] Holsapple, K. A. and K. R. Housen, *Icarus* v. 221(2) pp. 875-887 (2012). [9] Walker, J. D. and S. Chocron, *Proc. Eng.* v. 103 pp.636-641 (2015).

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