MULTI-PURPOSE IMPACT HAZARD MITIGATION MISSION CHARACTERISTICS AND SCENARIOS.

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Introduction: Los Alamos (LANL) and Sandia (SNL) National Laboratories have 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 hazardous object 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 devices impart momentum to the target object by vaporizing target material and lofting it, and in some cases entrained solid material, away from the body.

NASA/NNSA IAA: NASA and NNSA are collaborating through an inter-agency agreement to study the prevention of asteroid or comet impacts on Earth by modifying the orbit or disrupting and dispersing the potentially hazardous object (PHO) using either a kinetic impactor, a notional nuclear explosive device (NED), or a combined impactor and NED, delivered by a spacecraft. As part of the IAA, LANL has been tasked with modeling the deposition of energy into two different PHOs and their response. SNL has been tasked with studying the coupling of the mitigation method, or "physics package" with the spacecraft bus.

Design Reference Asteroids: 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.

DRA1, Bennu: Our models draw on the OSIRIS-REx DRA [1], and add specific simplifications and assumptions where necessary for the completion of our models [2]. We simplify the model to be a 500-m-diameter sphere of 1 g/cc density dry SiO_2, homogeneous sub-mesh porosity, Steinberg-Guinan strength, deflected by either a kinetic impactor or a 1 MT stand-off nuclear burst at 100 m above the surface.

DRA2, Didymos B: There are two extension models. The first is DRA 2, which is modeled after Didymos B, the 100-m-diameter moon of Didymos (Fig. 1). It is expected to be an LL5 chondritic rubble pile aggregated from mass shed from Didymos, with a bulk density of 2.6 g/cc, including void space and solid components similar to LL5 meteorite densities of 3-4 g/cc.

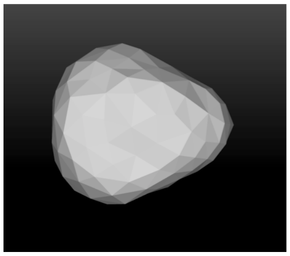

Fig. 1: Didymos B shape model, courtesy the AIDA collaboration. Didymos B is 100 m in diameter.

DRA3, Pre/Post Rendezvous Shape Models: We are conducting two rounds of models to explore the importance of shape model fidelity, one with the pre-rendezvous shape model for Comet 67P/C-G [3], and a second round of models using the ROSETTA shape model [4]. DRA3 is not modeled on Comet 67P, beyond the shape. The physical properties of the model are those of an LL5 chondrite, identical to DRA2. DRA3 is simply scaled down from Comet 67P/C-G to a maximum radius of 100m. The main axes are approximately 200m x 190 m, with a volume of 2.0×10^6 m^3, a mass of 1.0×10^9 kg, and a bulk density of 0.5 g/cc.

Model Results to Date: We have conducted a series of verification and validation models previously [5][6]. We have completed deflection models of DRA1 in collaboration with researchers at Lawrence Livermore National Laboratory and NASA GSFC [7]. Kinetic impact deflection models of DRA2 (Fig. 2) conducted by Gisler and Heberling are described in [8][9]. Further work on kinetic impactby Plesko, Truitt, and Weaver is ongoing. An account of that work and x-ray ablation models for nuclear stand-off burst deflection of DRA2 is in preparation.

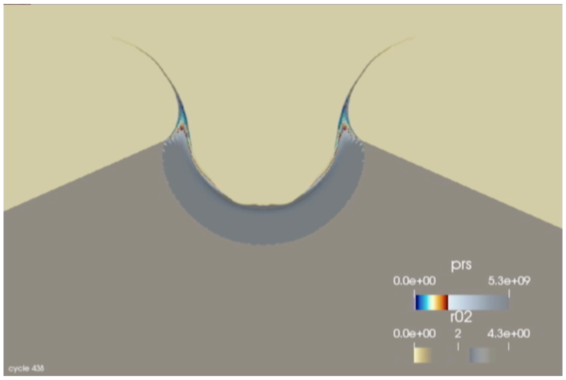

Fig. 2: DRA 2 Kinetic impactor models use a 1-metric-ton aluminum projectile striking at 10 km/s to impart a predicted velocity of order 1 cm/s.

Recent progress on DRA2 and 3 models: We have modeled the deposition of kinetic energy from a hypervelocity collision with an aluminum projectile using the RAGE hydrocode [10] to model the change in momentum of the DRA2 target (Fig. 2, 3). An impact of this size is expected to produce a change in velocity of order 1 cm/s given the projectile's momentum, the target's mass, and assumptions from [11] about the efficiency of momentum transfer. Previous validation models were consistent with these assumptions [6]. The modeling work is ongoing. Convergence in target velocity is expected well before final crater formation is complete, because only escaping ejecta contributes to the final momentum enhancement.

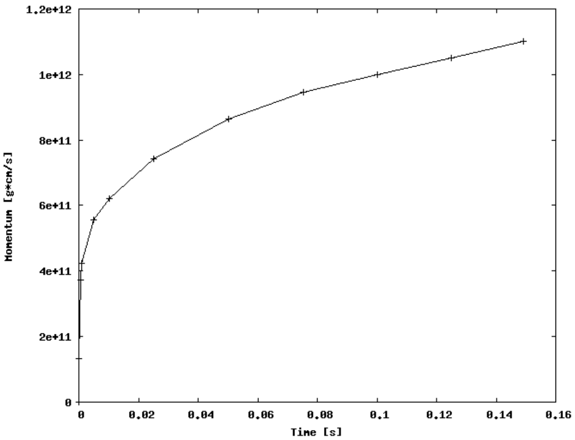

Fig. 3: DRA 2 Kinetic impactor model momentum transfer at early times, during the first 0.15 s of a predicted 470 s total formation time. Convergence in velocity is expected well before crater formation is complete.

Mission Characteristics (MCs): We have developed a requirements document for a notional non-specific mitigation mission based on these models. It describes the required capabilities of the spacecraft bus and the environments the phyiscs package payload will encounter en route to the target. It is intended to clarify the capabilities required of both the NASA (launch vehicle, spacecraft bus, kinetic impactor and sensor payload instruments) and the NNSA (NED, NED-related sensors and communications payload instruments) portions of the mission. This work extends the HAMMER Mission Design Lab study carried out at NASA Goddard in October 2015 [7]. The proposed mission characteristics include the ability to carry a kinetic impactor, a NED with a device yield between 200 kt and 1 Mt, a maximum mission lifetime of 25 years, including a maximum 10 years of flight time, and a basis for establishing points of contact with appropriate authorizations at the relevant NASA centers and NNSA labs. The MCs document provides guidance to the collaboration members as we develop a detailed Device-to-Target Sequence (DTS) report that will describe in detail the spacecraft, payload, construction, NASA and NNSA governing documents (pre-existing technical, safety, and security standards), and identify where new governing document and further research and development are required.

Conclusions: We have modeled multiple different impact hazard mitigation scenarios in collaboration with colleagues at NASA Goddard, LLNL, and SNL, and developed a an MCs requirements document for a notional non-specific mitigation mission based on these models.

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