LIMITS ON ASTEROID KINETIC IMPACT DEFLECTION FROM HYPERVELOCITY CRATERING.

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Introduction: Kinetic impact deflection was described in a 2007 NASA Report to Congress as "the most mature approach and could be used in some deflection/mitigation scenarios, especially for [Near Earth Objects] NEOs that consist of a single small, solid body." The two most critical factors are the amount of momentum transfer by the crater ejecta, which, together with the momentum of the impactor, determines the amount of deflection, and the minimum impactor kinetic energy that would shatter the asteroid, since disruption, which generates multiple fragments, some of which might remain on a collision course with the Earth, must be avoided. The physical properties of asteroids are important to the understanding of deflection by kinetic impactors and cratering or disruption resulting from natural or human-induced collisions. Both porosity and hydration influence the response to hypervelocity impacts. Meteorites sample most of the range of porosity, hydration, and composition of the NEOs. Slyuta et al. [1] noted "there are no analogues among terrestrial igneous and sedimentary rocks and ores [for the] physical and mechanical properties of the meteorites." To address effects of porosity and hydration on the maximum change in velocity that can be imparted by a single kinetic impact we conducted cratering and disruption experiments on meteorites, and, for the rare meteorite types, appropriate analog materials.

Procedure: Each target was suspended from the ceiling in the chamber of a two-stage light gas gun at the NASA Ames Vertical Gun Range. The chamber was pumped to ~0.5 Torr to minimize atmospheric interference with the projectile. The gun launched 1/16th to 1/4th inch diameter Al spheres at ~5 km/s at each target.

Cratering Measurements: The recoil speed of the target was measured from sequential high-speed video images. This allowed determination of β, the ratio of the momentum of the impactor to the recoil momentum of the target.

Disruption Measurements: We recovered the fragments from each disruption, and plotted the ratio of the mass of the largest fragment (M_L) to target mass (M_T) vs. the impactor kinetic energy per unit target mass (Q) (Figure 1).

Samples: We impacted targets of the Northwest Africa 869 (NWA 869) ordinary chondrite, an L3-6 ordinary chondrite (shock state S3, weathering state W1), the Northwest Africa 4502 (NWA 4502) CV3 carbonaceous chondrite (shock state S2 and weathering state W1), and CI simulant. We prepared the CI simulant by crushing fragments of NWA 4502 and NWA 869, and laboratory hydrated the powder in slightly alkaline water at high temperature in a pressure bomb for several months, a procedure developed by Jones and Brearley [2], to simulate on a shorter time scale the hydrothermal alteration occurring on the CI parent body. Targets were formed by drying this material.

Results: We measured mean values of β for the two anhydrous meteorites. NWA 4502 (mean porosity 2.1%, mean unconfined compressive strength 32.9 MPa, comparable to Allende) gave β = 3.55, and NWA 869 (porosity 6.4%, strength 87.4 MPa) gave β = 2.69. The lab hydrated NWA 4502 (porosity ~26 to 30%) gave β = 2.99. We determined the "threshold collisional specific energy," Q^*_D, the energy required so the largest fragment has 50% of the target mass, from the plot (Figure 1). For 10 disruptions of NWA 869 Q^*_D = 1795 J/kg, while the value for 7 disruptions of NWA 4502 is 224 J/kg, and for 6 disruptions of the CI simulant Q^*_D = 280 J/kg.

Conclusions: For any given impactor velocity the maximum ΔV that can be delivered by a kinetic impactor is proportional to βQ [3], where Q is the energy/unit mass that produces the desired fragmentation. If fragmentation giving $M_L/M_T = 0.5$ is acceptable, then Q is Q^*_D. For that case, the maximum ΔV transferred by a single kinetic impact at 5 km/s to an ordinary chondrite asteroid is almost six times that which can be delivered to an NWA 4502 or CI-like asteroid of the same mass. The lines in Figure 1 diverge for larger M_L/M_T, so the difference in maximum ΔV is even larger if the goal is to produce only cratering (M_L/M_T ~1) of each target type. Thus, carbonaceous asteroids are much more difficult to deflect without disruption than ordinary chondrite asteroids. *These results indicate multiple successive impacts may be required to deflect rather than disrupt asteroids, particularly carbonaceous asteroids.*

References: [1] Slyuta et al. (2008) *LPSC XXXIX*, Abstract #1056. [2] Jones C.I. & A. Brearley (2006) GCA 70, 1040-1058. [3] Flynn, G. J, et al., *LPSC LI*, (2020) Abstract #1228.

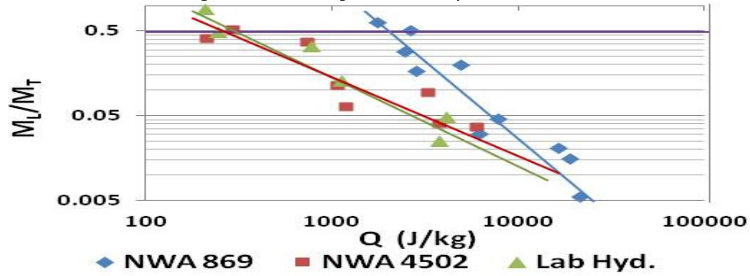

Figure 1: M_L/M_T vs. Q.