Laboratory Experiments on Kinetic Impactor Deflection of Bennu-like Asteroids

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Deflection of an asteroid on a collision course with Earth by kinetic impact 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 NEOs that consist of a single small, solid body.” Two of the most critical factors are the amount of recoil resulting from the crater ejecta, which determines the amount of deflection, and the impactor kinetic energy that would disrupt the asteroid, since disruption generates multiple fragments some of which might remain on a collision course with the Earth. We measured both factors in ~5 km/s hypervelocity impact cratering and disruption experiments on a typical ordinary chondrite meteorite [1], Northwest Africa (NWA) 869, a fragment of the most common type of asteroid in the main-belt. However, there have been no measurements on meteorites similar to the carbonaceous asteroid Bennu, a Potentially Hazardous Asteroid (PHA) with the second-highest cumulative risk rating on the Palermo Scale. OSIRIS-REx observations show Bennu has a very low bulk density, an absorption indicating widespread distribution of hydrated minerals, and a thermal infrared spectrum similar to aqueously altered CM carbonaceous meteorites. These features indicate a similarity to the low density, highly friable CI1 and CM1 carbonaceous chondrites, which are quite different from ordinary chondrites like NWA 869. But no hypervelocity impact experiments have been performed on any CI1 or CM1 meteorites because of their scarcity and small size. We prepared CI1/CM1-analog targets by laboratory hydrating NWA 869 and NWA 4502 (a CV3 carbonaceous chondrite) powders using a procedure simulating, at a more rapid rate, the hydration and thermal metamorphism processes that take place on hydrous asteroids [2], and performed hypervelocity impact cratering and disruption experiments for comparison with our NWA 869 results. We found the momentum transferred by the impactor is ~10% higher for the CI1/CM1-analog targets than for NWA 869, likely due to momentum enhancement by vaporization of water in clay minerals that dominate CI1/CM1 meteorites. However, the highly friable CI1/CM1-analog targets are far easier to disrupt than NWA 869, requiring only about 16% of the impactor energy per unit target mass. For successful asteroid deflection the disruption energy limits the impactor mass for any selected impactor speed, which in turn limits the maximum momentum that can be transferred to the target asteroid. While Bennu itself is not a threat until the last quarter of the 22nd century, the large number of meteors with inferred bulk densities <2 g/cm^3 and a Tisserand parameter indicative of asteroidal origin [3] demonstrates that Bennu-like objects are common among the Earth impacting population. Our results indicate the maximum momentum transfer to a CI1/CM1 PHA, like Bennu, is less than one-fifth the momentum that can be transferred to an ordinary chondrite asteroid, making these objects significantly more difficult to deflect without disruption than ordinary chondrite type asteroids.

References:

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[2] Jones, C., and A. Brearley (2006) Geochim. Cosmochim. Acta, 70, 1040-1058.
[3] Halliday, I. Et al. (1996) Meteorit. Planet. Sci., 31(2), 185–217