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Momentum enhancement due to hypervelocity impacts into rocky targets: Experiments to explore scale effects

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Abstract

Among the more technically practical methods of deflecting a potentially hazardous object (PHO) is kinetic impact, whereby the momentum change imparted to the object by the cratering impact of a targeted spacecraft or other projectile affects the required minor orbital change to avert impending disaster. The ratio of the momentum change of the target to the impact momentum is commonly denoted as β, the momentum enhancement factor. Knowledge of what values of β to expect for impacts into near-Earth asteroids (NEAs) in the range of size and composition representative of objects in the known population of PHOs is thus crucial in designing and planning for mitigation strategies focused on the kinetic impact method.

We present results of laboratory impact experiments, conducted with targets ranging in size from decimeter to meter size scales and measuring β in the process. Our impact experiments utilize the Southwest Research Institute's (SwRI) 50-mm powder gun, which can fire up to 260-gram mass projectiles at speeds of ~2 km/s, supplemented by smaller-scale experiments using the NASA Ames Vertical Gun Range (AVGR) as necessary to study a parameter space that includes projectile mass, speed, composition, impact angle as well as target mass, composition, and temperature (Fig. 1). Targets are mounted to allow recoil (on a conventional ballistic pendulum) and all impact experiments are documented by high-speed video allowing the required analysis to quantify impact outcome and target recoil.

To date we have completed 29 small-scale shots at the AVGR and 23 large-scale shots with the SwRI 50-mm powder gun. AVGR experiments include 13 shots into 10.2-cm and 15.2-cm right cylinders composed of a plaster-sand mix that is a good porous silicate asteroid analog, two shots into 15.2-cm pumice cubes, and 14 shots into 10.2-cm right cylinders of an iron-nickel alloy approximating the composition of iron meteorites. β values of ~1-2 and ~1 were obtained for the plaster-sand mix and the pumice, respectively, and ~1.7-2 for the iron-nickel shots, performed at temperatures of about 297 K and 149 K, thus spanning the ductile to-brittle fracture transition. For the metal target shots we see what appears to be a trend to higher β for higher speed shots and for the cryo shots. SwRI 50-mm powder gun shots were conducted with large pieces of pumice, concrete, and sandstone impacted with 2.54-cm and 4.45 cm aluminum projectiles at impact speeds of ~2.0 km/s. Although the pumice targets do not show a size scale effect and data from the sandstone shots are still being analyzed, the concrete material does show a significant size scale effect. Additional shots are planned for meter-scale targets composed of the same plaster-sand mix previously shot at decimeter scale at the AVGR, and decimeter-scale concrete targets previously shot at the SwRI Ballistics and Explosives Range.

Figure 1: Geometry of typical impact experiment setup for decimeter-scale AVGR targets (left) and meter-scale SwRI targets (right).