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Momentum transfer via direct impact: Experimental measurements

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ABSTRACT

Direct kinetic impact is an effective, relatively simple method for altering the orbits of potentially hazardous objects that are less than several hundred meters diameter. The method relies on the impulse delivered directly by the impacting spacecraft and, often more importantly, the impulse contributed by the asteroid material ejected during the impact. Of course, only the ejected material that escapes the asteroid contributes to momentum transfer. Nevertheless, given that a typical impact speed (10 km/s) is five orders of magnitude greater than the escape speed (10 cm/s) of a 200m asteroid, one would expect a significant momentum contribution from the escaping material.

The efficiency of this process is characterized by a parameter, β, defined as the total momentum change of the body divided by the momentum of the impacting spacecraft. In the limiting case of a perfectly inelastic collision (no ejecta), β =1. When a considerable mass of ejecta permanently escapes, β can be significantly greater than 1.

The purpose of the work reported here is direct measurement of β through laboratory impact experiments in a variety of geological materials. Additionally, we develop scaling laws to show how the results can be extrapolated to the actual cases of interest, where size scales are much larger, gravity is much smaller, and impact speeds are higher than in the experiments.

In our experiments the target material of interest is contained in a bowl suspended by springs (Fig. 1). The projectile impacts vertically at normal incidence to the target surface. The impact and ejection of material causes the target to oscillate vertically (Fig. 2). Given the impulsive nature of the loading (the impact and ejection occur on a time scale very short compared to the oscillation period of the system), the amplitude of the oscillation can be used to determine the total delivered impulse and, therefore, the value of β for the experiment.

At the last PDC, we described the results of our initial experiments to measure β (Fig. 3). The data are shown in the form of β-1 vs impact velocity. Three trends are evident. (1) The results show a power-law relationship between β-1 and impact velocity, as predicted by point-source scaling theory (Holsapple and Housen 2012). (2) The slope for porous materials, such as sand, is shallower than that for non-

porous materials, such as rock or aluminum. This is also consistent with the point-source scaling laws. (3) Materials with higher porosity have smaller values of β (see the single data point for cohesive pumice). This is a result of kinetic energy losses during permanent compaction of pore spaces (the energy goes into heating), which in turn causes ejection speeds and momentum multiplication to be low.

These data have important implications for the use of diversion methods relying on direct impact, and also on methods using explosives. First, the fact that β increases with impact speed means that momentum transfer in an actual mission could be much more efficient than observed in the relatively slow impacts performed in the lab. Second, the fact that porous materials tend to have a weaker dependence on impact velocity, coupled with their overall lower values of β indicates that porous bodies could be much more difficult to deflect than compact rocky objects.

We have just completed a second series of impact experiments in rocky and in highly porous materials. The new data, which are currently being processed and analyzed, will be presented at the meeting.

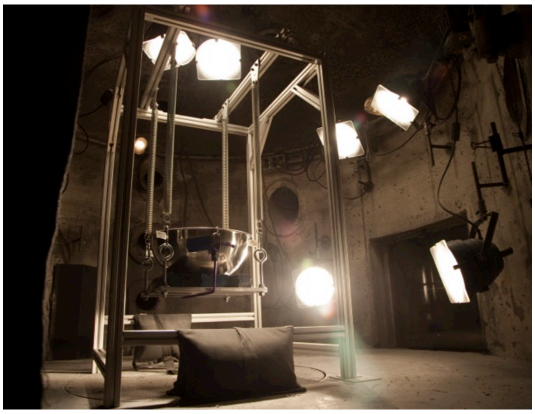

Fig. 1. Experimental test setup.

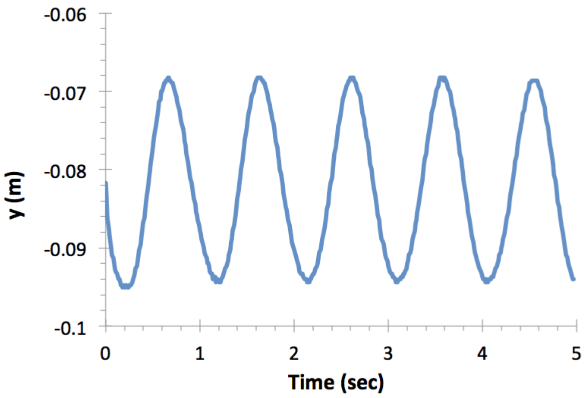

Fig. 2. Vertical oscillation of target after impact.

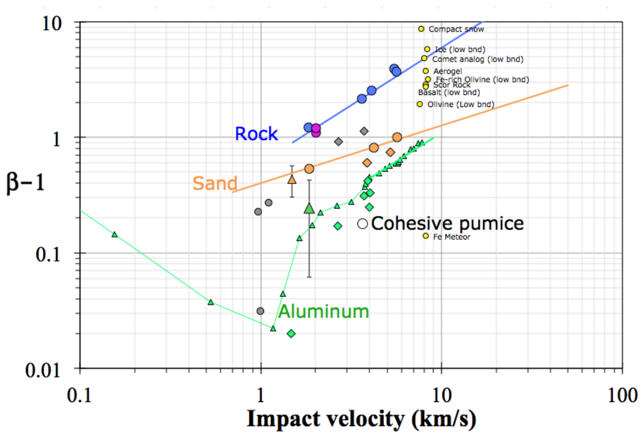

Fig. 3. Experimental measurements of β.

Ref. Holsapple, K. and Housen, K. (2012) Momentum transfer in asteroid impacts. I. Theory and scaling., *Icarus*, 221, 875-887.