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MEASURING THE MOMENTUM TRANSFER FOR ASTEROID DEFLECTIONS

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Abstract

The direct impact of a spacecraft into a threatening object may be a feasible NEO deflection method [1]. It relies primarily on ejecting surface material off the object surface, which changes the linear momentum of the hazardous object and its subsequent trajectory. But that ejection process depends on the structure and size of an asteroid and has not been studied in any detail. We have initiated a laboratory, computational and theoretical effort to study that problem.

1. The asteroid deflection problem

The fundamental physics for the effects of an impact into an asteroid or comet is simply the balance of momentum. If the projectile has mass m and initial velocity, U, relative to the asteroid, the velocity change of the asteroid (of mass M) is $\beta mU/M$ where β, the *momentum multiplication factor*, is >1. If a projectile buries itself in the target and no material is thrown out, the event is 'perfectly plastic' and β=1. However, a hypervelocity impact usually blasts out a crater many times the size of the impactor. Material is ejected at fairly large velocity, with a substantial component normal to the local surface. Therefore the total impulse imparted to the target body has two parts: the “primary” component from stopping the projectile, with β=1, and the additional component from the ejected material, which gives β>1 (normal to the surface). Depending on the mass and speed of the ejecta, the total transferred momentum can be significantly greater than the direct momentum of the projectile, i.e. β can be significantly larger than 1.

2. Scaling Theory

Laboratory experiments can be used to measure β directly, but only for small targets and impact velocities ranging to 6-7 km/s. Therefore, one must extrapolate (scale) the experimental results, which can be done using the scaling theory of hypervelocity impacts (see for example [1]. That theory delineates two cases:

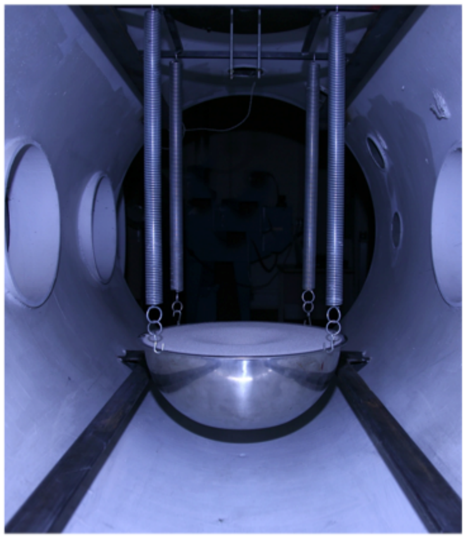
(a) if the crater size is determined by the strength of the asteroid material, then the excess of β over unity is proportional to $U^{3\mu-1}$, where μ is a constant for a given target material;

(b) if the asteroid material is nearly cohesionless, the crater size is determined by gravity g, and the excess of β over unity is proportional to $\left(U^2/g\right)^{(3\mu-1)/(2+\mu)}$.

Considering both of these cases, and since $1/3\leq\mu\leq2/3$, the exponent on impact velocity can range from 0 (so that β is independent of U) to 1.0 (β increases linearly with U). Note also that, for gravity-dominated impacts, β scales as gravity g to a power ranging from -3/8 to 0. Given that a deflection mission would involve a much larger U and smaller g than typical laboratory experiments, the value of β in the mission could be much larger than measured in the lab, which would be good news to the Earthlings. We have made initial experiments to determine the values for β and to compare to the scaling theory.

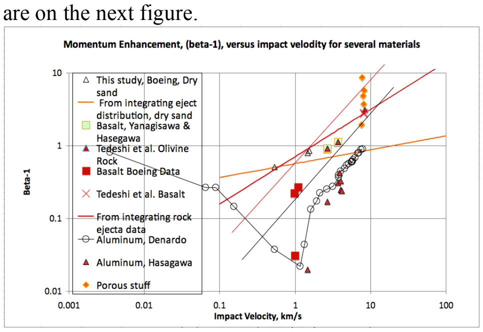
3. Experimental results

The experiments were made using a container hanging in a vacuum chamber from four springs, as shown below. That method has distinctive advantages over the simple swinging pendulum setup previously used by others. Specifically, this method allows the use of loose granular materials, such as dry sand. In addition, this method allows the slower moving ejecta to fall back on the specimen, so that ejecta does not contribute



to the momentum transfer. That is just as the case on a small asteroid. The velocity increment delivered was measured by the maximum displacement of the target assembly. The experiments were recorded with high-speed digital video cameras. We have several cameras in our lab that are well-suited to these experiments with maximum image resolutions ranging up to 1280x800 pixels and framing rates up to 10^6 pictures/sec.

The primary results were obtained at relatively low velocity, up to 2 km/s for dry sand targets. In addition, several results for other materials were found in the literature [2], [3], [4], [5]. The results are on the next figure.



Additional experiments are planned before the conference at the NASA Ames Research Center Vertical Gas gun at much higher velocity and for other materials. Form these studies, a picture of the momentum enhancement due to high speed impacts is evolving. The momentum enhancement effect is real and might be very significant.

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