Effects of target shape and impact speed on the outcome of catastrophic disruptions

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Because of the propensity of previous laboratory investigations to focus on idealized spherical targets, there is a bit of ambiguity in decoupling the relative importance/influence of low speed or spherical shape in producing the 'onion shell' fragment shape outcomes found in impacts into spherical targets [1,2]. If due primarily to impact speed/energy density as suggested by [3], this could play an important role in main-belt impacts due to the presence of non-spherical targets and non-negligible probability of low-speed (i.e., below about 3–4 km/s, subsonic in rock) impacts [4]. Also, [5] and [6] suggested that the shape of targets may affect the outcome of shattering processes, both in terms of fragment shape and mass distribution.

To examine explicitly the effects of target shape in impact outcomes, we chose to conduct impact experiments on both spherical and naturally-occurring irregularly-shaped basalt targets. We impacted a total of six targets (two spheres and four irregular targets). We focused on shots with impact speeds in the $\sim$ 4 to 6 km/s range by 3/16th-inch diameter Al-sphere projectiles fired at the NASA AVGR. Following each shot, the debris were recovered ($>$ 95 %) and large fragments ($>$ 0.20 g) were individually weighed, allowing us to carefully measure the mass-frequency distribution from each impact experiment. The 36 largest fragments of each shot were photographed and their largest axes accurately measured by the program "ImageJ". Their shortest axes were measured by means of a digital caliber. High-speed video of each impact was obtained to aid interpretation of the fragmentation mode of the targets. Images clearly show that shell-like fragments can be produced in shattering events not in the target's surface. Instead, those fragments may form around the core, well inside the target structure, independently on the target shape itself. This is a feature not reported to date. In order to understand what the bulk macro-porosity of a non-coherent set of fragments is, we gathered randomly together the fragments with weighed mass mimicking the post-shattering gravitational re-accumulation of fragments into an asteroid rubble-pile. For each set, we wrapped the fragments in a thin plastic film and measured the bulk volume by hanging and plunging the assemblage into distilled water. The volume is calculated straightforward from the density of water at the given temperature.

Cumulative mass distributions are derived and exponents $0.75 < \beta < 1.2$ are found for the relationship $N(> m) = Am^{-\beta}$ (m is the fragment mass, A is the corresponding constant) in the stationary part of the distribution. The exponent of each distribution and the mass of each largest fragment are found to be related to the corresponding specific energy of each impact as expected [3]. The mass distributions seem to show slightly larger values of β in the case of spherical targets when comparing two sets of close specific energy impacts. However, this feature needs further sets of impact experiments to be properly investigated. As for the shapes of fragments, b/a and c/a ratios were calculated along with the shape metrics $\Psi = \left[c^2/(ab)\right]^{1/3}$, $F = (a - b)/(a - c)$ for deviation from the spherical shape and relative flatness, respectively [7,8]. The average relationship between a, b, and c axes is 1:0.7:0.4, slightly different (flatter) than reported by former investigations (1:0.7:0.5) carried on in the 70s and 80s [7]. This result is quite stable and no differences are found in average shapes among spherical and irregular targets nor for different specific energy up to a factor of $\sim$ 3. This does not mean that fragments look like triaxial ellipsoids, instead they are quite irregular but their average relative sizes are distributed very nicely as described. Finally, the study of the macro-porosities of randomly aggregated fragments shows values in the 45 to 50 % range. This result may be useful in the interpretation of small asteroids' bulk densities and in the calibration of numerical modelling of internal structures.

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