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The Influence of Target Rotation on the Processes of Catastrophic Disruption

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Abstract

Collisional processes are a major factor in the evolutionary outcome of bodies in the asteroid belt. Although data from collisionally related, impact experiments exist (e.g. [1]), in these the target is always stationary. Here we present results from a programme of hypervelocity impact experiments into rotating targets. We find that target rotation does have an effect on the catastrophic disruption process; lowering the impact energy threshold defining the cross-over between cratering and disruption by approximately a third.

1. Introduction

Catastrophic disruption is considered one of the main evolutionary processes for bodies in the asteroid belt [2]. One way to study such events is in the laboratory using a light gas gun to accelerate projectiles up to hypervelocity speeds and impacting them into selected targets. Previous studies into catastrophic disruption have one characteristic in common: the target was stationary [3, 4]. However, many asteroids are found to have periodical rotations ranging from stationary asteroids (zero spin rate) to 'super fast' rotators (~1000 revolutions per day, e.g. [5]). Here we present results from experiments on rotating targets impacted using the University of Kent's light gas gun [6].

1.1 Experimental Procedure

The impact experiments were split up into two categories; hypervelocity impacts into stationary bodies (0 rev s^{-1}) and hypervelocity impacts into rotating bodies (3.44 ± 0.01 rev s^{-1}). The stationary target experiments established a 'ground truth' dataset from which results were compared to impacts into rotating targets to gain insight into the physical processes involved.

The targets were cement spheres made from a cast of two hemispherical moulds. Once removed from the moulds, the spheres were cleaned to remove casting lines and surface debris, then allowed to dry and cure completely over a period of four days. The target spheres were 75 mm ± 1mm in diameter and 370 g ± 27 g in mass (the values stated are the mean and standard deviation of the set of 28 targets described here). The projectiles were stainless steel spheres between 1 and 3 mm in diameter and were impacted into the target spheres at velocities in the range $1 \leq v_{imp} \leq 7.5$ km s^{-1}. By varying the projectile diameter and/or the impact speed a range of impact energies (Q, defined as projectile kinetic energy divided by target mass) were obtained. As Q increases the outcome of an impact changes from; i) a localised crater on the target to, ii) a larger crater with more significant mass removal to, iii) disruption of the target by fracturing that extend throughout the target (i.e. catastrophic disruption). The impact energy threshold (Q^*) that is often used [1] to designate the onset of catastrophic disruption is the value of Q required that results in 50% of the target mass in the largest single target fragment after the impact. After each shot was completed, the target and debris were removed in order to study the overall appearance, measure the fragment and fine particulate size distributions and the total target mass loss.

2. Results

In total, 12 static impacts and 16 rotational impacts were performed. Plots (Fig. 1) of accumulated mass fragment distribution were obtained as Q varied. The data show that rotation does have an effect on the outcome of the catastrophic disruption. The catastrophic energy threshold parameter, Q,* was found to be: Q^*_{stat} = 1401 ± 70 J kg^{-1} and Q^*_{rot} = 912 ± 118 J kg^{-1}. When we plot normalised mass against Q, we identify an area in the data referred to as the 'knee-joint' which corresponds to Q^*. When comparing the two regimes, the static case shows the expected discontinuity in the data from the cratering regime into the catastrophic regime as Q increases. However, for the rotating case, the 'knee-joint' shows a considerable spread in the data around this transition point. (Figure 1 top graph). We also note that the point at which final-to-initial mass ratio (m_f/m_i) drops below 0.8 is $Q = 620 \pm 31$ J kg^{-1} for the stationary case, and $Q = 342 \pm 44$ J kg^{-1}.for the rotating case. A marked difference in the power law exponent for the fragment distribution β was also noted with the range for $\beta_{stationary} = 0.21 \leq \beta \leq 1.15$ and $\beta_{rotating} = 0.48 \leq \beta \leq 0.90$ (Fig. 1, bottom graph).

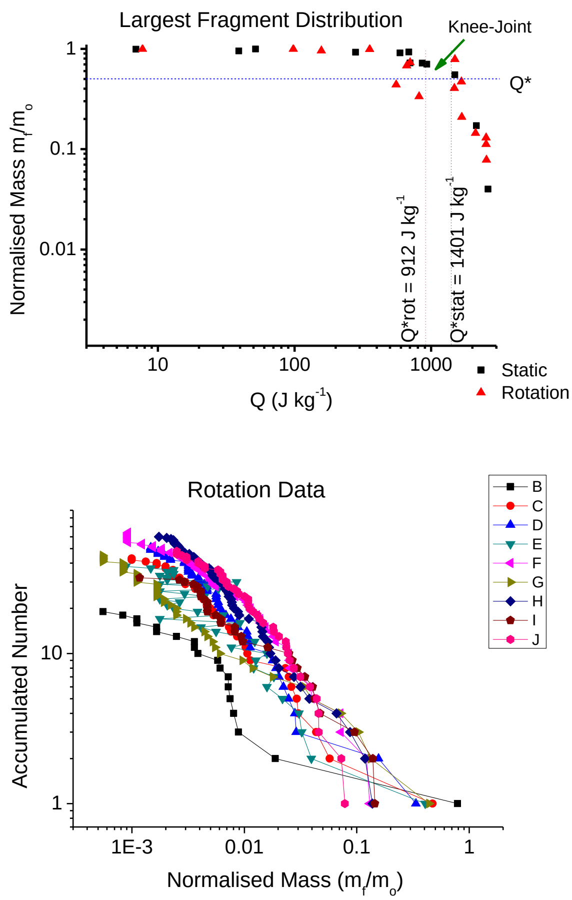

Figure 1 (top) largest normalised mass with varying impact energy and (bottom) mass distributions for the impacted target and ejecta. Each colour represents a different distribution.

3. Discussion and Conclusions

In conclusion, we find that target rotation reduces the impact energy threshold, Q^* and increases the average ejecta fragment size. A likely cause for this could be the extra stresses of rotation acting on the weakest sections of the target. This would result in a susceptibility to failure when coupled with the energy of the impact shock wave. These same flaws might have been able to withstand the shock wave if the additional rotationally induced stresses were not present. We also note that for rotating targets the data is more widely spread and therefore Q^* is poorly constrained, implying the effect of impact (cratering or disruption) is less predictable.

Further work is ongoing to obtain better statistics on the observed rotational dependence of Q^*, and will be published in due course.

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