EXPERIMENTAL STUDIES OF COLLISION AND FRAGMENTATION PHENOMENA

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Current work on this project is focusing on reduction and publication of an extensive data set collected in experiments over several years at Ames Research Center and PSI. Eileen Ryan, graduate student in geology, is assisting in the data reduction program, which involves measurements from our films and computer data reduction.

Hartmann has been assembling data sets from his experiments on catastrophic fragmentation of various materials, including basalt, other igneous rock, ice, and weak dirt clods. Measurements were made on the size of the largest fragments surviving after targets were struck at various velocities, energies, and projectile sizes. Early studies suggested that for target and projectile of the same material, half the impact energy went into each body. Assuming the energy density (joules/kg) from this result, we find an excellent correlation between the energy density and the size of the largest fragment scaled to original target mass. This result is shown in Figure 1, a computer plot newly derived from our data for ice. Hartmann pioneered such plots (WKH, Icarus 33, 50, 1978), which have recently been widely used to study fragmentation phenomena (see report of workshop on catastrophic disruption, Mem. Soc. Astr. Italiana 57, 1986, ed. D. Davis et al.). Such data sets will be important in studying solar system collision regimes, from small particle collisions in rings to collisions between large asteroids.

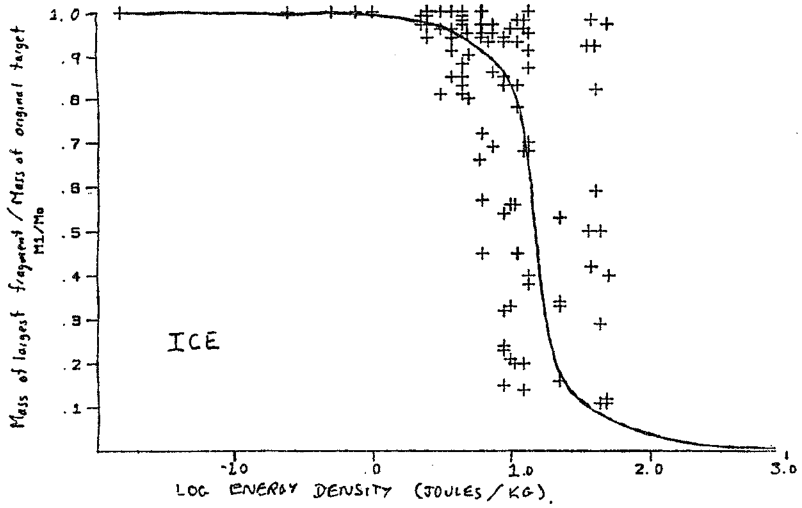

Figure 1. Plot of experimental data on collisional energy density vs. mass of largest surviving fragment (scaled to original target mass). Solid curve shows transition from rebound and chipping regime (upper left, negligible mass loss) to catastrophic pulverization (lower right, largest fragments less than a few percent of original mass).

Weidenschilling and Davis have continued to gather and reduce data on oblique impacts. Preliminary results were presented at LPSC 1986 (SJW and DRD, Lunar Planet. Sci. XVII, 931). The data indicate a power-law distribution of ejecta mass vs. velocity, with a slope that is independent of azimuth, and does not vary with impact angle from normal impacts to at least 75^{o} from vertical. Thus, a single relation can characterize ejecta velocities for the vast majority of impacts on solar system bodies. The total ejecta mass and the azimuthal distribution vary with impact angle. The degree of asymmetry in the ejecta blanket depends on impact velocity; in principle, this might be a means of distinguishing low-speed and high-speed impacting populations. The measured ejecta distributions refer to the low-velocity component that forms the continuous blanket out to $\lesssim$ 10 crater radii; the higher-velocity ejecta cannot be collected due to the limited size of the AVGR chamber. The net transverse momentum of the recovered ejecta accounts for $\lesssim$ 5% of the projectile's momentum. Earlier studies with a ballistic pendulum (DRD and SJW, Lunar Planet. Sci. XIII, 142, 1982) indicated only a tens of % of transverse momentum imparted to the target. It seems probable that most of the incident transverse momentum is carried off by a small fraction of the ejecta mass that forms a high-velocity "jet." To study this phenomenon, SJW performed a series of shots in 1986 with paper "witness sheets" downrange to record the angular distribution of high-speed ejecta. These impacts were also filmed with two high-speed Nova cameras; one viewing crossrange, and the other using a mirror to provide an effective view directly downrange. These data are still being analyzed.

In order to improve models of coagulation of dust aggregates in the solar nebula (SJW, Icarus 60, 553, 1984), SJW developed an apparatus for drop tests of fragile "projectiles." A dust charge is released from a spherical container by a solenoid. In vacuo, the cohesion of dust yields a coherent dust-ball impactor. Preliminary tests of this apparatus have demonstrated its feasibility, and will be used to plan protocols for imaging and ejecta collection in future experiments.

Davis and Weidenschilling continued to collect and analyze experimental data on collisional catastrophic disruption at the Ames Vertical Gun Range. Results of this program were presented at LPSC XVII, p. 156, 1986 and at the Pisa Workshop on Catastrophic Disruption, 1985. Our experimental program is designed to obtain data on the outcome of catastrophic collisions, particularly on the fragmental size and velocity distribution for a wide range of impact conditions. Of great importance is the velocities of fragments which determine whether or not ejecta can escape the gravitational binding of the larger, target body. Our goal is to construct an experimental database on the impact conditions that result in catastrophic disruption for a variety of solar system materials (e.g. silicate rocks, ices, iron-nickel bodies, etc.) and physical condition (e.g., coherent uniform bodies, weakly consolidated bodies, regolith covered cores, differentiated bodies, etc.), and to determine the fragment mass and velocity distributions for the collisional outcomes.

We have carried out impact experiments using targets of basalt, conglomerate rocks, ice-sand mixtures and concrete. Most of our shots have been using concrete mortar targets which are thought to be a reasonable analogue of silicate rocks found in the solar system. Mortar allows the strength of the target to be readily controlled over more than an order of magnitude and also permits construction of target bodies having different physical properties in their interior, i.e. simulated differentiated bodies.

The mortar targets were found to have a different disruption mode than do the basalt spheres used by Fujiwara (Fujiwara et al., Icarus 41, 277, 1977). The mortar spheres break up into sector or conical-shaped fragments, rather than spallation breakup leading to core-type disruption characteristic of the way basalt spheres fail in high-speed (~2-3 km/s) impacts. On the other hand, Matsui et al., LPSC XIII, 475, 1982, found that basalt targets broke up into sector-like fragments by low velocity impacts (tens to hundreds of m/s). The different types of failure may be due to the differences in the rise time of the stress pulse (Melosh, Geology 13, 144, 1985). Further work is in progress to understand both the origin and implications for different failure modes of material at different impact speeds.

Velocities of individual fragments have been determined from high-speed camera films of the disruption event. These fragments compose 60-70% of the mass of the target body for the barely catastrophic shots -- hence the bulk of the mass of a marginally disrupted target travels at speeds around 5 m/s for impact speeds ~1-2.5 km/s. Thus the mean ejecta speed is around 1% of the collision speed for the majority of the mass of the target body. There is also a trend toward higher fragment speeds with increasing collisional energy density: barely catastrophic impacts have the lowest mean fragment speed (~5 m/s), while a super-catastrophic impact, produces mean fragment velocities around 13 m/s.

We now compare our results on ejecta velocities with those found by Fujiwara and Tsukamoto Icarus 44, 142 (1980) and Waza et al, JGR 90, 1995 (1983). Fujiwara and Tsukamoto found that the bulk of the target mass (70-80%) travels at less than twice the antipodal fragment speed which varies from ~5 m/s to ~9 m/s between barely catastrophic and very catastrophic collisional outcomes. The impact speed was 2.5 km/sec. These results are not inconsistent with our results for similar impact speeds.

Waza et al (1983) measured fragment speeds for low velocity (tens to hundreds of m/s) impacts of both steel and basalt projectiles into basalt targets and found significantly higher fragment speeds for basalt fragments than those reported by Fujiwara and Tsukomoto -- typically 20-30 m/s for the bulk of the target mass. These fragment speeds are significantly higher than those found for the concrete targets, which is of interest since the failure mode of the concrete sphere is more like that for the low speed impacts on basalt targets than for the high speed ones.