

A NUMERICAL LABORATORY FOR FRAGMENTATION STUDIES: SOME INSIGHTS INTO COLLISIONAL PROCESSES AND OUTCOMES

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Laboratory impact events typically finish in a few microseconds; therefore, in even the most high-speed film loops we observe outcomes, not processes. We see a flash of jetting at the impact site, then usually a thin spall of surface material (showing that the stress wave has reflected from the target surfaces), and the subsequent frame-by-frame ejection of the fragments. The fragmentation occurs on a timescale $\tau \simeq 2D/0.4c_L$ (D = target diameter; c_L = longitudinal wave speed) $\simeq 20 \mu\text{s}$ for a 3 cm basalt target; film rates are $\sim 100 \mu\text{s}$ at best. Some new technique is needed to fully explore the process and detailed outcomes of fragmentation.

Our approach has been to simulate impacts with a numerical model of fragmentation in three dimensions for axially symmetric collisions (1). Our model is based on Grady and Kipp's (2) fragmentation algorithm, adapted to two dimensions, embedded in the numerical hydrocode SALE 2D, which was developed at LASL for high- and hypervelocity fluid dynamics simulations (3). The success of our code in reproducing the outcomes of laboratory collisions (4) has prompted us to extrapolate to the much larger sizes of asteroid impacts in order to understand the origins of asteroid families, the generation of regolith, the production of zodiacal dust, and other related solar-system processes. The intention here is to relate a new understanding of the fragmentation process that is evolving with the help of these simulations.

Our fragmentation model reproduces observed laboratory results for a wide range of input parameters, not just fragment sizes but other outcomes as well, such as the location of the two-slope transition, or "knee", in the distribution, and the fragment velocities.

Prior to photographic studies, "collisional outcomes" was synonymous with "fragment size distributions," since all that could be done was to gather and sieve the debris. Modern high-speed film analysis gives far more complete results, in that one can directly observe the fate of the fragments. But the great advantage of a realistic computer simulation based on physical (rather than phenomenological) principles is that the process and its outcomes can be studied to a fairly arbitrary level of refinement. Of course, the various parameters and scales of the impact can be varied at will, as long as the physics involved does not change (as it would, for example, with the onset of self-gravity). We observe the process as time-sequences of stress propagation through the target, times and modes of fracture, peak stresses achieved, particle velocities, and strainrates. For outcomes, we integrate cell-by-cell through the numerical grid to derive the following distribution: cumulative number of fragments exceeding a given mass ($N_{>m}$ vs. m), total mass exceeding a given velocity ($m_{>v}$ vs. v), and the total mass smaller than a given size ($m_{<L}$ vs. L). These distributions are shown below (Figure 1) for a typical impact, along with cell velocities plotted versus mean cell fragment size.

Figure 1a shows the two-slope transition observed in most fragment size distributions. This "knee" occurs at a size which correlates almost precisely with the mean fragment size for the impacts we have so far studied. While each computational cell fragments with its own particular size distribution, the integration of these distributions for all cells in a

spherical target simulation results most frequently in a sharp, bimodal profile. The slope at the high-mass end of the distribution tends to be determined by the cell suffering the lowest strainrate of fracture, whereas the slope at the low-mass end corresponds to the cell fractured at the highest strainrate.

Figure 1c shows how fragment velocities tend to correlate inversely to the fragment size. This corresponds to laboratory observation, and is due in part to the fact that the largest particle velocities cause the greatest strainrates, and thus the smallest fragments.

Figure 1d shows how, once the frame-of-reference velocity of the system (projectile plus target) is exceeded, the mass-velocity distribution drops off more steeply than a simple power law. We hope to incorporate these studies into future models for the ejection of meteorites from parent bodies and the evolution of asteroids and planetesimals, where simple power-law models have been the norm.

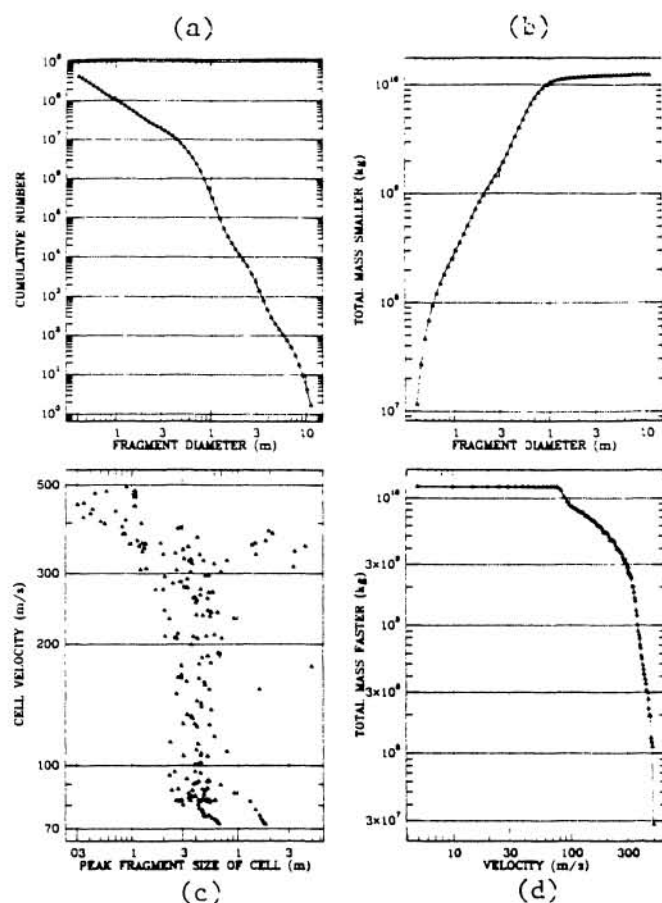


Figure 1. Simulation outcomes for a 22m radius basalt projectile impacting a 100m radius basalt target at 5 km/s. (a) and (b) are two versions of the fragment size distribution, (c) shows fragment velocity versus fragment size, and (d) shows the mass-velocity distribution.

- REFERENCES: (1) Asphaug, E., Ryan, E., and Melosh, H.J., LPSC XXI (1990). (2) Grady, D., and Kipp, M., *Int. J. Rock Mech. Min. Sci. and Geomech. Abstr.* 17 (1980). (3) Amsden, A., Ruppel, H., and Hirt, C., Los Alamos Scientific Lab Report LA-8095 (1980). (4) Ryan, E., Asphaug, E., and Melosh, H.J., *Third International Workshop on Catastrophic Disruption of Small Solar System Bodies*, Kyoto (1990).