

ENERGY PARTITIONING AND EJECTA ESCAPE FOR NORMAL AND OBLIQUE IMPACTS ON SELF GRAVITATING PLANETARY SYSTEMS; Catherine L. Smither and Thomas J. Ahrens, Lindhurst Laboratory of Experimental Geophysics, Seismological Laboratory, 252-21, California Institute of Technology, Pasadena, CA 91125

We have employed smoothed particle hydrodynamics (SPH) [1, 2] to study energy partitioning, shock-induced melting and vaporization as well as ejecta lost for impacts on earth and moon sized objects. We have used a SPH code developed at Caltech in which objects representing a mass distribution in space are described as a function of a characteristic length scale. For each particle, the position, velocity, density, internal energy, pressure and bulk sound speed are calculated at each time step in the simulation. The system is completely 3-dimensional and self-gravitating, and energy and momentum are conserved. The material properties are determined by a Tillotson equation of state [3] for anorthosite [4] for both target and impactor.

We modeled impacts on two different target sizes: 1700 and 6400 km in radius, corresponding to the size of the moon and the earth, respectively. Each target was hit with impactors of 40% and 60% of its radius (6% and 22% of its mass) at speeds of 5, 10 and 20 km/s. We varied the angle of incidence of the collision from normal, 0°, to completely oblique, 90°.

Initially, the energy of the system resides entirely in the kinetic energy of the impactor. Upon impact, some of the energy goes into ejection of material from the target, and some into heating (internal energy). Studies of impact onto a half-space [e.g. 5] show that little to none of the total energy remains in the kinetic energy of the impactor after the impact. However, for our cases of impacts on finite-sized bodies, we find that a significant portion of the total energy of the system remains in the kinetic energy of the impactor for highly oblique impact (Fig 1).

The impact causes melting of both the target and the impactor. For all but the most oblique collisions, all of the impactor is shocked to a state sufficient to cause complete melting. The smaller (1700 km) targets show much more melting than is seen in similar-sized impacts onto the 6400 km targets, as is shown in figure 2. Normal impacts melt much more material than the oblique impacts do. The two plots show the melting of the 6400 km target (left) and the 1700 km target. The lines on each graph are labeled to identify the impact velocity in km/s and the relative size of the impactor and target (in percent). For normal and low-angle impacts, the smaller impactor melts less of the target, both in terms of the number of projectile masses and the total mass melted. The difference between the different cases is much less pronounced for more oblique impacts. Also shown in figure 2 is the amount of mass that was vaporized after the impact. The impacts onto the 6400 km target produced much more vaporization (.1 to .25 projectile masses for the 20 km/s, 40% impactor, .3 to .4 projectile masses for the 20 km/s, 60% impactors).

We also studied the formation of ejecta, material thrown off the target body at velocities greater than the escape velocity of the target, and the amount of impactor material accreted to the target. For all cases of impact onto the 6400 km body, very little material was ejected. The smaller targets lost much more mass. The larger and faster impacts at low angles were sufficient to cause catastrophic breakup of the target, where the largest fragment remaining has less than half the original mass of the target. The 10 km/s impacts with the larger impactor did not cause catastrophic breakup, but did cause 40% of the target to reach escape velocity in the case of normal impact, and 8% to escape in the 90° (glancing) impact. As was the case with the 6400 km target, collisions with the 40% impactor did not generate large quantities of ejecta. Normal impacts at 20 km/s caused 12% of the target material to escape; 10 km/s impacts caused only 1 to 2% to escape.

Figure 3 compares the SPH ejecta results with the two-dimensional normal-impact models of O'Keefe and Ahrens [6]. The new results for the two escape velocities 2.4 and 11 km/s are plotted for the 60% impactors. Only the values for the normal and most oblique (90°) impacts are shown, as representative of the range of values. SPH simulations of impacts of the 60% impactor produced more ejecta than predicted by the O'Keefe and Ahrens results. The normal impact onto our smaller target produced as much ejecta as would have been produced by an impact of twice the velocity onto the half-space. We believe this increase in ejecta arises because of the greater gravitational potential energy of the impactor for an earth-sized target. For clarity, we did not show the values for the amount of ejecta produced by the collision of the 40% impactor onto the smaller target. The smaller normal impacts yield ejecta output much closer to that predicted by O'Keefe and Ahrens.

Acknowledgements. Research supported by NASA. We especially thank J. D. O'Keefe for his suggestions.

REFERENCES: ¹Monaghan, J. J. & Gingold, R. A. *J. Comput. Phys.*, **52**, 374-389 (1983). ²Benz, W. Slattery, W. L. & Cameron, A. G. W. I, *Icarus* **66**, 515-535 (1986). ³Tillotson, J. H. *General Atomic Report GA 3216*, 139 pp (1962). ⁴Ahrens, T. J. & O'Keefe, J. D., in *Impact and Explosion Cratering*, 639-656, Pergamon Press, New York (1977). ⁵O'Keefe, J. D. & Ahrens, T. J. *Proc. Lunar Sci. Conf. 8th*, 3357-3374 (1977a). ⁶O'Keefe, J. D. & Ahrens, T. J. *Science*, 1249-1251 (1977b).

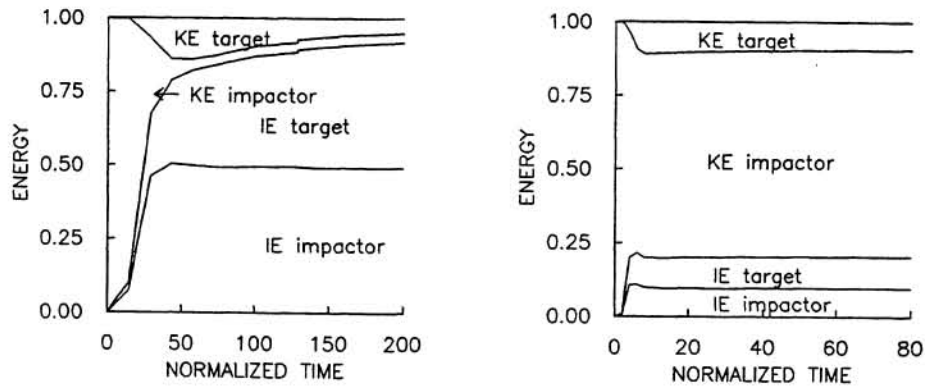


Figure 1: Partitioning of energy for impact on the 1700 km radius body. Left shows normal impact at 10 km/s with the smaller (40%) impactor. Right shows oblique (50%) collision with the larger impactor.

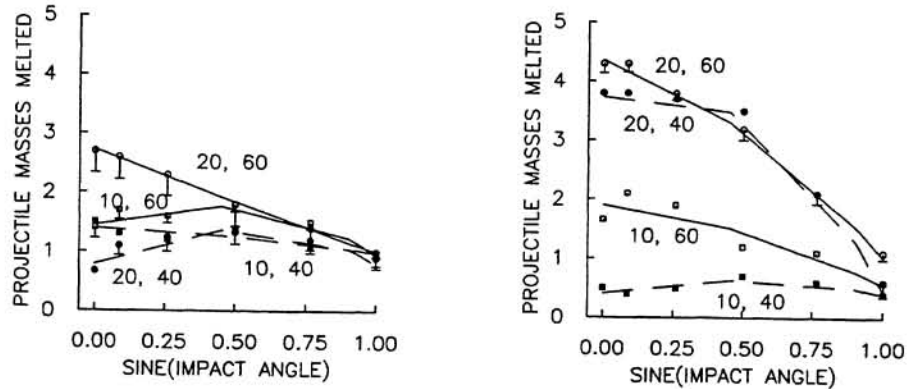


Figure 2: Melting of material on 6400 km (left) and 1700 km targets. The bars under some of the points show the amount of material vaporized. Four cases for each target are marked with two numbers, the first denotes the impact velocity in km/s, the second, the relative size of impactor.

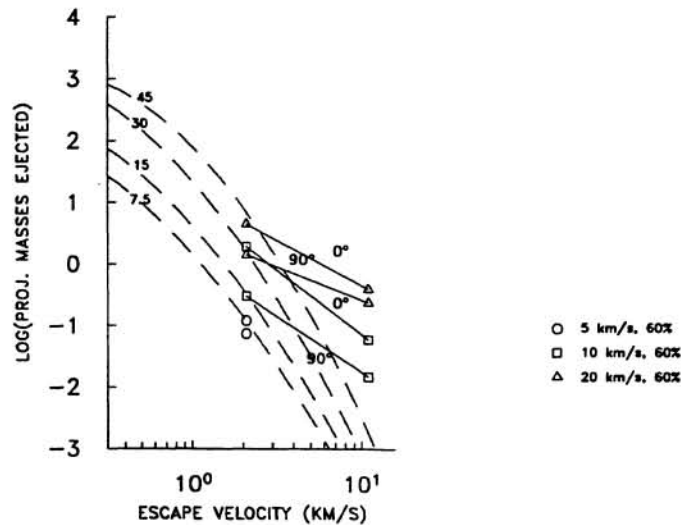


Figure 3: Mass of material ejected from the target, measured as multiples of the projectile mass. The dashed lines are modified from figure 2a of O'Keefe and Ahrens [6], and show the amount of ejecta produced by normal impacts at 7.5, 15, 30, and 45 km/s. The points plotted are from this study, and show the amount of ejecta from normal and glancing impacts of the larger projectile.