FRAGMENT VELOCITIES FROM COLLISIONAL BREAKUP EVENTS

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The disparity between fragment velocities, as determined from laboratory experiments, and those typically observed in asteroid families has been noted previously.[1,2] While median velocities in small-scale tests are typically less than 10 m/s, relative velocities inferred from measurements of asteroid orbital elements[3] are commonly of order 100 m/s. Resolution of this discrepancy has been hindered in part by the inability to experimentally simulate asteroid-size collisions. In particular, the collisional breakup of small bodies (diameters less than about 10 km) may be complicated by the dependence of material strength on strain-rate[2], while larger bodies are effectively strengthened by gravitational self-compression.[2,4] As a result of these factors, fragment velocities for decimeter-size targets are not expected to be representative of those for asteroidal collisions.[2]

An experimental technique has been developed to address the fragmentation of large asteroids, for which the effects of material strength are small compared to those of gravitational self compression. In order to simulate a target body whose radius is R, an experiment is performed in which a much smaller target is fragmented while being subjected to a gas overpressure that matches the average lithostatic stress in the interior of the body of radius R. Although this technique does not simulate the gravitational pressure gradient, it does provide a good first-order simulation of large bodies. Furthermore, hydrocode calculations[5] suggest that the effects of the gravity gradient are small in determining the size of the largest remnant fragment. Experimental results are described in ref. 6.

The high-pressure simulations described in ref. 6 were used to study only the mass of the largest fragment. Measurements of ejection velocities were not possible because the pressure chamber had no transparent surfaces through which experiments could be filmed. A new low-cost chamber has been designed and fabricated to remedy this situation. The new chamber is an aluminum cylinder with 1-inch thick plexiglas end plates. A light source is applied to one end of the chamber, while a camera films the event through the other end, typically at a rate of 6,000 frames/s. Although the entire ejecta velocity field can be observed, the initial tests reported here consider only the velocity of the largest fragment. The fragment velocity distribution will be the subject of future investigations.

The initial conditions and results of eight tests are shown in the table below. The targets were spheres of the weakly-cemented basalt described in ref. 6. As fabricated, this material has a nominal tensile strength of about 1 bar, which is thought to characterize large samples of jointed rock[7]. In four of the tests, the targets were fragmented by a projectile launched from a light-gas gun. The remainder of the tests used small explosive charges buried at a nominal depth of 2-2.5 charge radii, which has been shown to provide a good simulation of impact[8].

#	Y		q	m	d	d	d/a	P	M	ML	Q	ML/M	vL
shot no.	tensile strength	source type	specific energy	source mass	source density	burial depth	depth/ radius	ambient overpress.	target mass	largest frag	energy/ targ mass	frag/ total	vel of ML
-	(dyn/cm^2)	-	(ergs/gm)	(gm)	(gm/cc)	(cm)	-	(dyn/cm^2)	(gm)	(gm)	-	-	cm/s
1185	9.23E+05	imp	6.02E+10	0.537	2.8	-	0.00	0	4457	1405	7.26E+06	0.32	143
1186	9.56E+05	imp	5.99E+10	0.537	2.8	-	0.00	0	4434	933	7.25E+06	0.21	162
1187	9.94E+05	imp	5.92E+10	0.540	2.8	-	0.00	0	4451	1159	7.17E+06	0.26	160
1188	9.47E+05	imp	3.38E+10	0.537	2.8	-	0.00	0	4443	2536	4.09E+06	0.57	100
1193	9.27E+05	expl.	3.85E+10	0.800	1.48	1.21	2.39	0	4427	1629	6.96E+06	0.37	136
1383	1.23E+06	expl.	3.85E+10	2.000	1.48	1.81	2.64	1.03E+07	4356	3462	1.77E+07	0.79	190
1384	1.10E+06	expl.	4.25E+10	2.000	1.45	1.79	2.59	1.03E+07	4400	3486	1.93E+07	0.79	185
1399	1.13E+06	expl.	3.85E+10	0.500	1.48	0.92	2.13	8.27E+06	595	390	3.24E+07	0.66	180

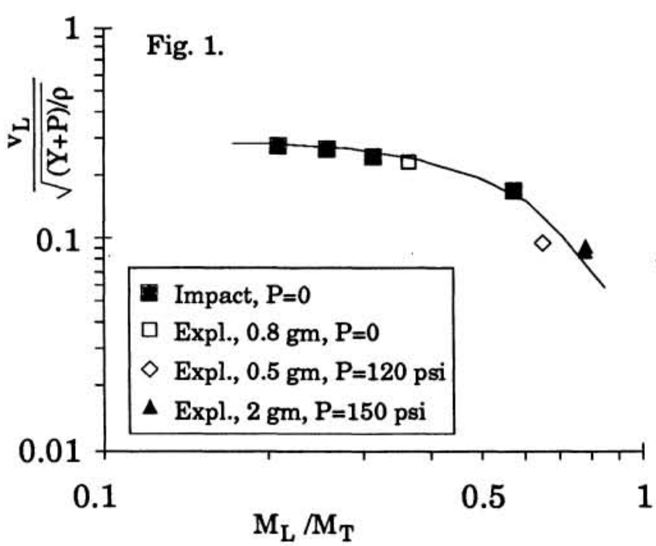
Notes: (1) P refers to the gauge pressure, so that P=0 represents standard ambient atmospheric pressure. (2) The specific energy for impacts is $U^2/2$, where U is the impact velocity. (3) Impactors were aluminum cylinders.

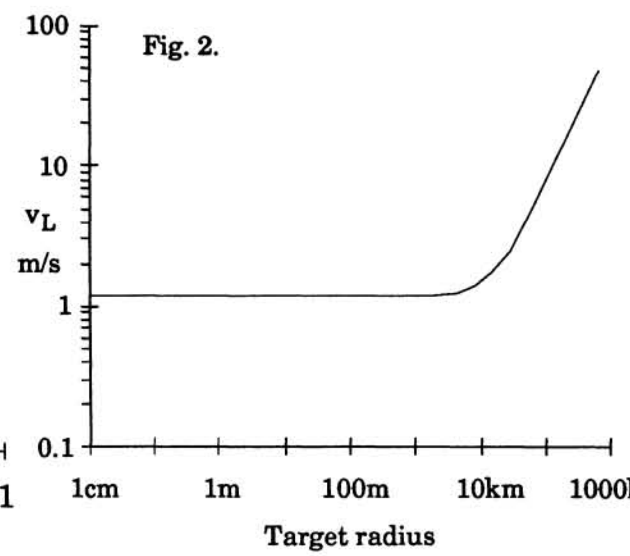
Scaling arguments developed in refs. 2 and 6 can be used to show that the velocity v_L and mass M_L of the largest fragment are related by

$$\frac{v_L}{\sqrt{(Y+P)/\rho}} = f\left[\frac{M_L}{M_T}\right]$$

where ρ and Y are the density and strength of the target material, P is the ambient overpressure used to simulate lithostatic pressure, and M_T is the mass of the target. The experimental results are plotted in this form in Fig. 1, from which three observations can be made. First, the fact that the data all lie on a common trend supports the above scaling relationship. Second, the velocity of the largest fragment decreases as the damage to the target decreases, i.e. the velocity decreases as M_L approaches M_T. Third, the burial depth used for the explosives provides a good equivalence for impacts, in the sense that the velocities measured in the explosive tests match nicely with those from the impacts.

The results shown in Fig. 1 can be scaled to larger bodies. Consider, for example, the fragmentation threshold, defined as M_L/M_T=0.5. In this case, Fig. 1 shows that v_L = 0.2 $[(Y+P)/\rho]^{0.5}$. Replacing P by the mean lithostatic stress for a body of radius R, i.e. $P=(4/15)\pi\rho^2 GR^2$, where G is the gravitational constant, gives a relation between v_L and target radius. This is shown in Fig. 2 using ρ=2.7 gm/cm^3 and $Y=10^6$ dyn/cm^2. The velocity of the largest fragment remains low (about 1 m/s) for target bodies smaller than about 10 km. The velocity increases for larger bodies because the effect of gravitational self compression (or ambient overpressure in the present experiments) requires significantly more energy per unit of target volume to fragment the target. Even so, the velocity for the largest asteroids is expected to be no higher than a few tens of meters/s. Of course, the remainder of the fragments will have significantly higher velocities. The velocity distribution will be measured in subsequent experiments.





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