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SIMULATION OF COLLISIONAL FRAGMENTATION WITH EXPLOSIVES

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For practical reasons, experimental studies of collisional fragmentation must at times rely on explosives to fragment a target body. For example, Housen *et al.* (1991) described experiments in which spheres were fragmented in a pressurized atmosphere. Explosives were used because impacts could not be performed in the pressure chamber. Explosives can also be used to study targets much larger than those which can be disrupted by conventional light-gas guns, thereby allowing size- and rate-effects to be investigated. The purpose of this study is to determine the charge burial depth required to simulate various aspects of collisions.

Explosions have long been used as analogues of impact cratering events (e.g. Shoemaker, 1963; Roddy *et al.*, 1975; Oberbeck, 1977). Although one cannot expect an explosion to reproduce all of the details of an impact, experiments have shown that, with a suitable choice of the explosive burial depth, various aspects of the problem, such as crater size or shape, can be simulated quite well. For example, Holsapple (1981) showed that, for an impact and explosion of equal energies, the impact crater volume could be reproduced by burying the explosive at a depth of 1 to 2 charge diameters, depending on the energy and velocity of the impact in question.

Various measures can be used to gauge the equivalence between impacts and explosions, such as the size distribution of fragments, fragment velocities, etc. As an example, consider the mass, M_L, of the largest target fragment. For a collision with a strength dominated target, M_L depends on the impactor mass, m, density δ, and specific energy q (i.e. velocity^2/2), and the target's density ρ, strength Y, and mass M. To simulate an impact, an explosive charge is used whose mass, specific energy and density are given by m', q', δ'. The center of the charge is buried a distance d beneath the target surface.

Housen *et al.* (1991) derived a nondimensional scaling law based on a point-source approximation for the impactor or explosive. In the point-source limit, the source variables are replaced by the single quantity $m\, q^{3\mu/2}$. Housen *et al.* showed that the scaling exponent μ for the weakly-cemented basalt used in their experiments is about 0.55, distinctly below the energy scaling value of 2/3. The point-source limit provides a relatively simple scaling form in which, for impact, the mass of the largest fragment is a function of a single parameter, π_Y, which is a measure of the intensity of the collision. For explosions, the largest fragment is a function of this same parameter, along with the nondimensional burial depth of the charge. That is,

$$\text{Impact: } \frac{M_L}{M} = F[\pi_Y]; \qquad \text{Explosion: } \frac{M_L'}{M} = F\left[\pi_Y',\ \frac{d}{a'}\left(\frac{Y}{\rho q'}\right)^{\mu/2}\right] \quad \text{where} \quad \pi_Y = \frac{Q}{q}\left(\frac{Y}{\rho q}\right)^{-3\mu/2}$$

and where Q is the source energy per unit target mass, mq/M, a' is the radius of the explosive charge, and π'_Y is the value of π_Y for the explosion. The equivalent burial depth is defined here as that depth which, for equal values of π_Y and π'_Y, results in equal masses of the largest fragment from an impact and an explosion.

A series of fragmentation tests were performed using spherical targets, 14.7 cm in diameter, constructed from the weakly cemented basalt described by Housen *et al.* (1991). The spheres rested on a foam pedestal inside a chamber which was lined with foam rubber to prevent breakage of fragments which struck the chamber wall. The impact tests used aluminum cylinders launched horizontally at velocities ranging from 2 to 3.5 km/s. The explosion tests used cylindrical charges made from green deta sheet. The events were filmed with a Fastax camera running at 6000 frames/sec. The masses of the largest fragments are shown in the accompanying figures and table.

Three identical impacts were performed to determine the experimental scatter in the largest fragment mass (see Fig. 1). Four explosion tests were then performed at the same value of π_Y as the three impacts. The burial depth was varied over a range of 2 to 4.2 charge radii. As shown in Fig. 1, the explosives buried at depths of 2 and 2.4 radii agreed well with the impact results, while the two tests at 3.4 and 4.2 radii produced largest fragments smaller than the impacts. This is also illustrated in Fig. 2, which shows the variation of the largest fragment mass with burial depth, for a value of $\pi_Y \approx 2.4$. As might be expected, the mass of the largest fragment steadily decreased as the charge was buried deeper in the target. Figure 2 suggests that a burial depth near 2.5 charge radii gives a largest fragment comparable to that of the impact tests (shown on the left axis of the figure).

Other measures can be used to assess the equivalence between explosive and collisional fragmentation. As an example, Table 1 shows the velocity of the largest fragment, as measured from films of the events. The three collision tests gave velocities in the range of 1.4 to 1.6 m/sec. For comparison, the explosion at a depth of 2.4 radii gave a velocity of 1.4 m/sec. The velocity for the deepest charge (4.2 radii) was only slightly higher (1.6 m/sec). Therefore, although the velocities from the explosions are in general agreement with the impact results, the velocity of the largest fragment is a relatively insensitive measure of equivalence.

These tests give a preliminary measure of equivalence between collisional and explosive fragmentation. For the value of π_Y studied here, which gives largest fragments close to the usual definition of the threshold for catastrophic fragmentation ($M_L/M \approx 0.5$), equivalence in the largest fragment is obtained if the center of the charge is buried at roughly 2.5 charge radii. This value may depend on the value of π_Y. Additional tests are planned to study this question.

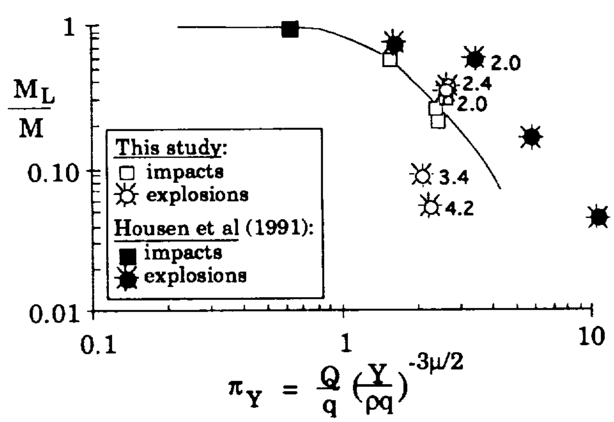

Fig. 1. Comparison of the mass of the largest fragment from impacts and explosions at various burial depths. The numbers next to the explosion points give the burial depth of the charge normalized by the charge radius.

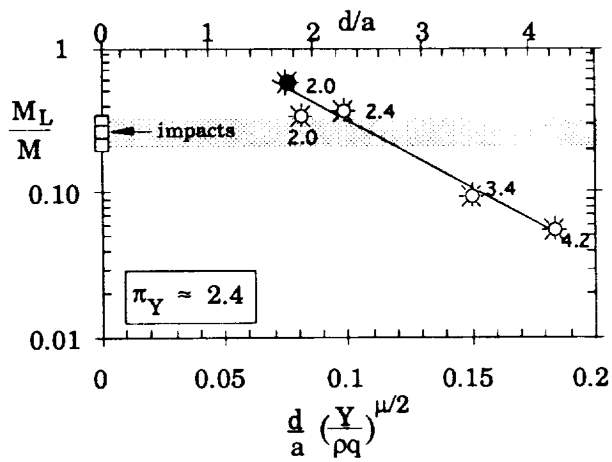

Fig. 2. The mass of the largest fragment from an explosion as a function of charge burial depth. Agreement with the impact results is obtained when the explosive is placed about 2.5 charge radii beneath the target surface.

Table 1. Summary of results of impact and explosive fragmentation tests.

#	Y		q	m	δ	d	d/a	M	ML	Q	πY	ML/M	vL
shot no.	tensile strength	source type	specific energy	source mass	source density	burial depth	depth/ radius	target mass	largest frag	energy/ targ mass		frag/ total	vel of ML
-	(dyn/cm^2)	-	(ergs/gm)	(gm)	(gm/cc)	(cm)	-	(gm)	(gm)	-	-	-	cm/s
1185	9.23E+05	imp	6.02E+10	0.537	2.8	-	0.00	4457	1405	7.26E+06	2.56	0.32	143
1186	9.56E+05	imp	5.99E+10	0.537	2.8	-	0.00	4434	933	7.25E+06	2.46	0.21	162
1187	9.94E+05	imp	5.92E+10	0.540	2.8	-	0.00	4451	1159	7.17E+06	2.37	0.26	160
1188	9.47E+05	imp	3.38E+10	0.537	2.8	-	0.00	4443	2536	4.09E+06	1.55	0.57	
1190	9.27E+05	expl.	3.85E+10	0.800	1.48	1.00	1.98	4499	1511	6.85E+06	2.57	0.34	120
1191	1.13E+06	expl.	3.85E+10	0.800	1.48	2.15	4.24	4456	244	6.91E+06	2.20	0.05	161
1192	1.21E+06	expl.	3.85E+10	0.800	1.48	1.72	3.40	4481	413	6.87E+06	2.08	0.09	141
1193	9.27E+05	expl.	3.85E+10	0.800	1.48	1.21	2.39	4427	1629	6.96E+06	2.63	0.37	136

References: (1) Holsapple K.A. (1981) *Proc. Lunar Planet. Sci. Conf. 11th*, 2379-2401. (2) Housen *et al.* (1991) *ICARUS* **9 4** 180-190. (3) Oberbeck V.R. (1977) *Impact and Explosion Cratering*, Pergamon (New York), 45-65. (4) Roddy *et al.* (1975) *Proc. Lunar Sci. Conf. 6th*, 2621-2644. (5) Shoemaker E.M. (1963) *The Moon, Meteorites and Comets*, Univ. Chicago Press, 301-306.