IMPACT VAPORIZATION BY LOW-ANGLE IMPACTS

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Introduction: Exploratory experiments previously revealed that oblique impacts into dry-ice enhance the production of a self-luminous cloud recorded in high-frame rate cameras (1, 2). Continued experiments and analysis have quantified the nature and efficiency of this process through a variety of complementary approaches. First, expansion of the vapor cloud permits deriving an estimate of the internal energy and amount of vaporization. Second, direct pressure measurements during and after passage of the cloud provides an independent estimate of vaporization. Third, spectra reveal the composition and state of the luminous vapor. And fourth, measurements of electromagnetic emissions provide new information about the ionized state and perhaps structure in the cloud. Results from the last approach are reported elsewhere (3).

Experimental Conditions: All experiments were performed at the NASA-Ames Vertical Gun Range using the two-stage hypervelocity launch facility. Aluminum spheres (0.635 cm diameter) were launched from 2-8 km/s into both dry-ice blocks (20 x 20 x 4 cm) and sand under different atmospheric pressures and compositions with impact angles from 7.5° to 90°. Beckman-Whitley (35,000 fps) and Nova (8000 fps) cameras were used to record the events.

Impact Vaporization: Under low atmospheric pressures, two different self-luminous clouds are observed for low-angle (15°) impacts. The first component travels downrange at about the velocity of impact while expanding at about half the impact velocity. Small (1-2 cm) spikes generally lead the cloud and may represent ricocheted fractions of the projectile. The second component forms a less brilliant hemispherical cloud rapidly expanding above the point of impact. Taylor (4) derived a simple expression relating the time history of a fireball to the source energy as shown in Figure 1. The constant K depends on the atmospheric density, ratio of specific heats (γ) pressure, and temperature. From approximations (4), the value of K can be given as a function of γ which depends on the composition of the fireball. In the impact experiments both air (γ = 1.4) and argon (γ = 1.7) were used. Although γ will change throughout expansion, it was shown to be reasonably constant (or behaved as though constant) at late times when 5/2 log R increases as log t for the radius (R) of the cloud at time, t. Consequently, solution to the equation in Figure 1 was possible only after about 0.2 ms.

Figure 2 reveals that the fraction of energy in the self-luminous cloud increased with increasing velocity and approached 30% at 6 km/s which corresponds to about 20 projectile masses. Preliminary results indicate the vaporized mass fraction increases as $v^{5.4}$. Figure 2 shows that without dry ice, the fraction of energy in the observed self-luminous cloud was 100 times lower; the nature of this cloud is uncertain. Vertical impacts were 10 times less efficient with or without an atmosphere in contrast with previous impressions based just on the cloud intensity (1). Preliminary results indicate that lower impact angles are also less efficient (Fig. 2).

Independent estimates of the vapor fraction were made by direct monitoring of pressure in the chamber during and after impact. Pressure measurements used an ultrasonic (40kHz) emitter/detector. Sound amplitudes, which varied nearly linearly with pressure over the experimental range (1 mm to 20 mm, Hg) yielded measurements with a time resolution of 25μs. During passage of the downrange cloud, pressure increased to about 20-30 mm but quickly reduced to a steady value of 1 mm (200 ms). The record is believed to indicate a measure of the total vaporized dry-ice fraction prior to the effects from the launch tube since impacts without dry-ice produced no measurable change over the same time. If the 1 mm is assumed to occupy the entire impact chamber, then the amount of released CO_2 exceeds 70 projectile masses. The difference in results is believed to reflect effects of additional CO_2 released by spalled fragments.

Spectra showed that the brilliant downrange vapor cloud contained strong emission lines of aluminum oxide, AlO. In order to avoid possible contamination by air, the impact chamber was evacuated to 5 mm (Hg) of air, refilled to 100 mm of argon, and re-evacuated to 5 mm. Consequently, it is believed that the AlO resulted from impact-vaporized dry ice reacting with Al melt (or vapor?). Impacts into dry-ice at low velocities (<3 km/s) and into sand only at high velocities (6 km/s) produced no identifiable spectra. Further experiments are planned in order to characterize further the interaction between projectile and target.

References: (1) Schultz, P. and Gault, D. (1985) *Lunar and Planet. Sci. XVI, 740-741*, LPI, Houston. (2) Schultz, P. and Gault, D. (1986) *Lunar and Planet. Sci. XVII*, LPI, Houston. (3) Crawford, D. and Schultz, P.H. (1987) *Lunar and Planet. Sci. XVIII* (this volume), LPI, Houston. (4) Taylor, G. (1951) *Proc. Royal Soc. Ac. 201A*, 175-186.

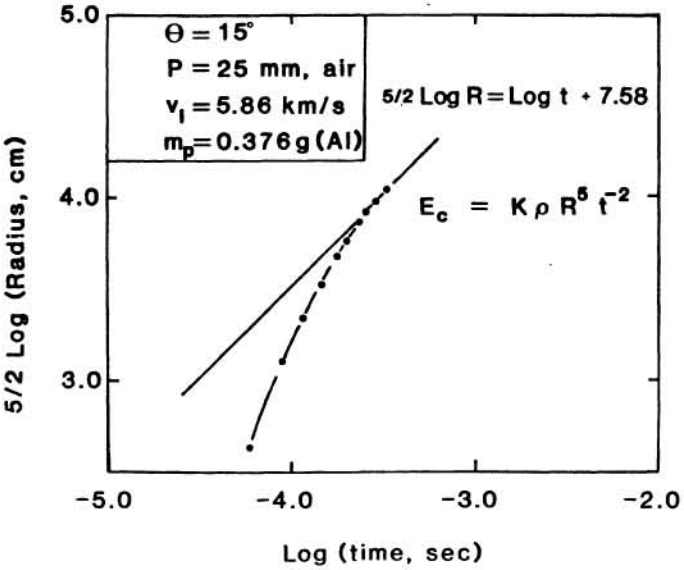

Figure 1. Radius of self-luminous vapor cloud above impact point as a function of time. Vapor cloud produced by the impact of an aluminum sphere (see insert) into a dry-ice block at 15° from the horizontal. When the cloud grows as 0.4 log t, it can be used to estimate the equivalent source energy following the blast-wave solution of Taylor (4).

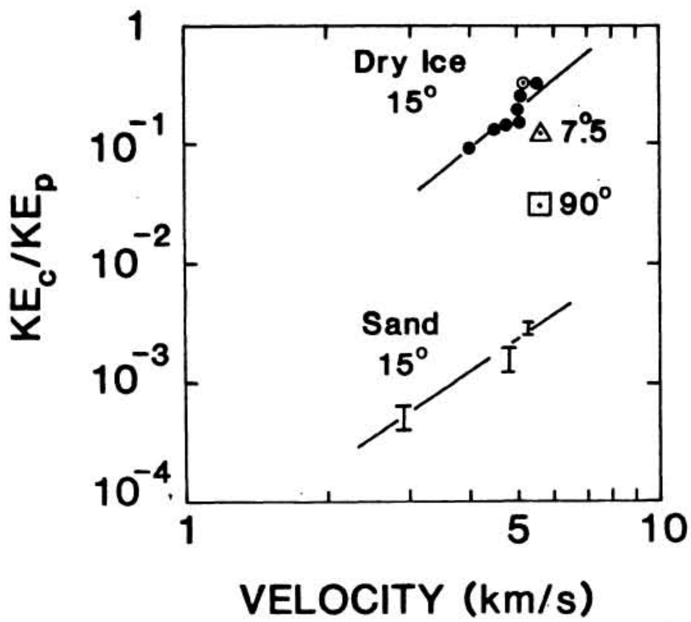

Figure 2. Energy partitioned to the self-luminous cloud relative to impactor kinetic energy as a function of impact velocity for 7.°5, 15°, and 90° from the horizontal. Atmospheric pressure in impact chamber was typically <25 mm (Hg) with one exception indicated by circle (700 mm, Hg, of argon).