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Explosive Acceleration of Projectiles*

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ABSTRACT

The velocity of a small projectile accelerated by a plane layer of explosive is calculated for three cases: the explosive is bounded on both faces by voids and the projectile is either ahead of or behind the slab, and the explosive is bounded by void in front and a rigid wall behind with the projectile in front. The detonation gases are assumed polytropic with $\gamma = 3$ and the force on the projectile is given by a simple drag formula. The presence of the projectile is assumed not to affect the gas flow. The results show that it is relatively easy to accelerate the projectile to half the detonation velocity, but quite impractical to obtain, say, nine-tenths of detonation velocity. The first configuration mentioned above is most satisfactory for experimental purposes. The maximum stagnation pressure on the projectile is estimated to be the order of 150 kilobars, and this is assumed to represent the magnitude of the deformation stress leading to fragmention. The case of the projectile imbedded in the explosive surface is not considered.

NOTATION

x — space coordinate
t — time coordinate
D — detonation velocity
γ — polytropic exponent of detonation gases, $= 3.0$
c — sound velocity in detonation gases
l — Riemann velocity, $= 2c/(\gamma - 1)$
m — mass of projectile
s — position of projectile at time t
K — drag coefficient
A — cross-sectional area of projectile
ρ — density of detonation gases at (x, t)
u — particle velocity of detonation gases at (x, t)
1 — subscript denoting values at the Chapman-Jouguet plane
ρ_0 — initial explosive density
v — projectile velocity, ds/dt
a — explosive thickness
b — initial position of projectile
Q — acceleration parameter, $= 2K\rho_0 Aa/9m$
y — dimensionless space coordinate, $= s/a$
z — dimensionless time, $= Dt/a$
y' — dy/dz
y_∞' — terminal velocity of projectile
y_0, z_0 — initial values
d — explosive diameter
L — explosive length
σ_0 — deformation stress on projectile

I. INTRODUCTION

Problems of ballistic missile re-entry and space travel have caused attention to be focussed on the consequences of high velocity impact of small projectiles on various shield configurations (*Johnson*, 1969) and on methods for producing projectiles with suitably high velocities in the laboratory (*Lukasiewicz*, 1965). High explosives have sometimes been used for accelerating small projectiles in a configuration which consists of the projectile mounted on or near one face of a cylinder of explosive, which is detonated at the opposite face. The projectiles are then accelerated in the direction of travel of the detonation front. Variations of this configuration include encasing of the explosive in a

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strong, heavy cylinder or forcing the detonation gases to flow through a nozzle and/or a blow-away barrel. Use of shaped charge jets is a different technique, but one which appears to yield higher velocities. It will not be discussed here.

In this paper we calculate the velocities of projectiles mounted at an arbitrary distance from the face of an explosive slab of finite thickness and of indefinite extent in transverse directions. These will provide upper limits to velocities produced by cylinders of finite diameter, encased or not, with projectiles mounted on an exposed face. The effect of a nozzle to direct the detonation gases adds another dimension to the problem and is not considered here.

The detonation is assumed to be a Chapman-Jouget detonation in which the detonation gases have a polytropic pressure-density relation with exponent γ, i.e.

$$p/p_1 = (\rho/\rho_1)^\gamma; \qquad l = 2c/(\gamma - 1)$$

$$u_1 = D/(\gamma + 1); \qquad c_1 = D\gamma/(\gamma + 1)$$

$$p_1 = \rho_0 D^2/(\gamma + 1); \quad \rho_1 = \rho_0(\gamma + 1)/\gamma.$$

We assume $\gamma = 3$, which assures that characteristics in the (x, t) plane are straight and simplifies the calculation. Experimental values of γ for condensed explosives are reasonably near this, ranging from 2.77 for 64/36 Comp. B to 3.17 for TNT (*Deal*, 1957). Computed values for the velocity of a rigid plate accelerated by explosive show that small variations of γ near three have little effect on the gas flow (*Aziz*, 1961). Consequently, we expect that values computed here are close to true upper limits to projectile velocities obtained in the geometry described.

The projectile to be accelerated is assumed to be initially at rest at an arbitrary distance from the explosive face, and it begins to move when the first detonation gases flow past it. Its presence produces a perturbation in the hydrodynamic field, but if the projectile is very small, the perturbation will be rapidly reduced to negligible magnitude by geometric divergence. The essential notion of the calculation is that the perturbation is negligible everywhere; the velocities thus calculated are correct for projectiles which are very small compared to explosive thickness.

The drag exerted on the projectile is assumed to be proportional to the square of the relative velocity, $(u - ds/dt)$, between projectile and gases and to the local gas density ρ. The equation of motion of the projectile is then

$$md^2s/dt^2 = \pm KA\rho(u - ds/dt)^2, \qquad (1)$$

where the sign is that of $u - ds/dt$, K is a drag coefficient and A is the projectile cross section presented to the gas flow. Initial conditions are $s = b$, $ds/dt = 0$ when the first signal from the detonation reaches the projectile. The procedure to be followed is to determine particle velocity, u, and density, ρ, for detonation gases at an arbitrary point (x, t) in the flow field. Then $u = u(s, t)$ and $\rho = \rho(s, t)$ along the trajectory. These are substituted into Eq. (1) and the resulting equation is integrated numerically.

II. GAS FLOW FIELD

Two explosive configurations are considered. In E1 the slab is bounded on either face by a void. In E2 the left boundary is rigid. In both cases the explosive faces are located at $x = 0$ and $x = a$ and the detonation is initiated at $x = 0$, $t = 0$.

A. Case E1

The flow field is represented in the (x, t) plane by Figure 1 and in the hodograph (u, l) plane by Figure 2.

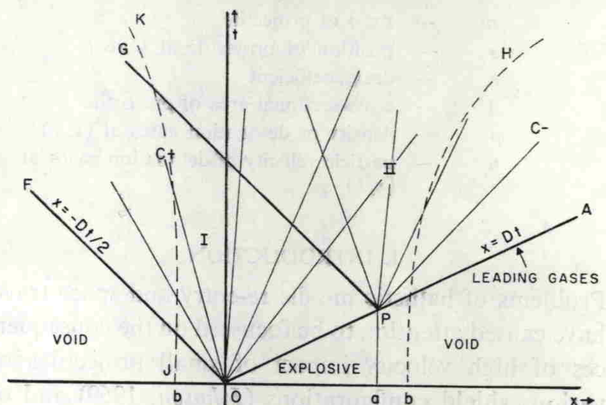

Figure 1

Flow field for unconfined explosive, case E1.