
Design and Construction of a Helium Gas Gun For Hypervelocity Impact[1]

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A helium gas gun, sometimes called a light gas gun, was designed and constructed for an experimental study of a limited phase of hypervelocity impact. The particular phase of hypervelocity impact that is of interest deals with the penetration and reflection of shock waves from the fluid-plastic-elastic interface that results from the impact. This is an extension of the analytical work on shock propagation that has been conducted in this laboratory. (Lake and Todd, 1962; Sodek and Todd, 1963). The

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analytical studies are being continued and some major phases are completed but not yet published.

In order to produce a hypervelocity impact, a particle, or projectile, must be accelerated to a hypervelocity. In the following discussion, hypervelocity is defined as a velocity that is greater than the velocity of sound in the target. There are several methods that have proved successful in accelerating small particles to hypervelocities: (a) acceleration by electrostatic fields in a van der Graaf generator (Frichtenicht and Hamermesh, 1960); (b) drag by high velocity gases which are heated by a condenser discharge (Scully and Gowan, 1960); (c) drag by high velocity gases from the explosion of shaped charges (Kineke, 1960); and (d) propulsion by hydrogen, or helium, in a light gas gun (Charters, *et al.*, 1957).

Light gas guns have been employed for various studies relating to hypervelocity impact, and particularly for crater formation. A micrograph of the crater from a hypervelocity impact was published in a previous issue of these *Proceedings* (Sodek and Todd, 1963); the impact was obtained from Scully, but the micrograph was prepared in the Research Laboratories of the Continental Oil Company. An exhaustive literature search has revealed intensive study of the craters that are produced by hypervelocity impact, of the spray from an impact in sand or dust, and of the light flash from the impact. There has been only limited study of the shock in the solid that is propagated away from the point of impact of a microparticle. Since information on this subject is essential for a basic understanding of hypervelocity impact, this paper describes a helium gas gun for the study of shock wave propagation as it is affected by the self-produced fluid and plastic media in the target and the physical coupling of these media to the elastic material of the target.

OPERATION AND DESIGN PARAMETERS FOR A LIGHT GAS GUN

Light gas guns employ two different sizes of gun barrels. The larger barrel is called the pump tube since the detonation of the gunpowder in the breech of the gun drives a free piston down the length of this barrel so the piston "pumps" the low pressure, low atomic weight gas that initially fills the barrel up to a very high pressure. The smaller tube is called the launch tube. The compressed, light gas, either hydrogen or helium, ruptures a diaphragm and applies pressure directly to the base of the projectile that is to be accelerated to hypervelocity. The basic features of the gun are illustrated by the schematic diagram in Fig. 1. The free piston at the breech end of the large tube and the projectile in the launch tube, a 20-caliber rifle barrel, are held in their initial position by a shearable diaphragm and by a shearable flange, respectively.

The pressure of the detonating gunpowder reaches 30,000 to 60,000 p.s.i. as it accelerates the free piston down the pump tube. The relatively heavy piston attains a high velocity but is eventually stopped by the back pressure of the helium that has been "pumped" into a very small volume. The pump tube is a 20-mm cannon barrel with a length of 100 inches, as shown in Fig. 2. Since the heavy, free piston is very rapidly decelerated by the small volume of low molecular weight gas, this gas may reach pressures of 20,000 to 100,000 p.s.i. A diaphragm is designed to rupture at a preselected pressure in the above range and this starts the projectile down the launch tube. The rupture of the diaphragm permits the entire pressure of the light gas to act on the base of the projectile, and this pressure shears the bullet from its supporting flange and accelerates it down the launch tube. The arrangement of the components of the gun is illustrated in Fig. 2.

The potential energy of the hot, highly compressed, low molecular weight gas is converted to kinetic energy of both the gas and the bullet as they move down the launch tube. The light gas in direct contact with

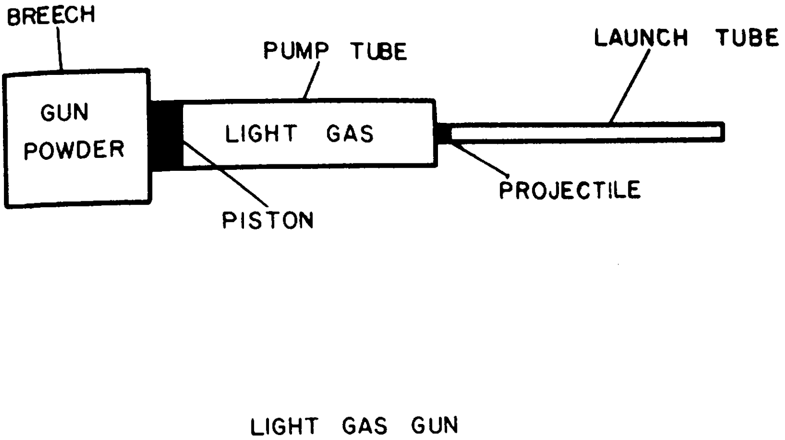

Fig. 1. Basic components of a light gas gun.

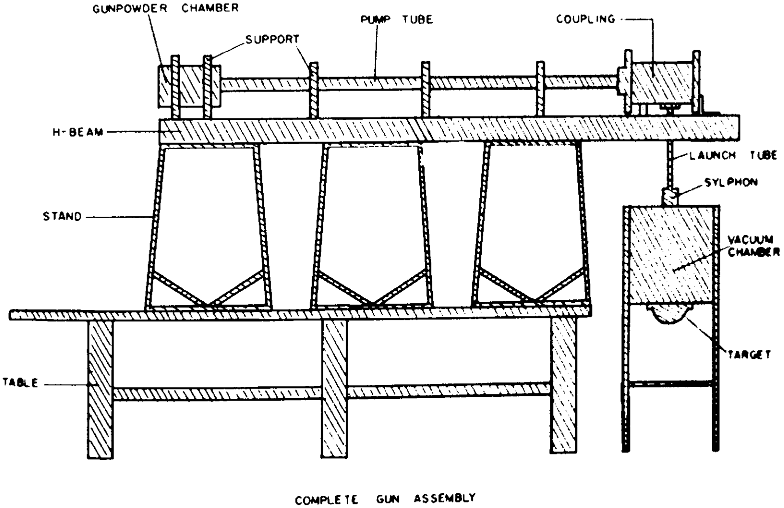

Fig. 2. Complete assembly of light gas gun.

the projectile gives it a greater push than would the products of the detonated powder. If the bore ahead of the projectile is evacuated, the projectile will accelerate until it reaches the velocity of efflux of the propelling gas into a vacuum. The velocity of efflux for a transient, centered expansion is given by

$$2c/(y-1)$$

where *y* is the ratio of specific heats for the light gas, and *c* is the velocity of sound; this in turn is given by the relation

$$C = RyT^{1/2}/M$$

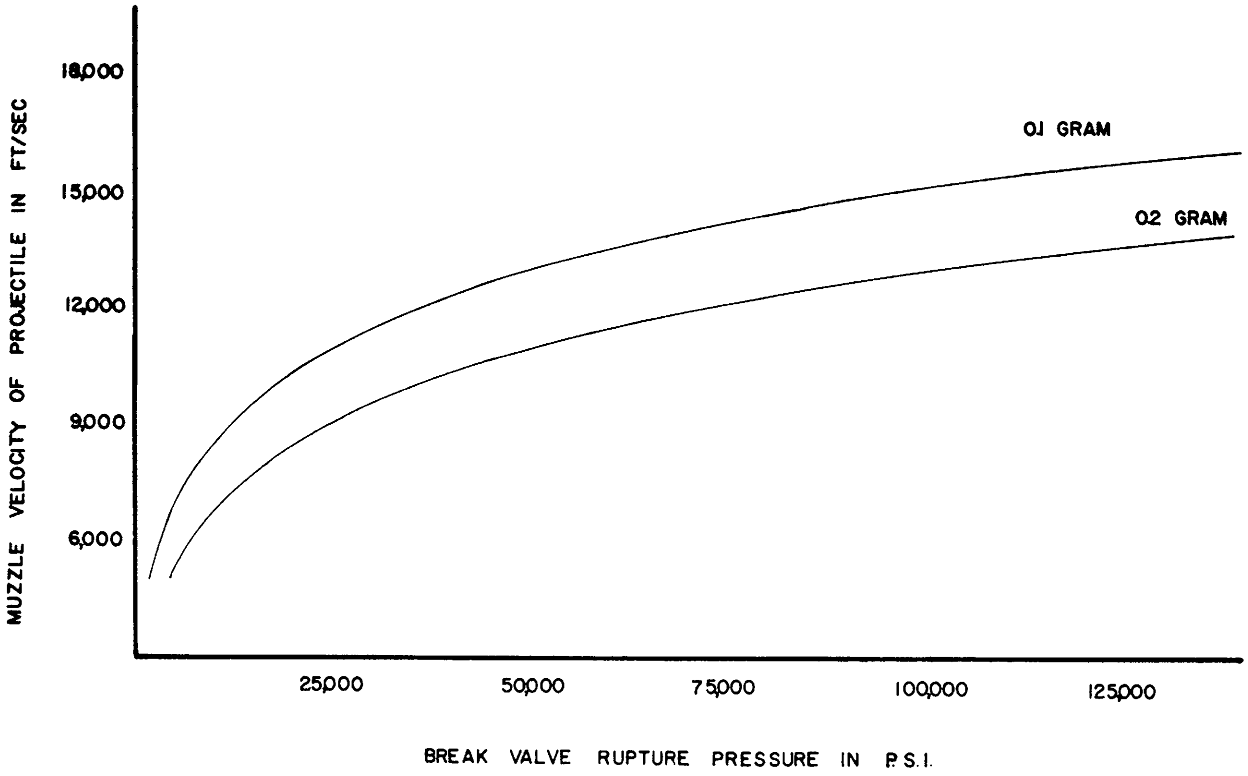

Fig. 3. Performance chart: Predicted muzzle velocity vs. break rupture pressure.

where T is the temperature of the compressed light gas. For a given temperature the gas with the smallest molecular weight, M, will have the highest efflux velocity and the highest corresponding projectile velocity. For an ideal gas, the efflux velocity is equal to

$$2c/(5/3-1) = 3c$$

The highest muzzle velocities are obtained with the minimum practical weight of projectile and the maximum permissible pressure in the cannon barrel. The potential energy of the compressed, light gas divides between self-propulsion of the gas and propulsion of the projectile. The considerations in the preceding paragraph show that low molecular weight gases, such as hydrogen, atomic mass 2, and helium, atomic mass 4, expand more rapidly than the detonation products of gun powder which have an average molecular weight of approximately 28. This is the basis for designing the light gas gun with two pressure steps. Helium must be employed in a gun that is to be used in a school building for the sudden release of some 16 cubic feet of hydrogen at normal temperature and pressure presents a real danger of explosion.

DESIGN OF THE GUN

The design procedures for the light gas gun are those that were presented by Charters, *et al.*, (1957). In order to employ simple equations, they made the following basic assumptions: (1) the motion of the free piston in the pump tube is negligible during the actual launch of the projectile; (2) the free piston must not reach the end of its travel for it may jam and the pressure would fluctuate wildly; (3) the perfect gas law is applicable as the equations of state for the detonation products and for the light gas; (4) all thermodynamic processes are adiabatic and isentropic. The original article discusses limitations on these relations, and their results indicate sufficient accuracy for design purposes. The design equations from Charters *et al.* give the weight of gun powder, the mass of the free piston, the initial pressure of the light gas in the pump tube and the rupture strength of the projectile restraint.

The proposed equations for calculation of the design constants were formulated in a FORTRAN program for an I.B.M. 650. Some dimensions were determined by the availability of gun barrels. The velocity of the projectile was calculated as a function of the rupture pressure for the diaphragm at the projectile. The upper curve in Fig. 3 shows the calculated muzzle velocity for a projectile with a mass of 0.1 grams. The lower curve in this figure shows the muzzle velocity for a projectile with a mass of 0.2 grams. The calculated practical velocity limit for the 0.1 gram projectile is about 15,000 feet per second, while the practical limit for the 0.2 gram projectile is about 12,000 feet per second.

CONSTRUCTION DETAILS FOR THE HELIUM GAS GUN

The general arrangement of the components is indicated by the sketch in Fig. 2. The launch tube directs a projectile into a steel box which is evacuated simultaneously with the bore of the launch tube. The target is attached to the bottom of this evacuated steel box. The projectile is projected vertically downward into the horizontal face of the target; as a consequence of this physical arrangement, liquid targets may be used. The velocity of the projectile is measured on its trajectory through the vacuum steel box by placing two accurately spaced, focal points of light along the projectile path. The velocity of the projectile is then measured by the time interval between interruption of the two beams of light.

Significant components of the gun are illustrated by a series of drawings. The arrangement of the breech, or gunpowder chamber, is illustrated in Fig. 4. This sketch shows the location of the powder and the electric squib, the gas tight seal between the cannon barrel and the breech, and the position of the piston at the breech end of the cannon barrel. The piston support and the gas tight seal are the same. After traveling down the 20-mm cannon barrel, the piston is stopped and the projectile is started down the launch tube in the coupling chamber. At the bottom of this chamber, which is illustrated in Fig. 5, the rupture of the break valve starts the projectile vertically down the launch tube.

The break valve, or rupture diaphragm, is a critical component and is illustrated in Fig. 6. As mentioned earlier, this break valve may be designed to rupture at any preselected pressure and its rupture is necessary for the gas pressure to be applied to the projectile. The accurately predictable rupture pressure is controlled by the depth of the V that is cut into the block to form the break valve. The deep scratch on the back side of the block, opposite to the bottom of the V, acts as a stress riser to insure brittle fracture at the desired, critical pressure. The physical arrangement of the components is indicated by the photograph in Fig. 7. The gunpowder chamber is at the upper right and the coupling chamber is at the upper left. The gages on the coupling chamber are to introduce helium gas into the bore of the gun barrel and the coupling chamber.

For the study of shock propagation from the point of impact, the shape of the target is very important. The surface of the target on which the displacement is to be measured should be sufficiently far from edges so the anticipated structure of the shock wave may be observed before reflected, secondary shocks can reach the surface on which the observations are being made. A hemispherical target best meets these requirements. The projectile strikes near the geometric center of the hemisphere and produces a hemispherical shock front that reaches the entire polished hemispherical surface of the target at approximately the same instant. Several techniques may be used to follow the surface displacement that is produced by the shock.

RESULTS OF AN EXPERIMENTAL FIRING

A successful firing was made with a reduced charge in order to observe the performance of the gun. The powder charge was about 1/3 of the maximum, permitted value. There was incorrect functioning of some auxiliary equipment, but the gun performed as anticipated. By the design charts, the predicted velocity of the projectile was 6000 feet per second.

An aluminum projectile was fired into a steel plate for this performance test. The crater produced by the 0.2 gram projectile is shown in the photograph designated as Fig. 8. The initial diameter of the projectile was 0.2 inches and the basic length was 0.2 inches but a 1/16-inch long tip was on the front end of the projectile. The imprint from this tip appears at the bottom of the crater in the photograph. The location of this impression at the center of the crater indicates that the projectile does not wobble. This is very important for the proposed tests. The collected remainder of the projectile is the small, thin disc with the remnant of the initial projection crushed back, almost even with the surface. The remainder of the aluminum from the projectile was observed as a spray which was splattered radially from the point of impact. This spray pattern is characteristic of high velocity impacts. The third item to be noted in the photograph in Fig. 8 is the washer-shaped flange that was initially an integral part of the projectile. The initial, outside diameter of the projectile is the inner diameter of this washer-shaped flange from which the projectile was sheared.

The shape of the crater is that expected from an impact at a high velocity, which is however substantially less than the velocity of sound in iron. The rim around the crater compares favorably with those created by other high velocity impacts (Kineke, 1960)

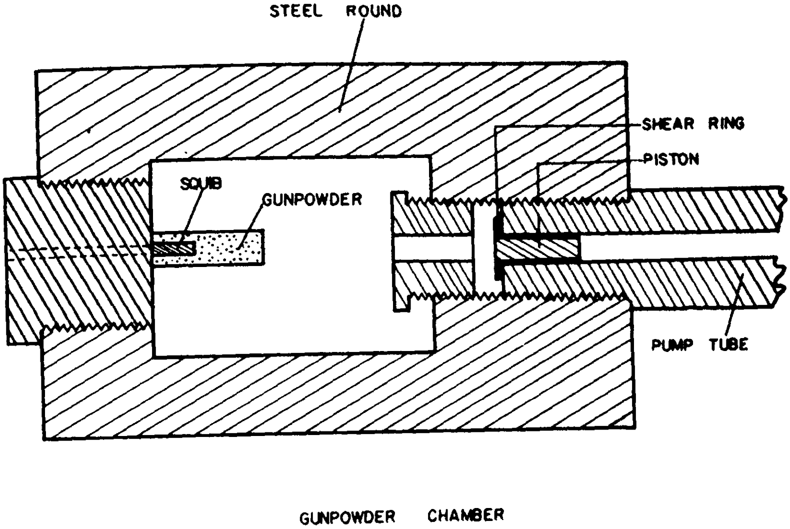

Fig. 4. Gunpowder chamber.

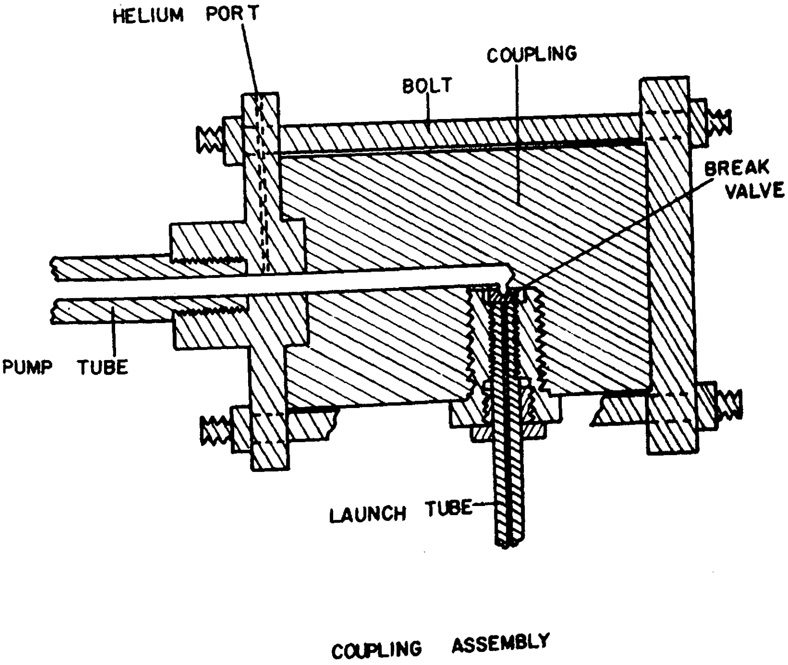

Fig. 5. Coupling assembly.

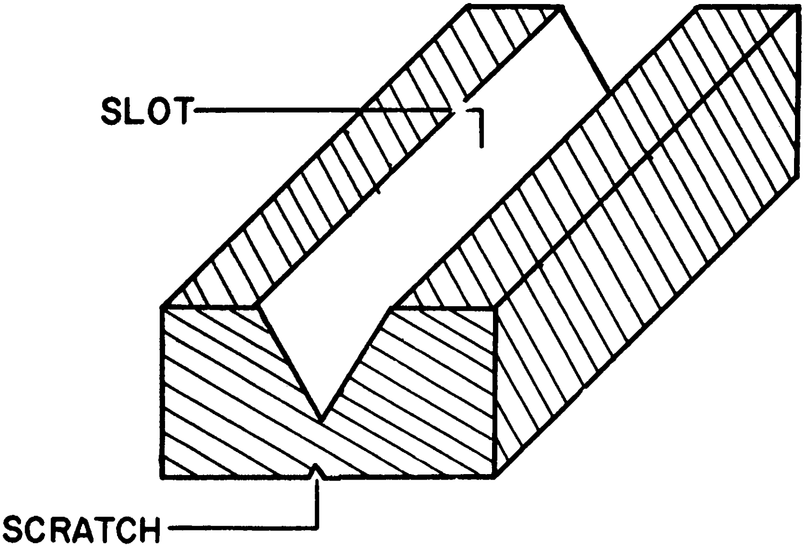

Fig. 6. Break valve.

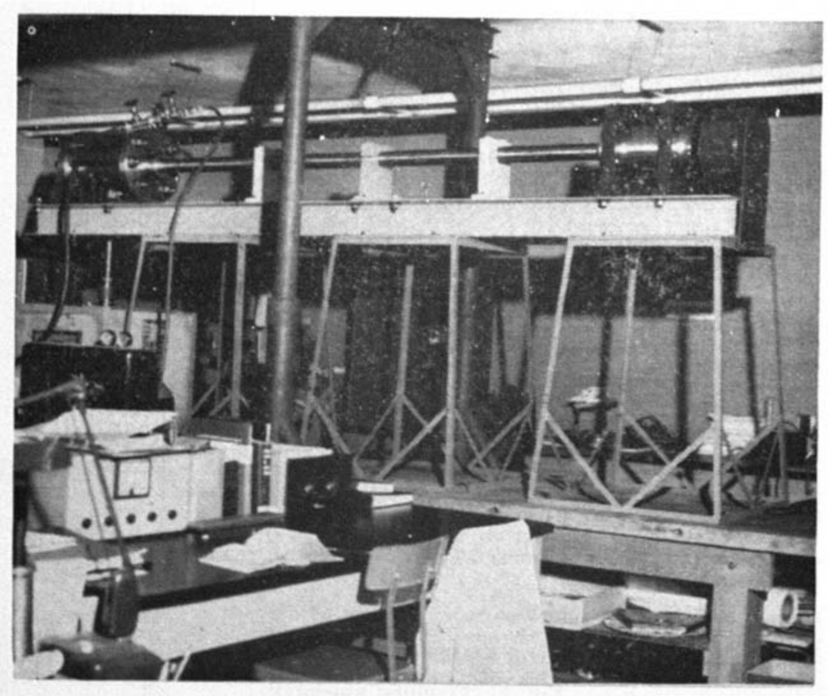

Fig. 7. Helium gun in laboratory.

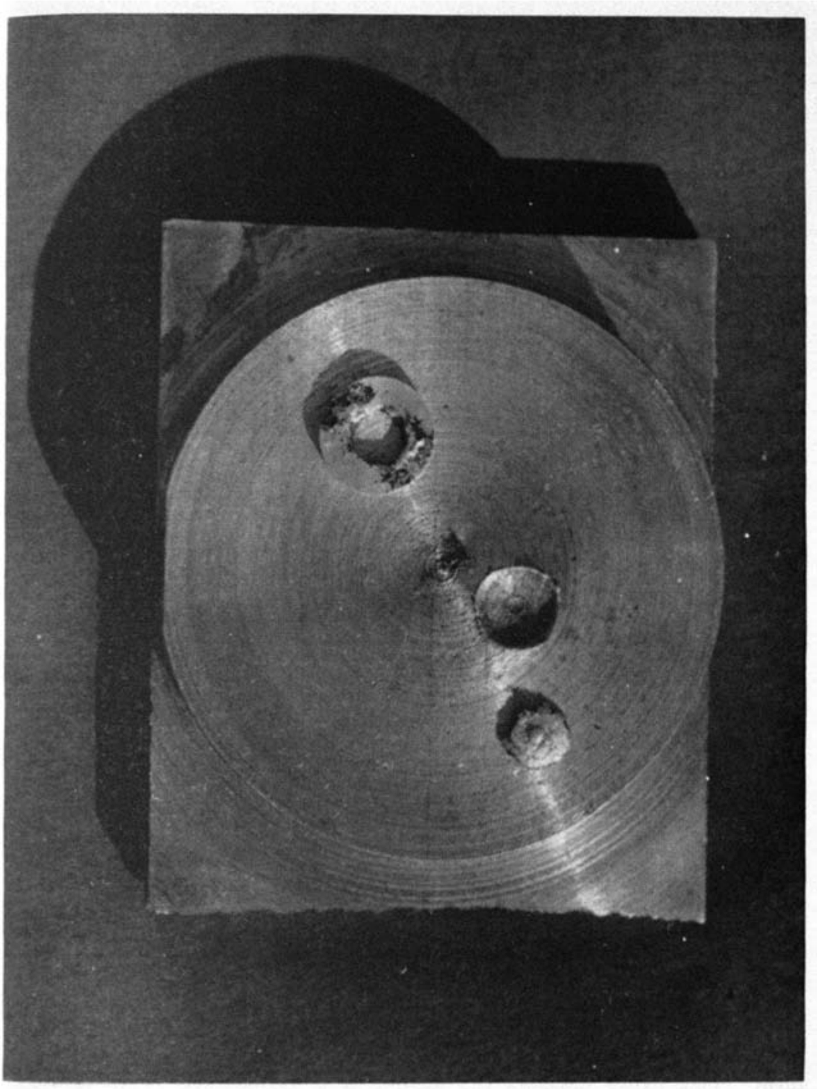

Fig. 8. Crater in steel plate, projectile flange, and remnant of projectile.

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