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# PENETRATION OF POLYETHYLENE INTO SEMI-INFINITE 2024-T351 ALUMINUM UP TO VELOCITIES OF 37,000 FEET PER SECOND

*by B. Pat Denardo*

*Ames Research Center*
*Moffett Field, Calif.*

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# PENETRATION OF POLYETHYLENE INTO SEMI-INFINITE 2024-T351

# ALUMINUM UP TO VELOCITIES OF 37,000 FEET PER SECOND

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## SUMMARY

Penetration parameters are presented for 1/3-caliber polyethylene cylinders impacting semi-infinite 2024-T351 aluminum targets at velocities ranging from 20,000 to 37,000 ft/sec.

Variations of the penetration parameters with impact velocity indicate, in accord with the trends previously established at lower speeds, that penetration depth increases with the two-thirds power of velocity. This power law is currently in use by most investigators for the fluid-impact region.

## INTRODUCTION

The advent of the light-gas gun in 1949 was virtually the beginning of hypervelocity impact research. Since that time, investigators have examined the many facets of cratering phenomena, and have published a wealth of information for impact at velocities up to 30,000 ft/sec. Based on this information, a number of penetration criteria have been proposed and have been used to extrapolate to velocities of 100,000 ft/sec to evaluate the hazard of meteoroid impact. The uncertainty of this extrapolation from about 30,000 to 100,000 ft/sec makes it essential that the highest possible velocities be attained in laboratory experiments in order to establish an accurate penetration criterion for such velocities.

To this end, experimenters are constantly striving for higher velocities in the laboratory. Modifications to the original light-gas-gun concept and various other launching techniques have, over the years, provided the researcher with penetration data at steadily increasing velocities. The present paper describes the results of a short test program at the highest velocities attained until now with a light-gas gun.

Standard penetration parameters will be presented in tabular form, and graphically as functions of the impact velocity. Also, the apparatus used in this experiment will be described briefly.

## DESCRIPTION OF APPARATUS

This experiment was conducted in the impact range at Ames Research Center. Projectiles were right-circular cylinders, with lengths nominally one-third the diameter, made of a linear high-density polyethylene. Projectile sizes are listed in table I. Targets were made of 2024-T351 aluminum alloy and all their dimensions were large compared to the impact craters.

The projectiles were launched from an accelerated reservoir light-gas gun (ref. 1). Nominal gun dimensions were:

0.220-inch-diameter launch tube, 5 feet long
1.28-inch-diameter pump tube, 12 feet long
$15^\circ$ tapered coupling, 4.2 inches long
3.00-inch-diameter powder chamber, 16 inches long

Nominal loading conditions were: initial pump-tube pressure (hydrogen), 40 psia; 100 gram polyethylene pump piston; 60 to 125 gram powder charge (type IMR 4227), depending on the velocity desired.

The projectiles flew through a 20-foot-long flight-observation chamber (with a nitrogen atmosphere at pressures of 1 to 20 mm Hg) prior to impact with the target. This chamber was instrumented with six spark-photographic stations, each presenting two side views of the projectile $90^\circ$ apart. Exposure times, provided by the use of Kerr-cell shutters, were the order of 5 nsec. These photographs gave assurance of the structural integrity of the projectile after launch, and when used in conjunction with 10-Mc counter chronographs, gave the impact velocity to an accuracy of about 0.2 percent.

Figure 1 is a photograph of the gun-range area, showing some of the items discussed in this section.

## RESULTS AND DISCUSSION

A summary of the pertinent penetration data resulting from this experiment is presented in table I.

Dimensionless penetration depth as a function of the impact velocity is plotted in figure 2. The break in the curve at approximately 25,500 ft/sec marks the beginning of the fluid-impact regime. This transition point, as discussed in reference 2, is dependent upon the physical and mechanical properties of both the projectile and target, as well as the test conditions (i.e., projectile shape, impact velocity, etc.). Above the transition point, in the fluid impact region, the volume of material ejected from the crater should be proportional to the kinetic energy of the projectile (penetration $\propto$ velocity$^{2/3}$). A straight line with a slope of two-thirds has been passed through these higher velocity points and as can be seen by the fit of this line, the condition is satisfied, at least up to a velocity of 37,000 ft/sec.

The equation of the line in figure 2 is

$$\frac{P}{d} = 1.19\times10^{-3}\ V^{2/3}$$

To transform the Ames penetration equation for spheres (ref. 2),

$$\frac{P}{d} = 2.28 \left(\frac{\rho_P}{\rho_T}\right)^{2/3} \left(\frac{v}{c}\right)^{2/3}$$

into the same form

$$\frac{P}{d} = kv^{2/3}$$

it is necessary to relate cylindrical and spherical data. A common assumption, as pointed out in reference 3, is that the penetration of a sphere of given diameter is equivalent to that of a 1-caliber cylinder of the same diameter

$$\left(\frac{P}{d}\right)_{\text{sphere}} = \left(\frac{P}{d}\right)_{\text{1-caliber cylinder}} .$$

Aside from the effects of shape, the penetration of a 1-caliber cylinder should differ from that of a 1/3-caliber cylinder by the cube root of their mass ratio

$$\left(\frac{m_{\text{1-caliber cylinder}}}{m_{\text{1/3-caliber cylinder}}}\right)^{1/3}$$

The value of $k$ thus deduced is $1.35\times10^{-3}$ instead of $1.19\times10^{-3}$.

The 13-percent difference in constants is not large, considering the differences in densities, masses, and shapes. Furthermore, the 2.28 constant in the Ames penetration equation is for low-strength, highly ductile targets; whereas, high-strength hard material was used in the present work.

For general interest, the ratios of penetration to projectile length $(P/l)$, penetration to crater diameter $(P/D)$, crater diameter to projectile diameter $(D/d)$, and crater volume $(U)$, as functions of the impact velocity, are plotted in figure 3. These graphs are consistent with previously established trends. The parameters of $(P/l)$, $(D/d)$, and $(U)$ all increase smoothly with velocity. The plot of $(P/D)$ versus velocity indicates that at velocities above about 25,000 ft/sec, that is, in the fluid impact region, the crater shape has become constant, corroborating the proportionality between crater volume and kinetic energy.

Figure 4 displays photographs of the target from round number 568, $v = 37{,}060$ ft/sec and the plaster replica of the crater. Also seen in the photograph is a typical projectile used in this experiment. It is interesting to note that the shape of the crater, as shown by the replica, is more conical than hemispherical; this probably is a result of the projectile shape and target strength.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Dec. 17, 1965

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2. Summers, James L.: Investigation of High-Speed Impact: Regions of Impact and Impact at Oblique Angles. NASA TN D-94, 1959.

3. Walsh, J. M.; and Johnson, W. E.: On the Theory of Hypervelocity Impact. Proc. Seventh Symposium on Hypervelocity Impact, Tampa, Florida, Nov. 17-19, 1964. Vol. II: Theory. Martin Co., Orlando, Fla., 1965, pp. 1-75.

TABLE I.- SUMMARY OF PERTINENT UNCORRECTED[a] DATA

| Round number | Impact velocity, v, ft/sec | Projectile mass, m, gram | Projectile[b] diameter, d, in. | Projectile length, $l$, in. | Penetration depth, P, in. | Crater diameter, D, in. | Crater volume, U, in.$^3$ |
|---|---|---|---|---|---|---|---|
| 566 | 34,735 | 0.0457 | 0.2220 | 0.074 | 0.284 | 0.665 | 0.0422 |
| 567 | 35,520 | .0438 | .2240 | .072 | .283 | .635 | .0381 |
| 568 | 37,060 | .0453 | .2245 | .071 | .297 | .670 | .0482 |
| 581 | 31,485 | .0427 | .2230 | .071 | .261 | .588 | .0314 |
| 583 | 25,510 | .0414 | .2180 | .071 | .223 | .528 | .0226 |
| 587 | 22,115 | .0431 | .2230 | .071 | .188 | .482 | .0138 |
| 588 | 20,980 | .0438 | .2235 | .071 | .173 | .469 | .0128 |

[a]Uncorrected for slight changes in projectile mass.

[b]Changes in projectile diameter were dictated by the changes in launch-tube diameter.

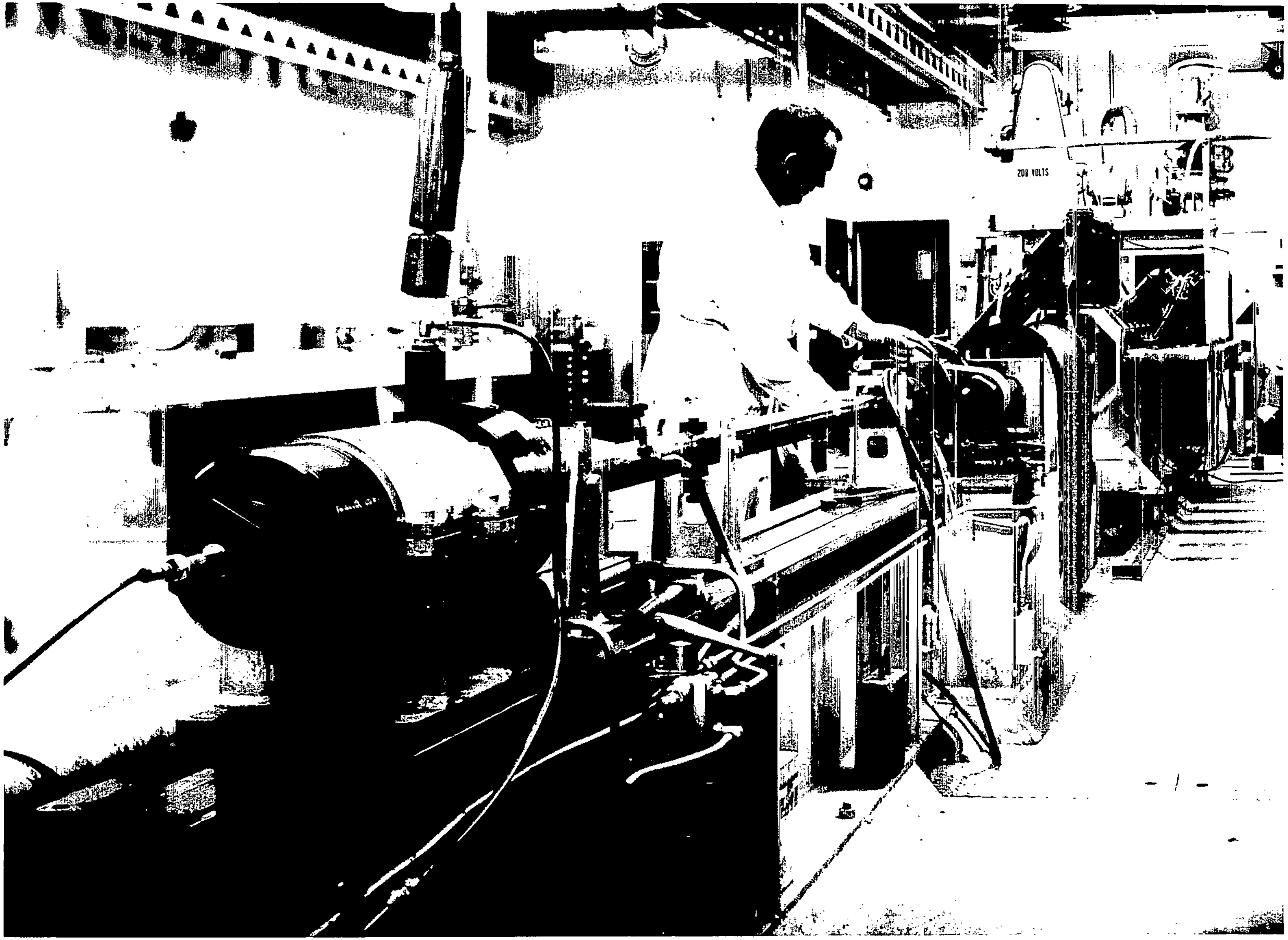



Figure 1.- Gun-range area.

A-35741

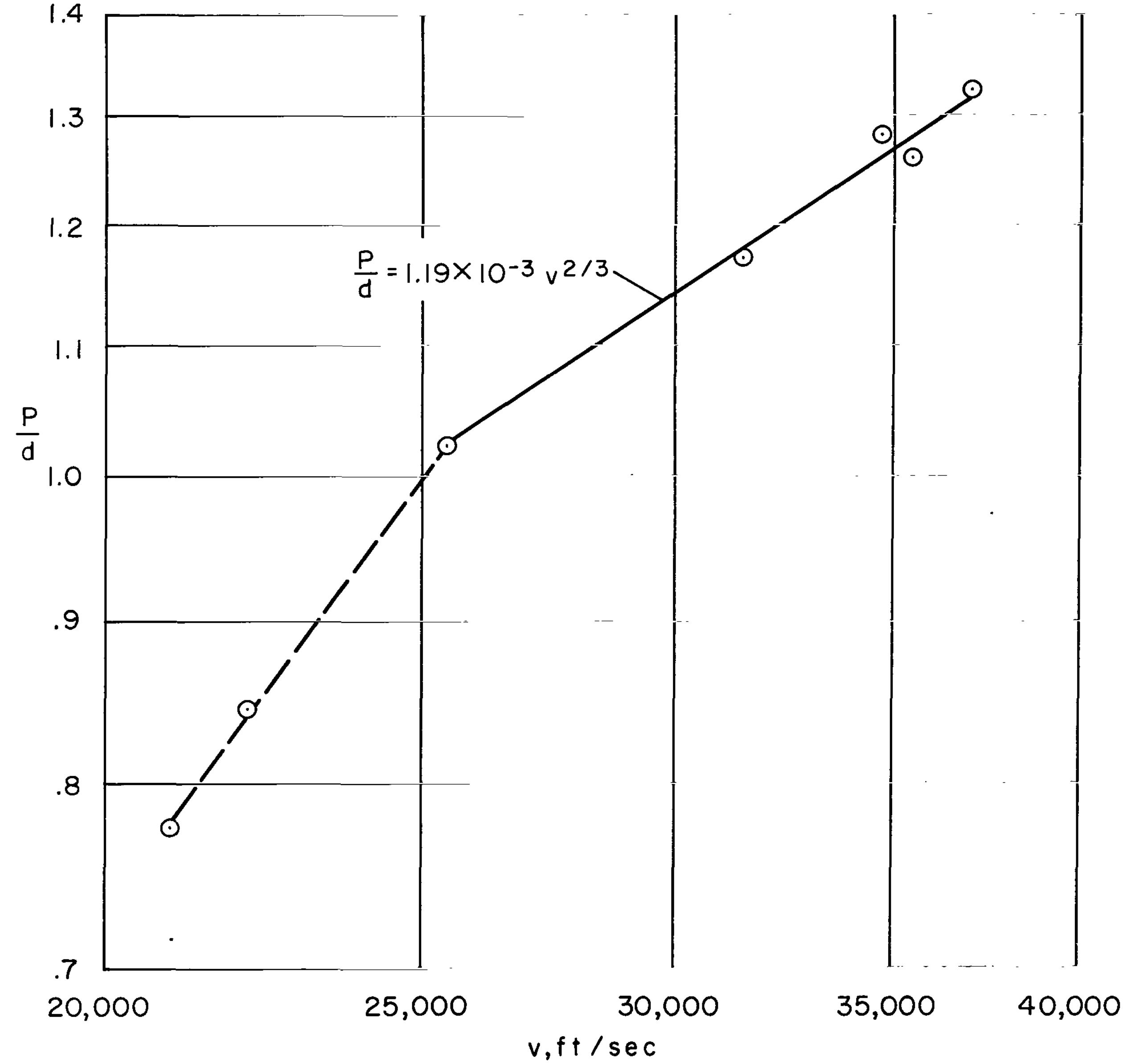



Figure 2.- Penetration versus velocity.

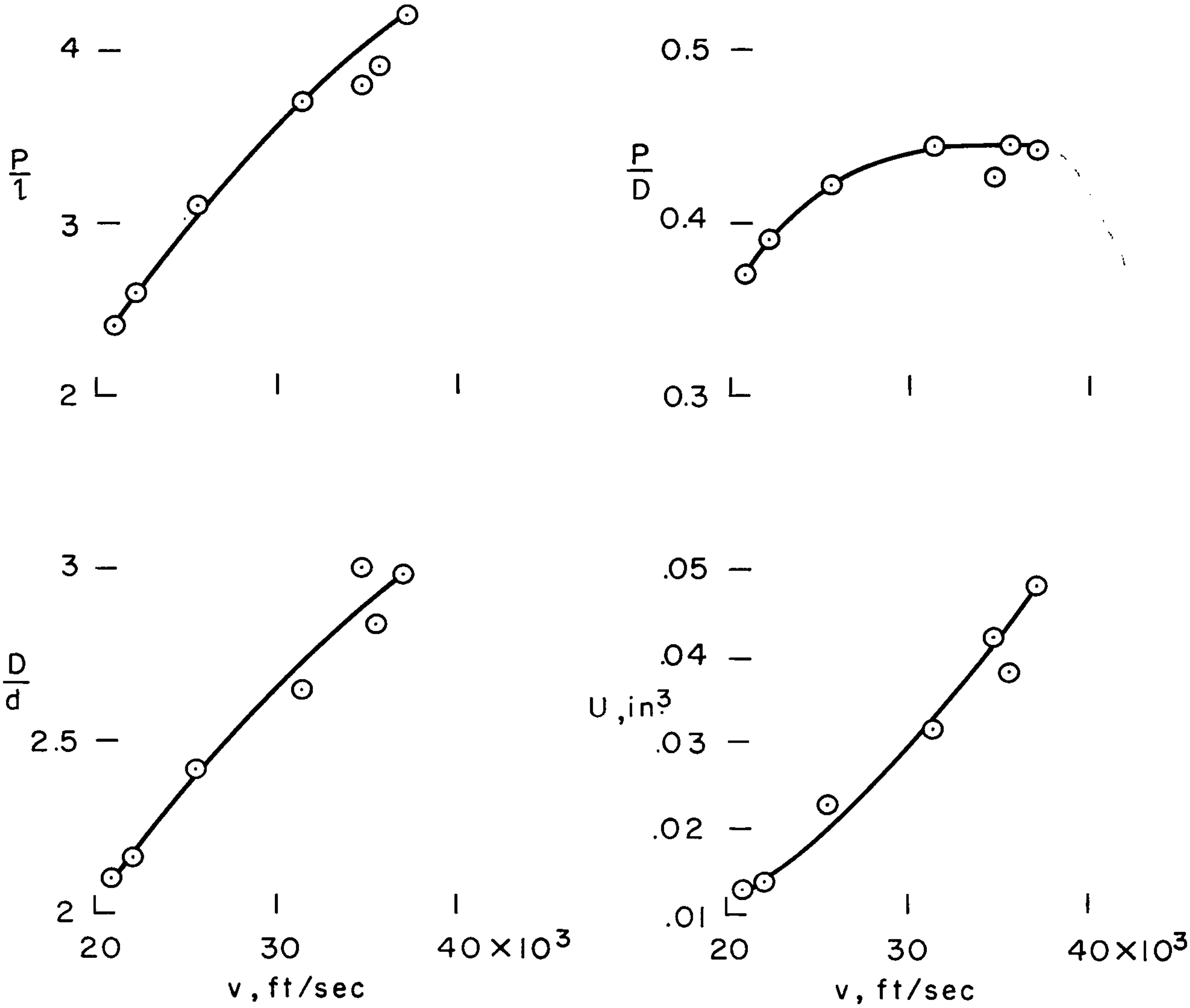
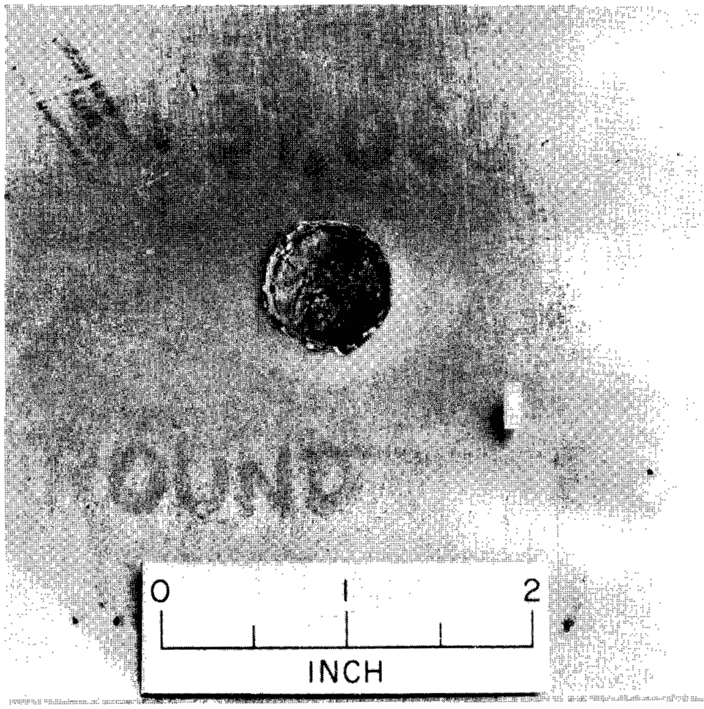



Figure 3.- Penetration parameters versus velocity.

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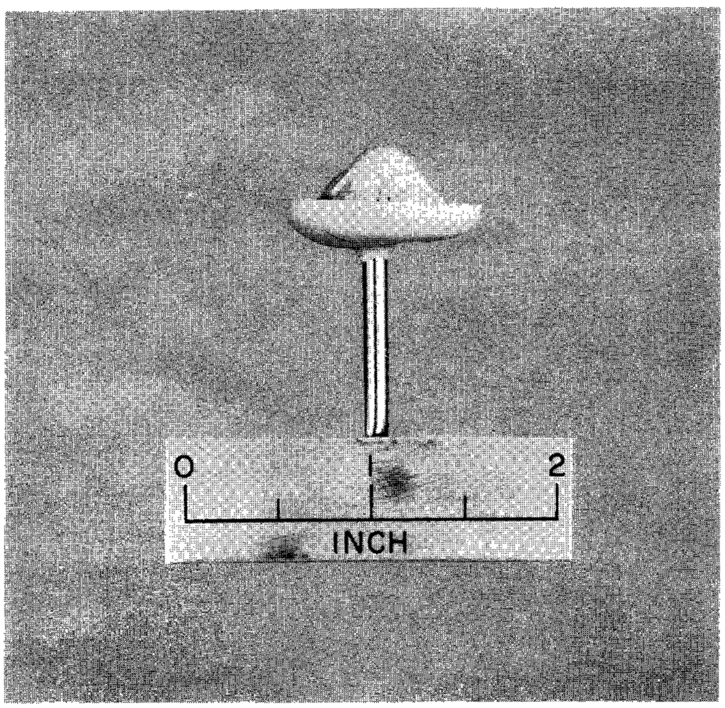


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Figure 4.- Photographs of target and projectile along with plaster replica of crater. (Round No. 568, $v$ = 37,060 ft/sec)



NASA-Langley, 1966 A-2271

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