REPORT NO. 0-2263

DATE 20 March 1944

SUBJECT

Report on Velocity Loss of a 1/2 inch Model Projectile when it Penetrates 1/32 inch cold rolled steel

FR-2263

SERIAL No. 23

[redacted]

20 March 1944

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NRL Report No. 0-2263

CLASSIFICATION CANCELLED OR CHANGED TO RESTRICTED BY AUTHORITY OF 3400A Vol I ON Sept 1949

NAVY DEPARTMENT

Report on

Velocity Loss of a 1/2-inch Model Projectile When It Penetrates 1/32-inch Cold-Rolled Sheet Steel.

[redacted] [redacted]

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages:	Text 4	Plates 7
Authorization:	BuOrd Ltr. S13-1(4/173)(08) of 13 December 1934	
Date of Tests:	October 1943 to March 1944	

Prepared by:

Gilbert D. Kinzer
Physicist

Alice C. Jantzen
Ensign W-V(S), USNR

Reviewed by:

Ross Gunn, Superintendent,
Mechanics & Electricity Division

Approved by:

A. H. Van Keuren
Rear Admiral, USN
Director

Distribution:

BuOrd (10)
Naval Ordnance Lab. (2)
NRL (13)

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ABSTRACT

This investigation was made in order to obtain an estimate of the velocity loss of a 4-inch HC Mark 15 projectile penetrating thin plate at velocities well above limit. In order to improve the accuracy of the velocity loss measurement, the experiment was performed with a 1/2-inch model projectile using a ballistic pendulum to measure the momentum loss. Besides giving the desired information, the experiment showed the interesting result that at a striking velocity of 2100 feet per second the velocity loss in 1/32-inch cold rolled steel had a minimum value. It was a surprise to find a minimum at so low a striking velocity. If this is a general characteristic of high velocity penetration of thin plate, it is important not only to the fuze designer but also to the fundamental study of the mechanism of armor penetration.

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INTRODUCTION

1. This investigation was authorized by the letter listed as reference (a). One other reference in the report is listed as (b).

(a) BuOrd ltr. S13-1(4/173)(Q8), of 13 December 1934.
(b) NRL Report No. 901778, of 4 September 1941.

2. To help in designing a fuze at the Naval Ordnance Laboratory, it seemed desirable to determine what velocity loss would be expected when a 4-inch HC Mark 15 projectile penetrated a 1/4-inch steel plate. Ordinary methods of measuring striking and residual velocities have provided some information about the velocity loss of large caliber projectiles in thin plate, and, from a few measurements well above the limit, charts have been constructed to show the variation of velocity loss with striking velocity. Unfortunately, the accuracy of these measurements is such that the velocity loss, that is, the difference between the striking and the residual velocity, is only roughly known. Furthermore, the extrapolation used to construct the charts may possibly be based on penetration theories not too well established.

3. It was realized that a more accurate method of finding velocity loss was needed, a method which would allow using a wide range of striking velocities. Facilities providing such a method existed at NRL. They consisted of a Cal .50 machine gun barrel mounted in line with a ballistic pendulum and a pair of chronograph screens so that a projectile could be fired through the pendulum, through the screens, and into a backstop. The momentum transferred during penetration to a thin plate mounted in the pendulum would be equal to the product of the velocity loss and the mass of the projectile. The velocity loss would thereby be determined with as much accuracy as is possible in pendulum measurements. Since the experiment promised to give useful data, a series of measurements were made using the pendulum for finding the velocity lost by a 1/2-inch model projectile during penetration of 1/32-inch cold rolled steel plate. The striking velocity was varied from 900 to 3700 feet per second.

4. An objection can be made to the extrapolation necessary to extend the results of such an experiment as this from one scale to another because it might be no more certain than the extrapolation mentioned in paragraph 2. However, the results in this experiment are sufficiently precise to establish the trend of the velocity loss at small scale, and it should be possible with fewer calibrating penetrations to predict the velocity loss at larger scales.

5. A short account of how the data were obtained is interesting because it illustrates the flexibility of the equipment available at NRL. The arrangement and the spacing of the apparatus is shown on Plate 1. A 370-pound pendulum constructed in the same way as the 110-pound pendulum described in reference (b) was stripped down by removing its top, sides, and bullet stopping material. This reduced its weight to 57 pounds. The final weight was 67 pounds after a holder was added for 5-inch square

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specimens of 1/32-inch cold rolled steel. Since the momentum transfer was small for high striking velocity and thin plate, it was necessary to make the pendulum as light as was practicable in order to give deflections having a magnitude large enough to be read accurately. Slider friction was avoided by using a traveling microscope to read the deflections, but this introduced some damping error because the pendulum would swing through several oscillations before the readings were made. Accumulated error in the velocity loss measurements should not have exceeded 4-1/2 percent. The residual velocities of the projectiles were measured with the chronograph screens placed about 11 feet apart with a maximum likely error of about 1/4 percent at 900 feet per second and 1 percent at 3700 feet per second. The striking velocity was found by adding the velocity loss to the residual velocity. The experimental points along curve A of Plate 3 show the results of the investigation. At the higher striking velocities some error was undoubtedly introduced by the tendency of petals to loosen from the specimens and to be projected to the rear. Although care was taken to catch as many of these with the pendulum as possible, they may not have been completely caught in all the rounds of firing. It is believed that some of the points lying below curve A on Plate 3 may be too low because of this, and these points were not given as much weight as the higher points when curve A was drawn to indicate the trend.

6. A notable feature of the perforations in the specimens was the manner in which their area increased with the striking velocity. In order to describe this, the areas were measured by first making contact negatives of the openings on Reprolith film with parallel light illumination; next, prints from these negatives were enlarged six times; and last, the areas on the prints were measured with a planimeter. The results, plotted on Plate 4, are expressed in units of the cross-sectional area of the projectile. Photographs showing other features of typical perforations are included on Plates 5 and 6.

7. The photographs on Plate 7 show how the 1/2-projectile was constructed. It was made of 4340 SAE steel having a hardness of 29 Rockwell "C", and it was intended to be a model of the 4-inch HC Mark 15 projectile. In order to match the m/d^3 form factor of the latter, the model was hollowed out and closed at the base with a threaded plug. The form factor of the 1/2-inch model was 440 pounds per cubic foot as compared to 420 pounds per cubic foot for the 4-inch projectile.

8. The thin plate specimens were cut from available stock of 1/32-inch cold rolled sheet steel. No particular care was used in selecting the stock, but the hardness and thickness only varied from 88 to 101 Vickers and from 0.032 to 0.033 inches, as indicated by a number of random measurements.

RESULTS

9. Referring to curve A on Plate 3 it will be seen that a minimum velocity loss occurs at a striking velocity of about 2100 feet per second. Previously, it was a common opinion that the velocity loss should have a minimum at some sufficiently high striking velocity, but it was not suspected that it might occur at a value as low as 2100 feet per second.

The importance of this result to the fuze designer is obvious for it indicates that within the range of striking velocities expected in actual practice there may occur a minimum velocity loss and consequently a minimum impulse for which the fuze must operate. If this minimum value is known the designer will have a lower limit on the energy available to operate the fuze.

10. From the gradual increase in the severity of the deformation, evident in the photographs on Plates 5 and 6 and from the curve on Plate 4, it is suspected that inertial resistance may become more and more important in absorbing energy from the projectile as the striking velocity becomes larger and larger. If, for a moment, it be assumed that inertial resistance is the only means by which the projectile can be slowed, then, by a qualitative argument, it can be shown that the loss in velocity by the bullet will be proportional to the striking velocity and the velocity loss should follow along a straight line through the origin such as B, shown on Plate 3. On the other hand, if the effect of inertial resistance be neglected and only the resistance due to the material strength be considered, an approximate description of the velocity loss can be obtained by assuming that the resistance is independent of the striking velocity. This is equivalent to assuming that the energy absorbed is constant regardless of the striking velocity. It is not hard to show that this predicts a change in velocity loss which would follow such a curve as C on Plate 3.

11. Up to a striking velocity of 2000 feet per second the trend of the experimental points seems to be along a curve such as C, but from 3000 feet per second on toward higher values the trend seems to be along a straight line through the origin such as B. The existence of a minimum velocity loss thus appears to be caused by a fundamental change in the plate resistance, from resistance at low striking velocity due mainly to material strength to a nearly pure inertial resistance at high striking velocity. If this point of view is correct, then the position of the minimum velocity loss must depend on such factors as the tensile strength of the plate, the thickness and density of the plate, the weight and diameter of the projectile, the angles of obliquity and of yaw, and possibly the scale size.

EFFECT OF SCALE

12. There are no examples of known scale effect measurements which are available to use to predict just what the performance of the 4-inch projectile against 1/4-inch plate would be on the basis of results with the 1/2-inch model, and the uncertainties associated with making such a prediction with what is known about scale effects seem too great to give reliable information. It is preferable to consider the results in this report as being true for a particular set of conditions and to perform one or more additional experiments in order to get the desired information. Two things can be done. One is to use a 37 mm model projectile and thus obtain results for a scale about halfway between the 1/2-inch model and the 4-inch projectile. This experiment is now started at the Naval Research Laboratory. The second thing which could be done is to obtain a calibrating perforation at or near the full scale size and thus establish a magnitude of the velocity loss at some striking velocity. Knowing the results of these experiments, it should be possible to arrive at a reasonably certain estimate of the magnitude and of the trend of the velocity loss of the 4-inch projectile.

13. There are two characteristics of the perforations at 1/2-inch scale which might lead one to expect the scale effect to be small. The first is the fact that penetration occurs with rather large rates of strain, and, although in this type of deformation the strain rate must be inversely proportional to the scale size, even at large scales the rates may be considerably higher than some critical value below which the resistance to deformation will depend on the rate. The other characteristic is the apparent dependence of the velocity loss upon the inertia of the perforated material, particularly at striking velocities above 2100 feet per second, and since the inertia is mostly dependent on the density, there seems to be little that could introduce a scale effect at the higher striking velocities so long as the density of the struck material is unchanged.

CONCLUSIONS

14. Besides furnishing information for the fuze designer this investigation has revealed a penetration characteristic which is of interest to the study of the mechanics of armor penetration. This is the existence of a minimum velocity loss at reasonably low striking velocities. It is not known yet whether this is a general characteristic of all thin plate penetrations or whether it just occurs in cold-rolled sheet steel at an e/d of about 1/16. Attempts to fit the data to what seems to be a likely penetration theory, that of Poncelet, are not as successful as combining the approximations of constant energy absorption at low striking velocity and a pure inertial resistance at high striking velocities.

15. It is believed that a more reliable estimation of the velocity loss to be expected when a 4-inch projectile strikes thin plate can be made on the basis of results obtainable with a 1/2-inch model projectile using a ballistic pendulum to measure the momentum loss than can be made from full scale measurements of the striking and residual velocity, because it is difficult to obtain the latter with sufficient accuracy. It is considered advisable, however, to substantiate any prediction made on the basis of the results with the 1/2-inch model with results of a similar experiment using a 37 mm model and at least one calibrating test at full scale.

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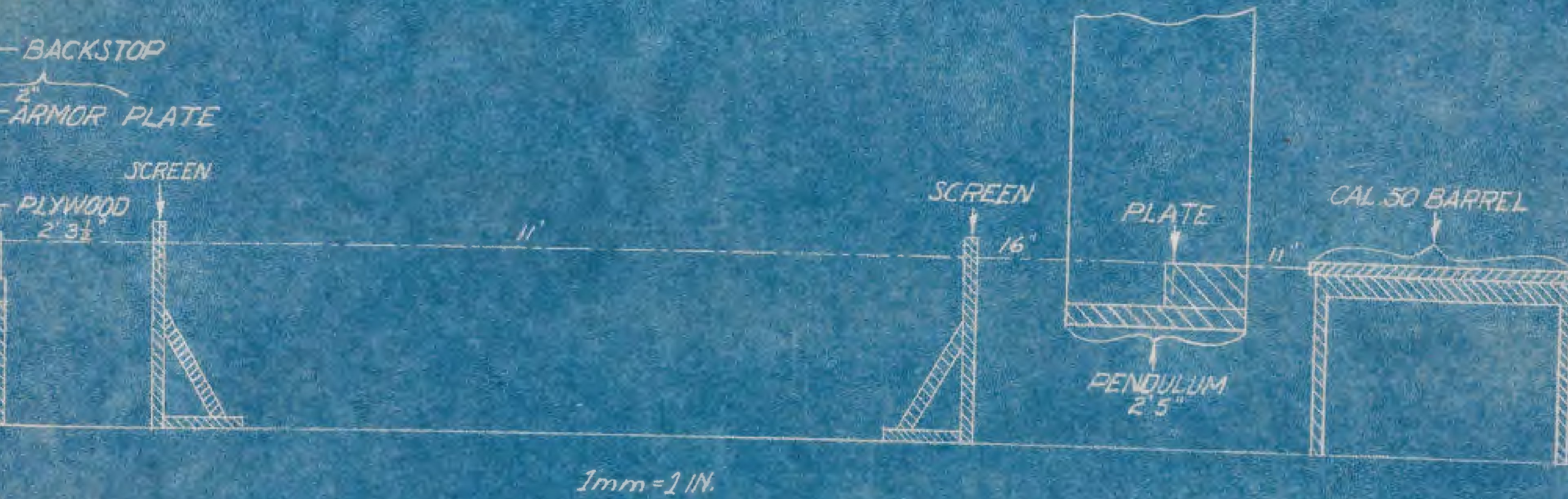
BACKSTOP
2" ARMOR PLATE
SCREEN
PLYWOOD 2' 3½"
11'
SCREEN
16"
PLATE
PENDULUM 2' 5"
11"
CAL .50 BARREL
1mm=1 IN.

PLATE I

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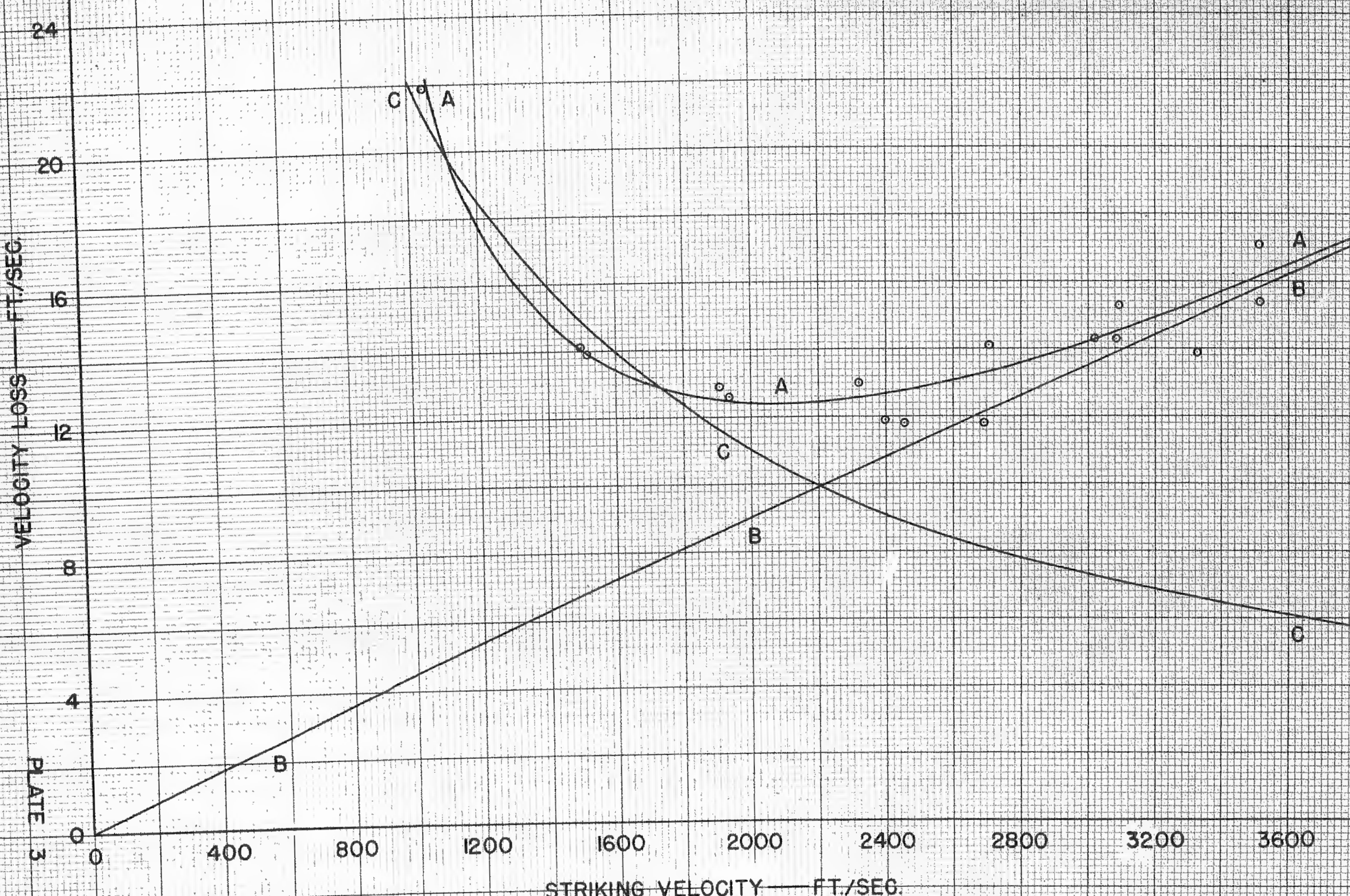
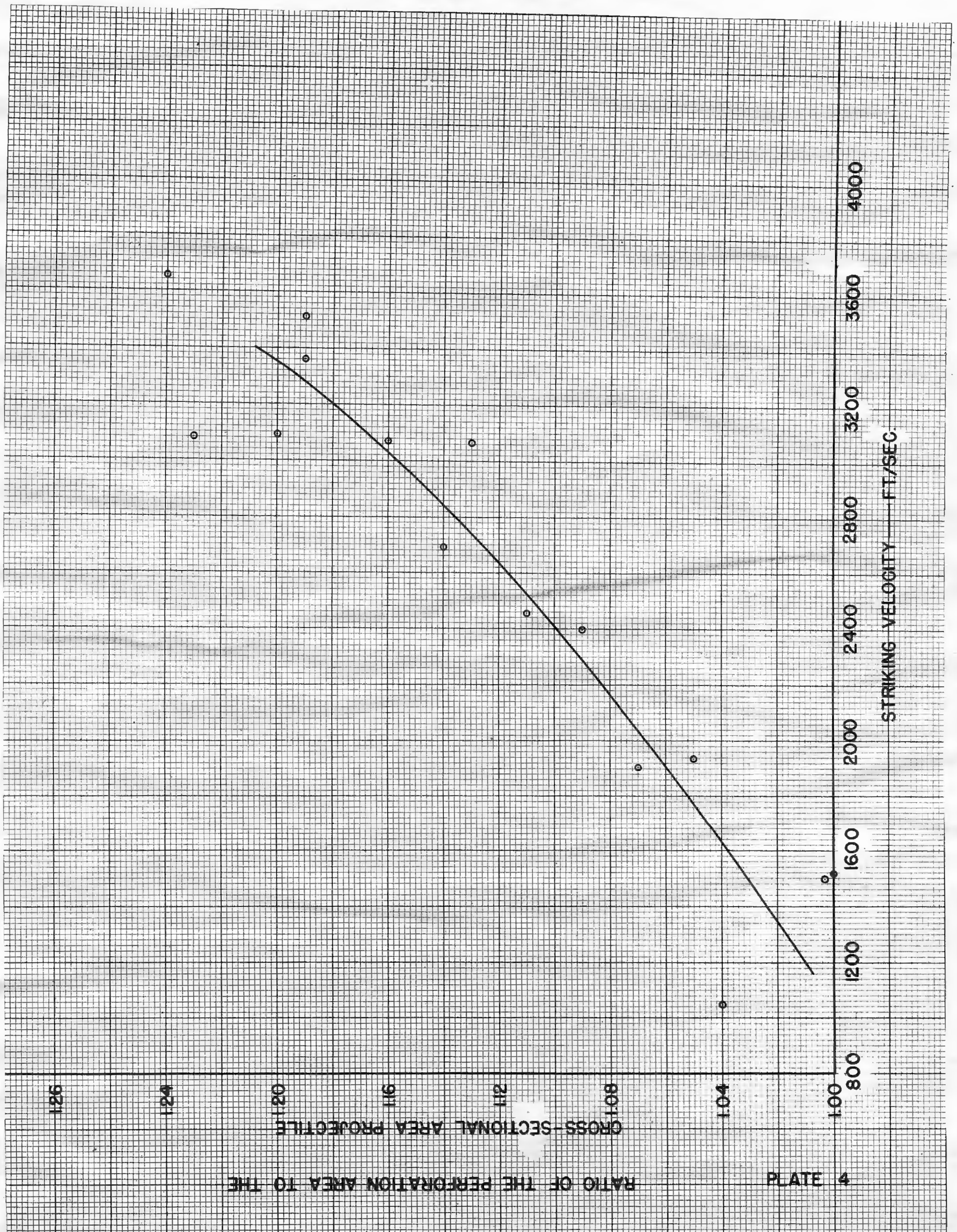


VELOCITY LOSS — FT./SEC.
24
20
16
12
8
4
0
0
400
800
1200
1600
2000
2400
2800
3200
3600
STRIKING VELOCITY — FT./SEC.
A
B
C

PLATE 3



STRIKING VELOCITY — FT/SEC.
800
1200
1600
2000
2400
2800
3200
3600
4000
RATIO OF THE PERFORATION AREA TO THE
CROSS-SECTIONAL AREA PROJECTILE
1.00
1.04
1.08
1.12
1.16
1.20
1.24
1.26

PLATE 4


R 7
S.V.=1515 ft./sec.
V.L.=14.95 ft./sec.
Round No. 7
S.V.=1904 ft./sec.
V.L.=13.89 ft./sec.
Round No. 2
S.V.=2454 ft./sec.
V.L.=12.66 ft./sec.
Round No. 3
R 4
S.V.=2691 ft./sec.
V.L.=12.77 ft./sec.
Round No. 4
S.V.=3082 ft./sec.
V.L.=14.81 ft./sec.
Round No. 8
R 5
S.V.=3089 ft./sec.
V.L.=15.76 ft./sec.
Round No. 5
R 6
S.V.=3513 ft./sec.
V.L.=18.14 ft./sec.
Round No. 6

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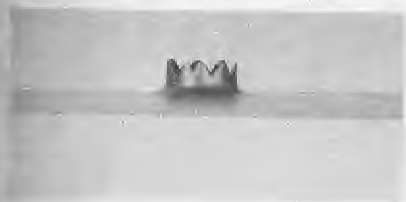
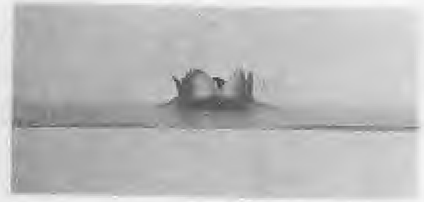
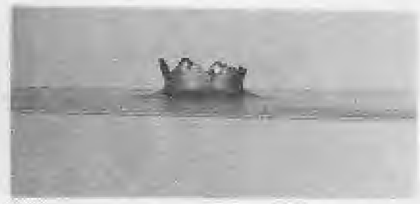


S.V. = 1515 ft./sec.
V.L. = 14.95 ft./sec.
Round No. 7

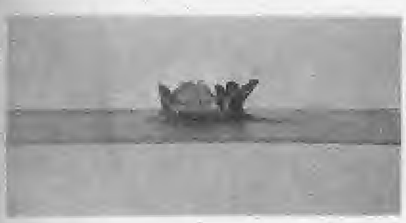


S.V. = 1904 ft./sec.
V.L. = 13.89 ft./sec.
Round No. 2

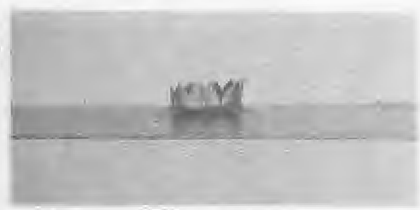
S.V. = 2454 ft./sec.
V.L. = 12.66 ft./sec.
Round No.3



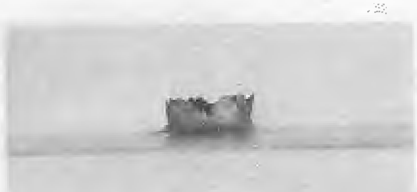
S.V. = 2691 ft./sec.
V.L. = 12.77 ft./sec.
Round No. 4



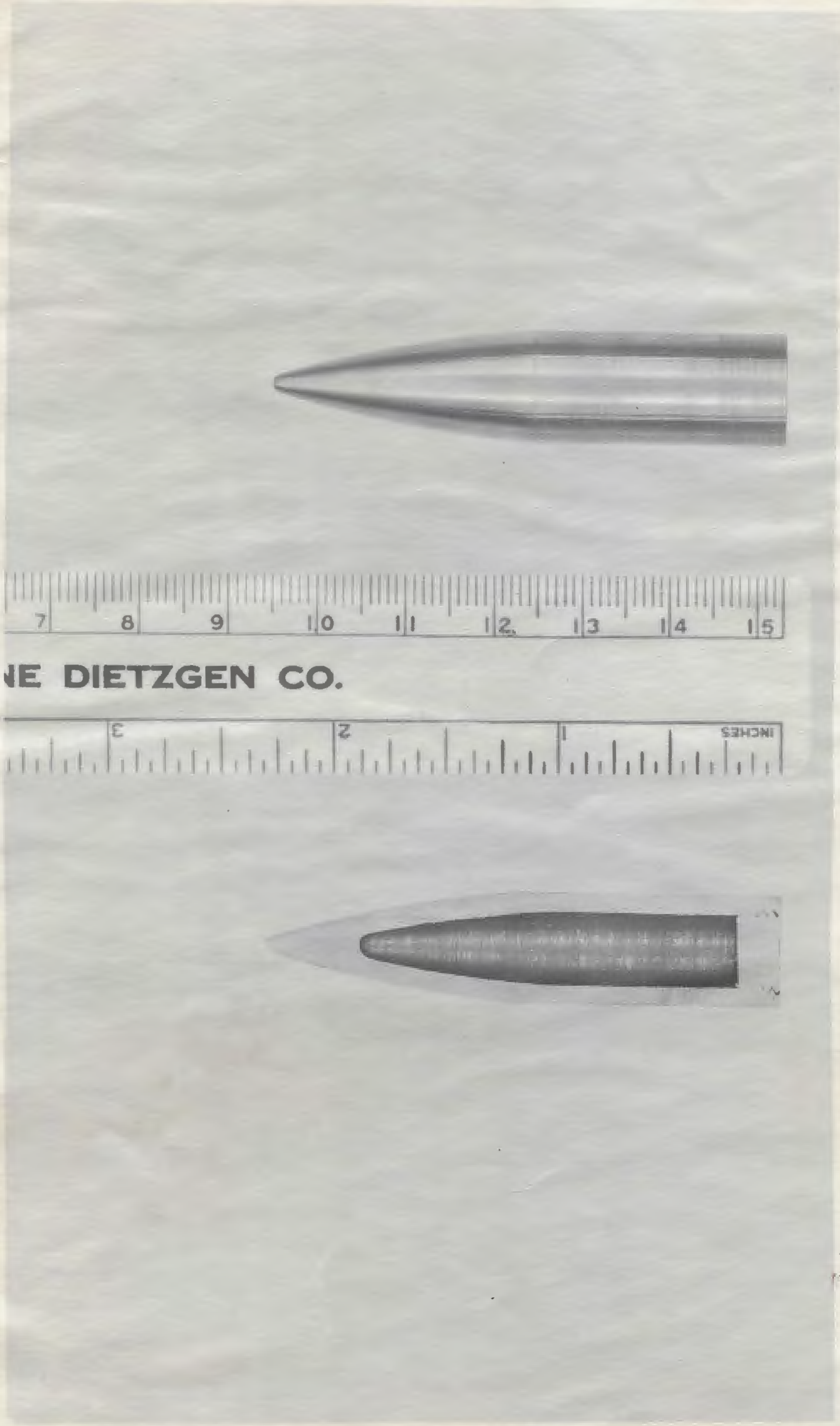
S.V. = 3082 ft./sec.
V.L. = 14.81 ft./sec.
Round No. 8



S.V. = 3089 ft./sec.
V.L. = 15.76 ft./sec.
Round No. 5



S.V. = 3513 ft./sec.
V.L. = 18.14 ft./sec.
Round No. 6


DIETZGEN CO.