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BRL 202

BRL

REPORT NO. 202

TEST OF CALIBER 0.50 BARRELS HAVING REDUCED HEIGHT OF LANDS

by

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U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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TEST OF CALIBER 0.50 BARRELS HAVING REDUCED HEIGHT OF LANDS

Abstract

Yaw and pressure firings were carried out in a barrel having reduced lands and in a standard barrel. Bullets fired from the reduced height of lands barrel were practically smooth and the yaw data indicated instability in flight. Calculations show that the reduced height of lands should augment the velocity by about 100 f/s at a velocity of about 3000 f/s.

Introduction

In accordance with instructions given in a letter from the Chief of Ordnance (0.0 472.54/6459) eight Caliber 0.50 machine gun barrels having standard bore diameters but heights of lands varying from .0015" to .0050" were fired at the Proving Ground. Results of these tests were given in the "88th and 99th Partial Reports on Functioning and Mechanical Tests of Machine Guns and Machine Gun Accessories".

At the completion of the firings described in the previously mentioned reports, Barrel C7 (land diameter = .5075) was modified for use as a piezo-electric gauge gun by the Ballistic Research Laboratory. The following indorsement was sent to the Chief of Ordnance after the firing of several rounds:

OO 472.54/6459
APG 472.5/289A 5th Ind. JRL/emh

"1. In carrying out the pressure firings recommended in par. 2b of the 3rd Ind., it was noted that the bullet had a large yaw as it passed through the second velocity screen placed at the end of the research laboratory firing range, a distance of about forty-four feet from the muzzle. Since this yaw might have been due to the muzzle contact of the velocity screens, several additional rounds were fired without any obstacles along the trajectory other than a single yaw card at forty-four feet. The results are given in the table below:

Barrel	Bullet	Yaw
C7 (lands - .5075)	AP M1	40°, 18°, 13°, 2 rds. 1°
C7 (lands - .5075	Ball M1	62°, 40°, 13°, 2 rds. 7°
Standard	Ball M1	6 rds. 1°

"2. As reported in the '88th Partial Report on Functioning and Mechanical Tests of Machine Guns and Machine Gun Accessories', the Small Arms Section fired ten M1 Ball bullets from the same barrel (C7) through yaw cards placed at 10', 12', and 14', supposedly the region of the first maximum yaw. Only two rounds of the ten fired had yaws as great as 6°. If the first maximum yaw were really at 12', it should have been larger than the yaw at 44'. In an attempt to explain this apparent inconsistency, six yaw cards were placed along the 44' range and two rounds were fired through the cards. Photostats of the yaw cards showing the yaws and orientations of these two rounds are attached herewith. The first round had practically no yaw while the second had a maximum of about 28°. The yaw and orientation angles are plotted as a function of the range on Plot No. 1. The slope of the orientation-range line (φ') is $.053\pi$ whereas the theoretical value derived from the moments of inertia and twist of rifling is $.069\pi$; the first maximum yaw occurs at about 30'. It is evident, then, that the bullet is not getting full spin but is slipping in the bore; the effect of this slippage is to reduce the stability factor from 1.55 when fired from a standard barrel to 1.07 in the reduced land barrel.

"3. In view of these results, permission is requested to cancel that part of the program relating to the test of the machine gun at high temperature outlined in par. 2a of the 3rd Ind. There does not appear to be any reason for obtaining the yaw at high temperatures when the yaw is so large at room temperatures."

In reply to this, the 6th Ind., the pertinent paragraphs of which are given below, was received from the Chief of Ordnance:

"1. Cancellation of part of subject program requested in paragraph 3 preceding indorsement is authorized.

"2. Attention is invited to the fact, however, that all the subject barrels were fired for recovery of bullets and no slip worth mentioning occurred in any case. This firing was reported in 99th Partial Report on OP 5082, and recovered bullets are on hand at this office. It is, therefore, requested that the conclusion advanced in paragraph 2 preceding indorsement be checked by further recovery firing or other means."

In accordance with these directions, two rounds of Caliber 0.50 M1AP were fired for recovery with a charge of 255 grains of Herc. 1770.159C from Barrel C5 (Land diameter - .5075"). Yaw cards were placed along the trajectory at five foot intervals from ten to sixty feet ahead of the muzzle and at ten foot intervals from sixty to one hundred feet. The angles of yaw and orientation obtained from the yaw cards are given in Table I below and are plotted as a function of the distance from the muzzle in Plots Nos. I and II.

Table I.

Results of Caliber 0.50 M1AP Bullet Yaw Firing

Charge - 255 grains Herc. 1770.159C

Barrel - C5 (Land Diameter - .5075")

	Round No. 1		Round No. 2	
Distance from muzzle	Yaw	Orientation	Yaw	Orientation
10'	0°	1.64π	7°	.40π
15'	1°	1.68π	15°	.43π
20'	5°	1.70π	35°	.51π
25'	8°	1.72π	67°	.56π
30'	19°	1.77π	108°	.68π
35'	40°	1.78π	130°	.94π
40'	80°	1.79π	103°	1.16π
45'	125°	1.82π	62°	1.26π
50'	160°	1.99π	35°	1.32π
55'	151°	2.50π	23°	1.32π
60'	110°	2.58π	25°	1.30π
70'	31°	2.61π	72°	1.38π
80'	8°	2.54π	126°	1.72π
90'	16°	2.45π		
100'	61°	2.46π	Hit Wood	
110'	151°	2.58π		
120'	127°	3.25π		
130'	43°	3.30π		
140'	20°	3.27π		

From the yaw and orientation angles, the actual spin of the projectile may be calculated. The equation of motion of the projectile* relating these three functions is

$$AN \cos \delta + B \sin^2 \delta \, \dot{\varphi} = F$$

where the symbols are defined below:

- A axial moment of inertia
- B transverse moment of inertia
- δ angle of yaw
- φ angle of orientation
- $\dot{\varphi}$ spin about trajectory
- N spin of projectile about its axis of symmetry
- F a constant

By setting $\delta = 0$, F is found to equal AN and (1) becomes

$$(2) \quad AN (\cos \delta - 1) + B \sin^2 \delta \, \dot{\varphi} = 0$$

Substituting Ω for $\frac{AN}{B}$ and simplifying, we get

$$(3) \quad \dot{\varphi} = \frac{\Omega}{1 + \cos \delta}$$

Also,

$$(4) \quad \dot{\varphi} = \frac{d\varphi}{dt} = \frac{d\varphi}{dx} \cdot \frac{dx}{dt} = \frac{d\varphi}{dx} \cdot v \cdot$$

Combining (3) and (4), and considering v constant over the relatively short range (140 feet), it follows that

$$(5) \quad \varphi = \frac{\Omega}{v} \int_0^s \frac{dx}{1 + \cos \delta} + \varphi_0$$

φ_0 and Ω were arbitrarily chosen so that the calculated and empirical curves could be compared on the same plot.

A comparison of the empirical orientation-distance curve and the curve obtained by mechanical integration of Equation (5), both of which are plotted for each round on Plots Nos. I and II, shows that the two types of curves agree very well in general contour for each round. It is, therefore, possible to

* "The Elementary Treatment of the Motion of a Spinning Projectile About Its Center of Gravity", Ballistic Research Laboratory Ref. No. 85 by R. H. Kent.

calculate the value of Ω , and since A and B can be measured, the value of N, the spin. By means of the equation

$$(6) \quad N = \frac{2\pi v_o}{nd} ,$$

we can calculate the corresponding n, the effective twist of rifling for the particular round. The barrel is rifled with a twist of 1 in 30 calibers but since the bullet slips and strips in the bore, the effective twist is very much less. The calculated spin of the bullet corresponds to a twist of rifling of about 1 in 700 for the first round and 1 in 200 for the second round. The very low values for the effective twist indicate that the bullets started to strip long before they reached the position of maximum pressure.

As stated previously, the same two rounds discussed above were fired for recovery and Photograph No. APG 40921 shows the two recovered bullets and a third one fired from a standard barrel. The two bullets fired from Barrel C5 (land diameter = .5075") are almost smooth and show practically no signs of rifling.

As a result of this firing, it is clear that a Caliber 0.50 barrel having a diameter across the lands of .5075" is not satisfactory.

Pressure Cycle of Reduced Land Barrel

As stated previously, Barrel C7 (land diameter - .5075") was modified for use as a piezo-electric gauge gun. Several combinations of charge and powder were fired for pressure-time records and, in some cases, for velocity. A resume' of the firings is given below:

Table II.

Comparison of Pressures and Velocities in Barrel C7 and Standard Barrel

C7 45" Barrel; Land Diameter - .5075"; M1AP Bullet

Powder	Charge (Grains)	No. of Rds.	Mean Maximum P.E. Press. (lb/in^2)	Vel. (f/s)	Corrected Vel. (f/s)	$\frac{\text{Press.}}{\text{Corr. Vel.}^2}$
Herc. 1830	248	2	53,100	3020	2910	6.27×10^{-3}
" 1770.159C	248	15	49,600	2991 (5 rds.)	2881	5.98×10^{-3}
" 1770.159C	255	2	53,300	3078	2968	6.05×10^{-3}

36" Barrel; Standard Land Diameter - .500"; M1AP Bullet

Powder	Charge (Grains)	No. of Rds.	Mean Maximum P.E. Press. (lb/in^2)	Vel. (f/s)	$\frac{\text{Press.}}{\text{Corr. Vel.}^2}$
Herc. 1830	248	2	56,700	2943	6.55×10^{-3}
" 1770.159C	248	2	56,700	2945	6.54×10^{-3}
" 1770.159C	255	2	64,100	3059	6.86×10^{-3}

The velocities given in the above table for the 45" Barrel must be reduced to the 36" Barrel in order to make the comparison of the barrels valid. The increase in velocity due to the use of the longer barrel is about 110 f/s.*

Both the corrected velocities and the pressures are lower in the barrel having the larger land diameter. As a first approximation, the ratio of the pressure to the square of the velocity should be constant for about the same condition of gun and charge. In the case of these two barrels, the ratio is smaller for the barrel having the land diameter increased to .5075". Assuming the mean ratio for Barrel C7 and a pressure of 56,000 lb/in^2, the corresponding velocity in Barrel C7 is found to be 3050 f/s. In other words, the maximum pressure which corresponds to a velocity of 2940 f/s in the standard barrel would give a velocity of 3050 f/s in the reduced land barrel.

Four of the pressure-time records were read for integration and for determination of passive resistance, as follows:

1 round of 248 grains of Herc. 1830 in Standard Barrel
1 round of 248 grains of Herc. 1770.159C in Standard Barrel
1 round of 248 grains of Herc. 1830 in Barrel C7
1 round of 248 grains of Herc. 1770.159C in Barrel C7

The pressure-time curves were obtained directly from the piezo-electric oscillogram. Acceleration curves $(\frac{d^2x}{dt^2} \text{ vs } t)$ were derived from these curves; integration of the acceleration curve gives a velocity curve $(\frac{dx}{dt} \text{ vs } t)$ and integration of the velocity curve gives a travel curve (x vs t). The final

* 55th P.R. on Functioning and Mechanism Tests of Machine Guns and Accessories and 1st P.R. on Test of 45" Barrels for Caliber 0.50 Machine Guns O.P. 5082 T.S.T.P. No. 1931-625.

velocity and travel obtained by the integrations are higher than the known measured values since we have neglected the forcing resistance and gas friction. The total friction is considered to be the sum of bullet friction and gas drag. The bullet friction f_1 (x) is assumed to be equal to

$a\left(1 - \frac{x}{2x_e}\right)$ where

a is a constant
x is instantaneous travel
x_e is exit travel

The gas drag f_2 (t) is assumed to be equal to $b\rho v^2 S$, where

b is a constant
ρ is the density of the charge
v is the velocity of the projectile
S is the bore surface from the breech to the projectile

all values being taken at time t. The constants a and b are determined in such a way that the integrated values of the velocity and travel equal the measured values.

Four curves are shown on Plots No. III - VI for each round:

A - a pressure-time curve
B - a pressure-travel curve
C - a velocity-travel curve
D - a friction-travel curve

The means values of the friction-travel curves shown on the D plots were obtained by Simpson's rule and are given below:

Barrel C7	Herc. 1830	5420 lb/in^2
Standard Barrel	Herc. 1830	7280 lb/in^2
Barrel C7	Herc. 1770.159C	4310 lb/in^2
Standard Barrel	Herc. 1770.159C	6890 lb/in^2

The mean decrease in friction from the standard barrel to the barrel having reduced height of lands for the two rounds is 2220 lb/in^2. Assuming that the energy lost by the increased friction of the standard barrel is used to accelerate the projectile and charge, the increase in velocity due to the decrease in friction of the reduced land barrel may be calculated from the equation

$$\Delta P_f \, As = \frac{\left(m + \frac{c}{3}\right)\left(v^2_{c-7} - v^2_{st}\right)}{2g}, \text{ where}$$

ΔP_f is the mean difference in friction between the barrels
A is the area of the bore
s is the travel (of 36" barrel)
m is the weight of the projectile
c is the weight of charge
v_{c-7} is the muzzle velocity of the C7 Barrel
v_{st} is the muzzle velocity of the Standard Barrel
g is the gravity constant

Assuming a velocity of 2940 f/s for the standard barrel, the velocity of the reduced land barrel is calculated to be 3050 f/s, which checks very well with the value previously calculated by assuming a constant ratio of pressure to velocity squared; in fact, the agreement is undoubtedly better than one should expect from the two methods used.

Recommendations

While the .5075" barrel is not satisfactory, it has not been proved that the principle of reducing land diameters in the Caliber 0.50 is entirely unsatisfactory. It is, therefore, recommended that a .5035" barrel be modified for use as a piezo-electric pressure gauge and similar firings be carried out in it.

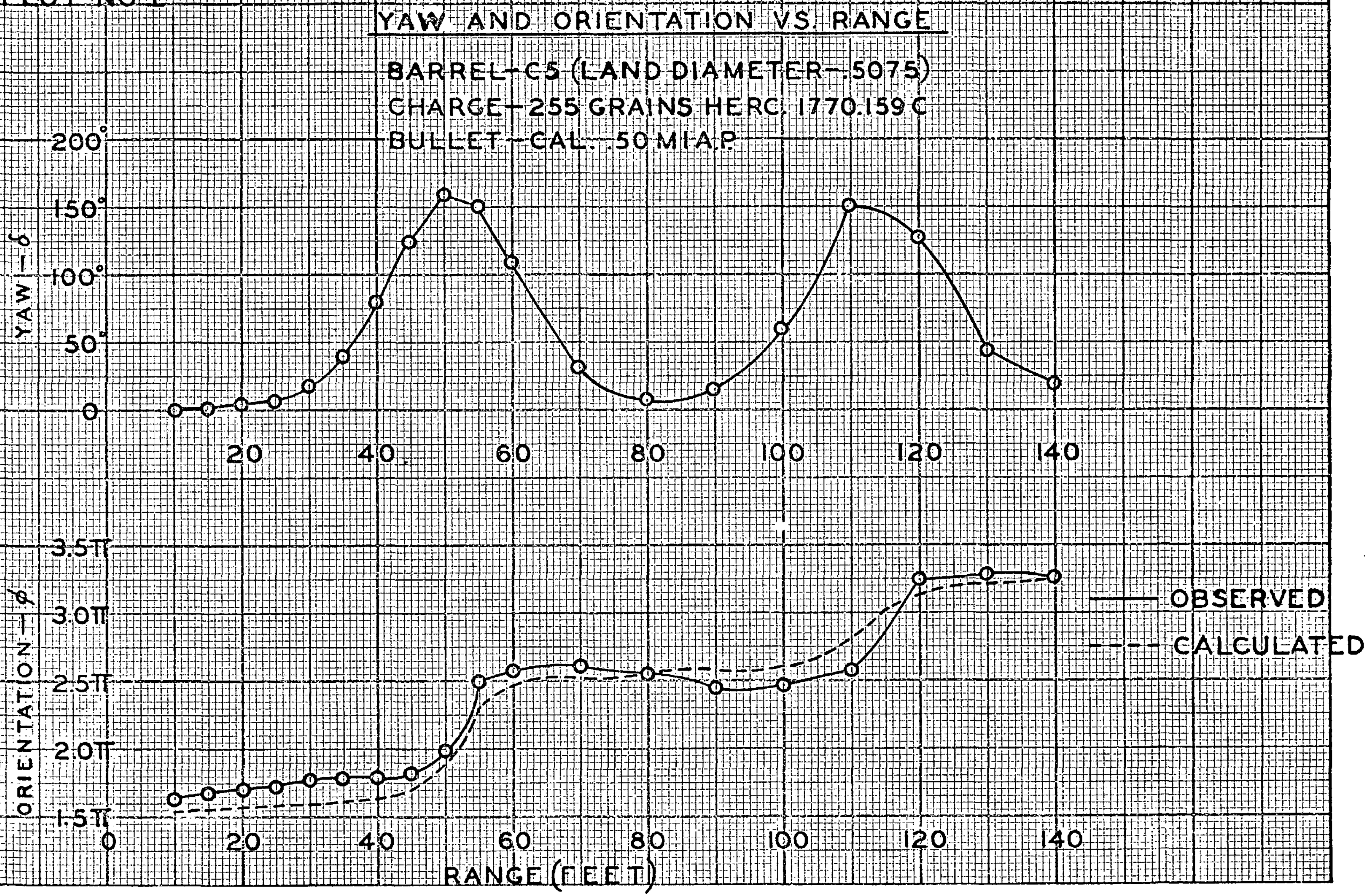
Resume'

The analysis of the pressure-time records obtained in a standard barrel and a barrel having a land diameter of .5075" shows that the reduced height of lands result in a reduction in maximum pressure of about 5000 lb/in^2 at a pressure of over 50,000 lb/in^2. By using a large enough charge in Barrel C7 to give a maximum pressure equal to that in the standard barrel, it appears that the velocity of the reduced land barrel should be augmented by about 100 f/s at a velocity of about 3,000 f/s.

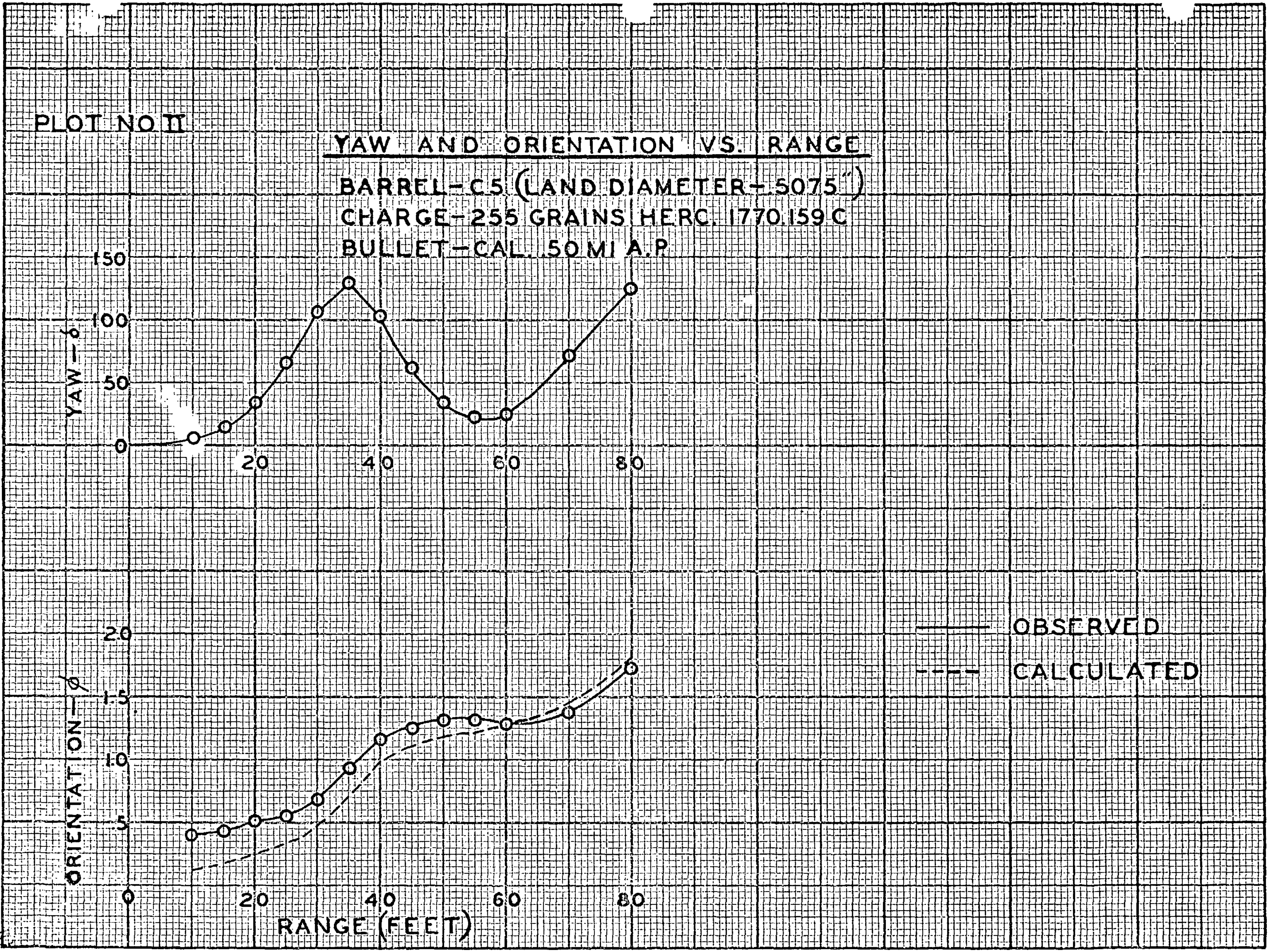
Acknowledgement: The interior ballistic calculations consisting of pressure-travel and velocity-travel curves were carried out by Miss Mark.

J. R. Lane.

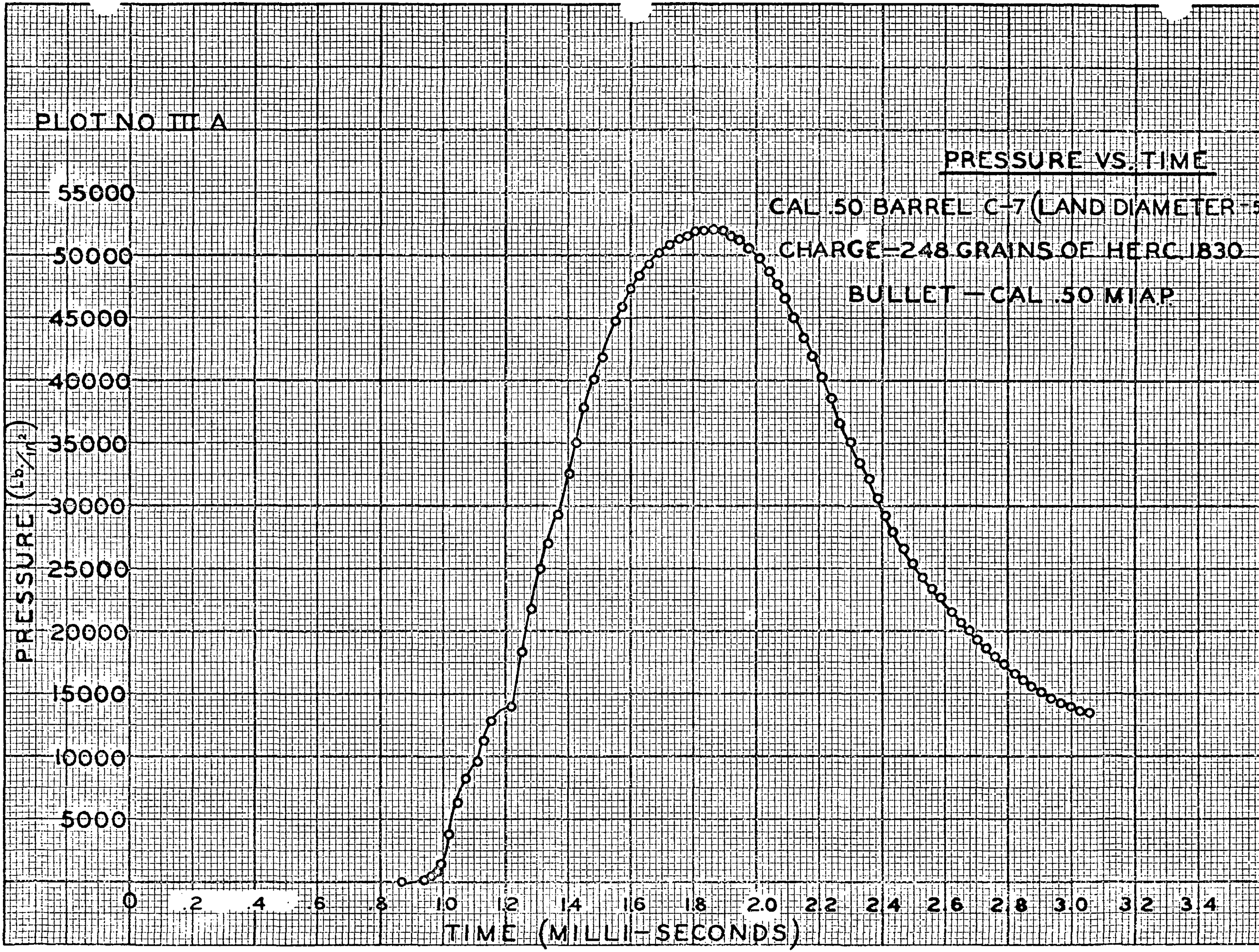
PLOT NO I

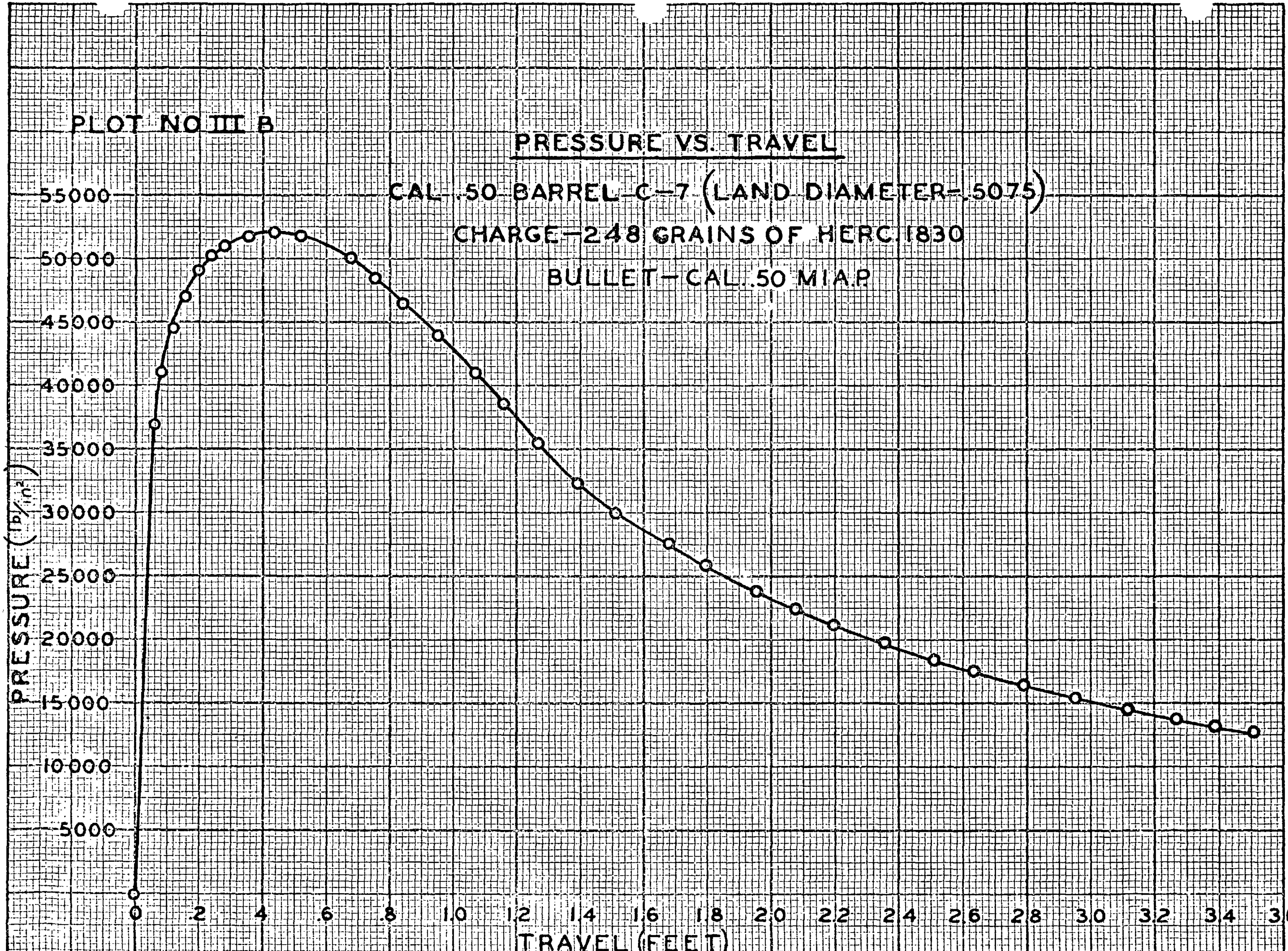


YAW AND ORIENTATION VS. RANGE
BARREL—C5 (LAND DIAMETER—.5075)
CHARGE—255 GRAINS HERC. 1770.159 C
BULLET—CAL. .50 M1 A.P.
YAW — δ
200°
150°
100°
50°
0
20
40
60
80
100
120
140
ORIENTATION — φ
3.5π
3.0π
2.5π
2.0π
1.5π
0
OBSERVED
CALCULATED
RANGE (FEET)



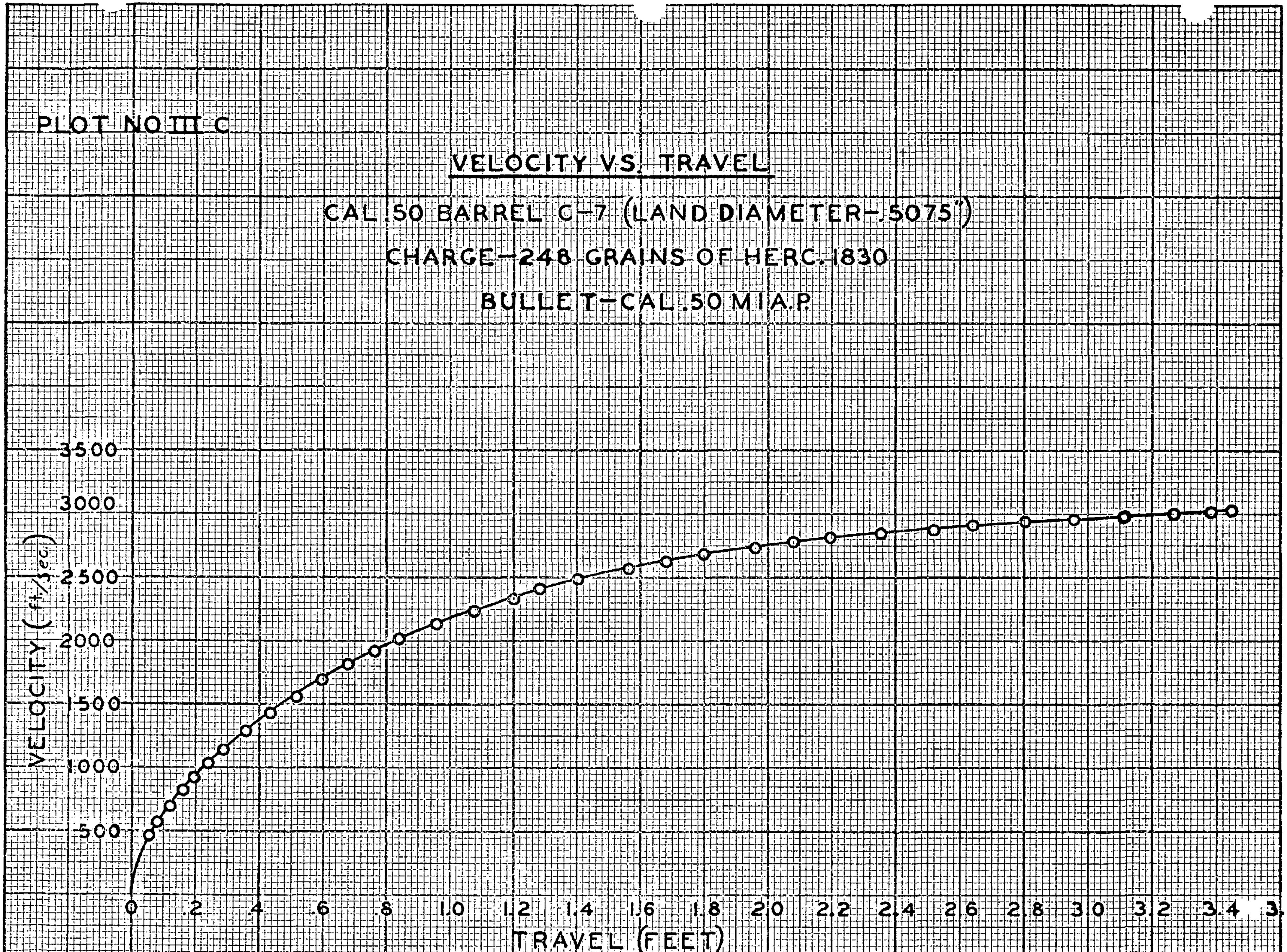
PLOT NO II
YAW AND ORIENTATION VS. RANGE
BARREL - C5 (LAND DIAMETER - .5075")
CHARGE - 255 GRAINS HERC. 1770.159 C
BULLET - CAL. .50 M1 A.P.
YAW - δ
150
100
50
0
20
40
60
80
ORIENTATION - φ
2.0
1.5
1.0
.5
0
20
40
60
80
RANGE (FEET)
OBSERVED
CALCULATED


PLOT NO III A
PRESSURE VS. TIME
CAL .50 BARREL C-7 (LAND DIAMETER -.5075")
CHARGE—248 GRAINS OF HERC 1830
BULLET—CAL .50 M1AP
PRESSURE (Lb./in²)
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
TIME (MILLI-SECONDS)



PLOT NO III B
PRESSURE VS. TRAVEL
CAL .50 BARREL C-7 (LAND DIAMETER-.5075)
CHARGE-248 GRAINS OF HERC 1830
BULLET-CAL .50 M1 A.P.
PRESSURE (lb/in²)
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
TRAVEL (FEET)

12


PLOT NO III C
VELOCITY VS. TRAVEL
CAL.50 BARREL C-7 (LAND DIAMETER-.5075")
CHARGE-248 GRAINS OF HERC. 1830
BULLET-CAL.50 M1 A.P.
VELOCITY (ft/sec)
3500
3000
2500
2000
1500
1000
500
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
TRAVEL (FEET)

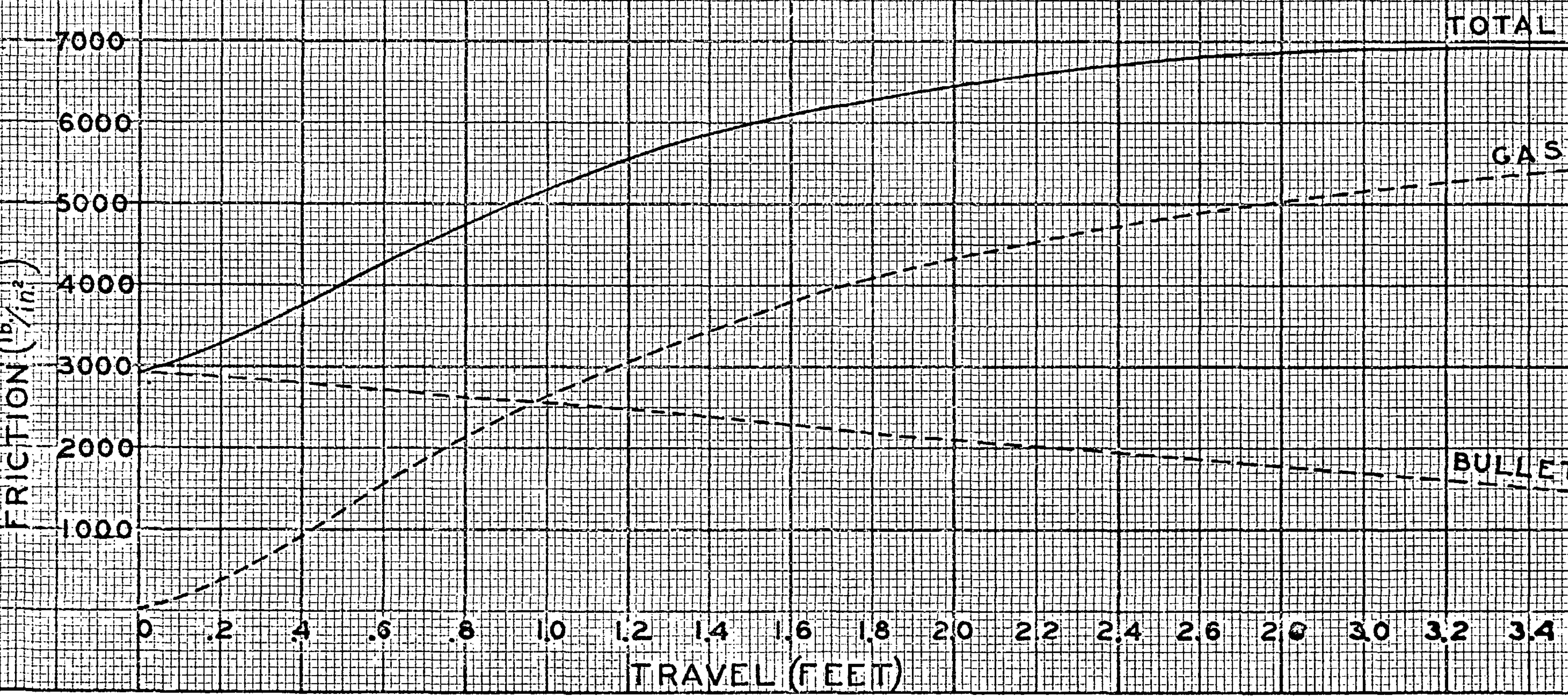
PLOT NO III D

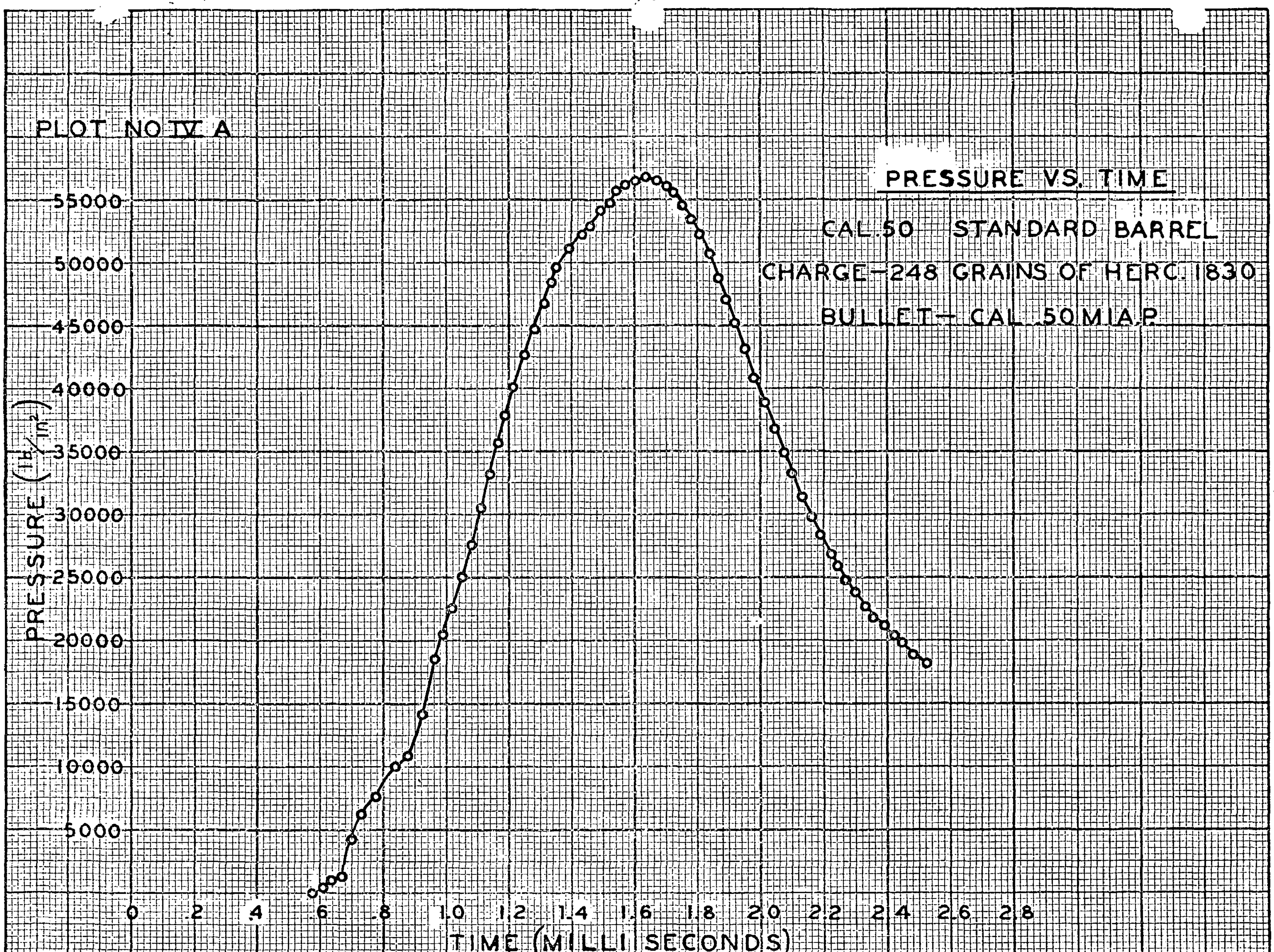
FRICTION VS TRAVEL

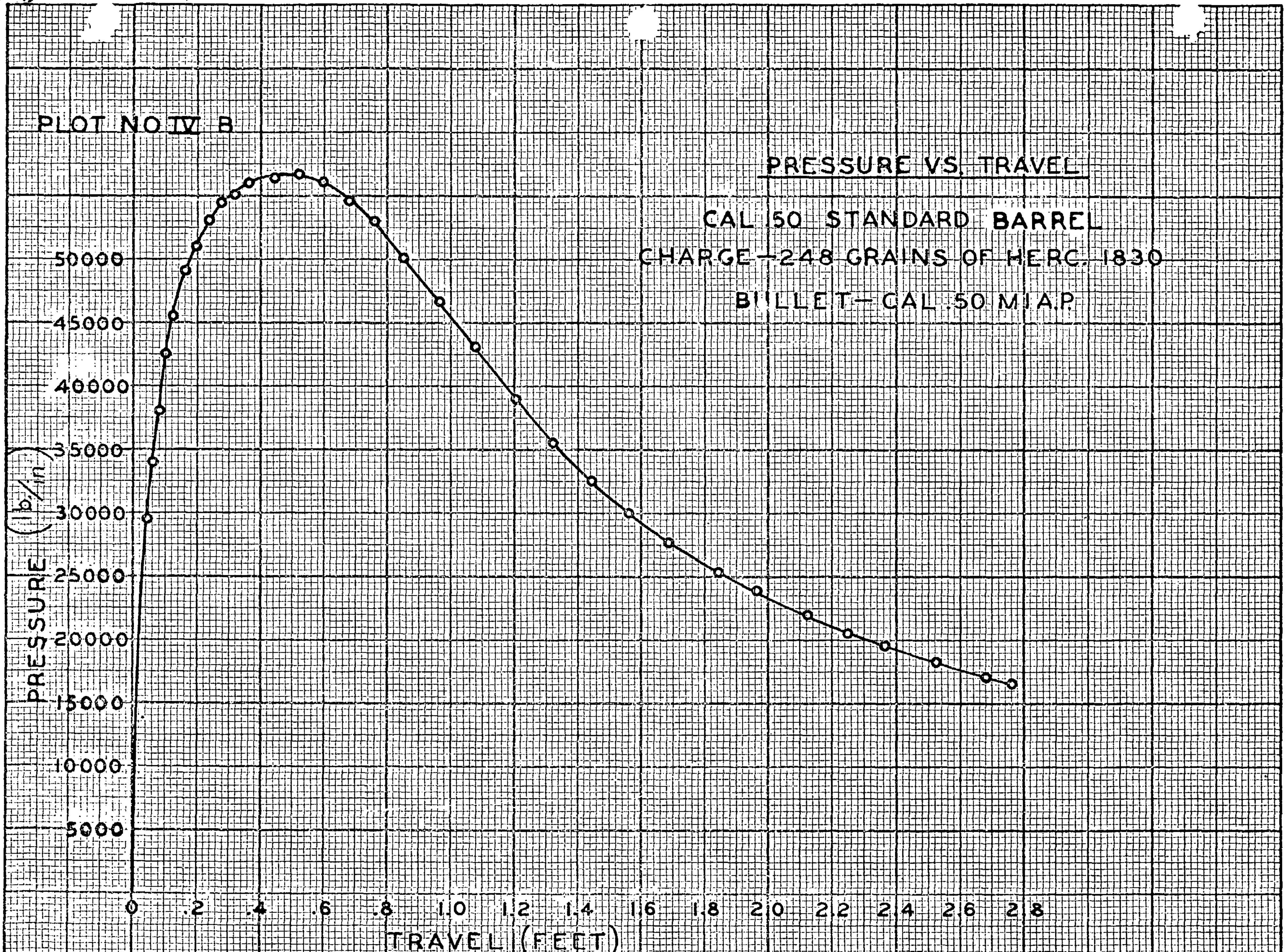
CAL .50 BARREL C-7 (LAND DIAMETER-.5075")

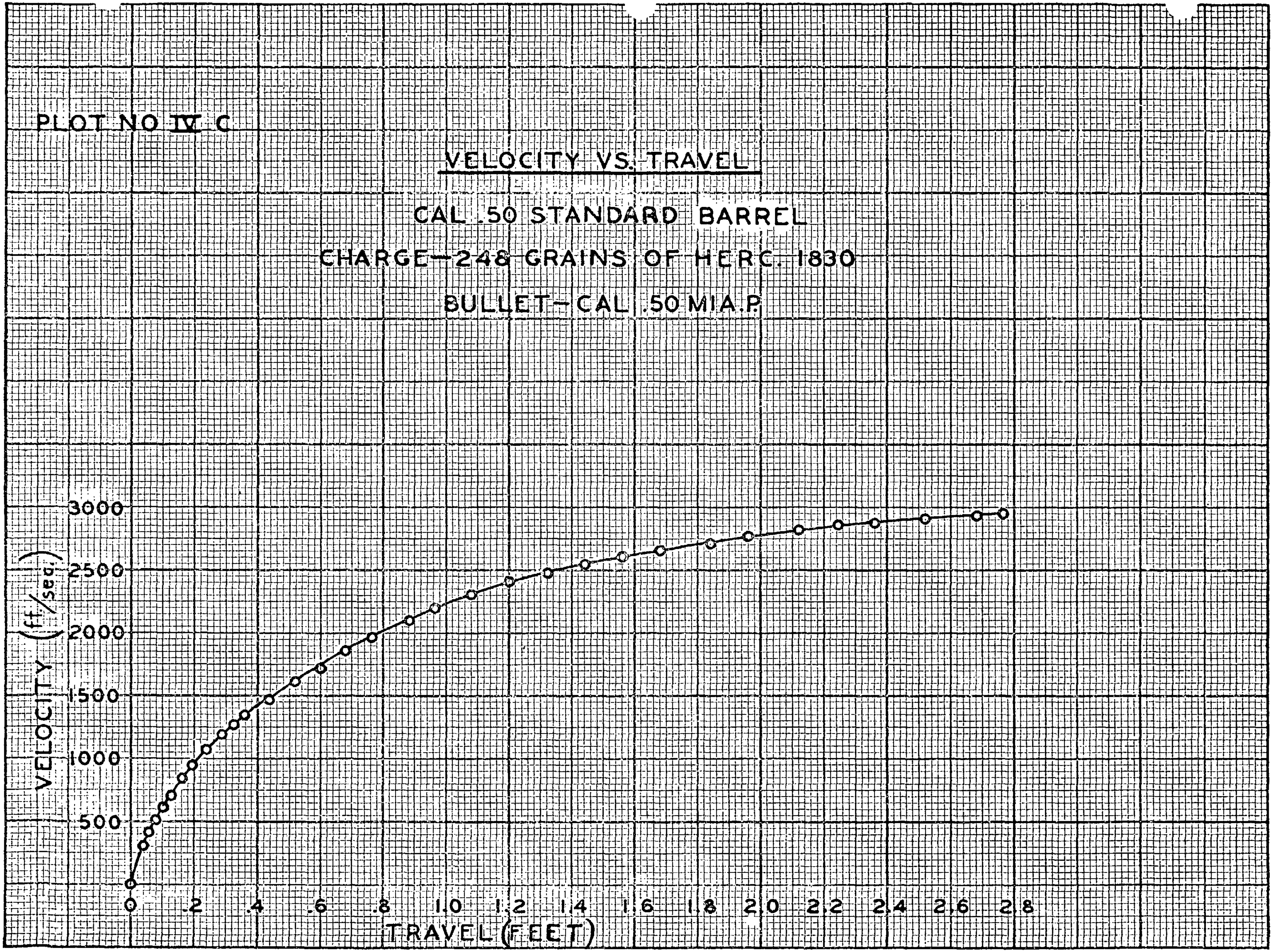
CHARGE-248 GRAINS OF HERC. 1830

BULLET-CAL .50 M1 A.P.

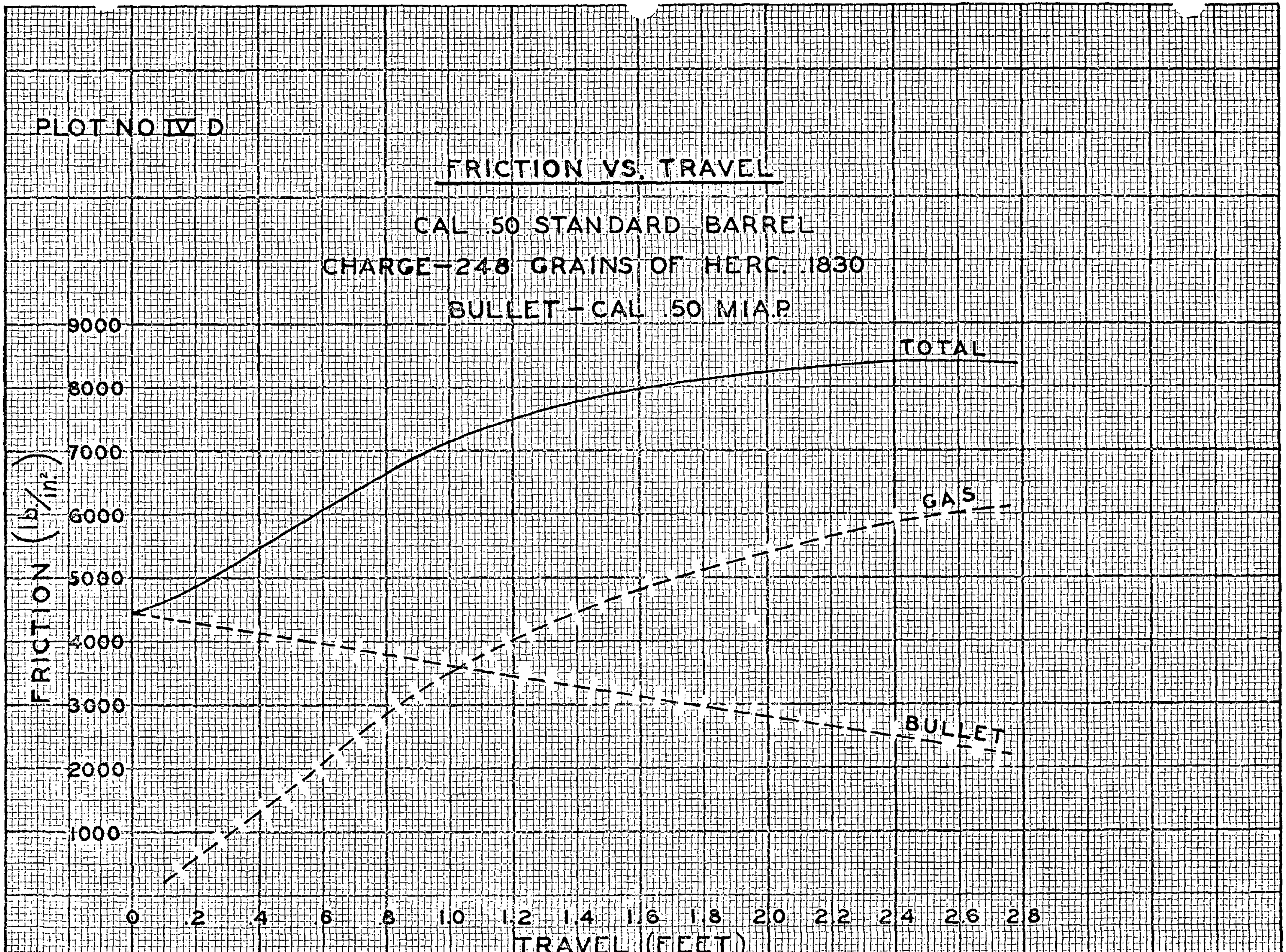


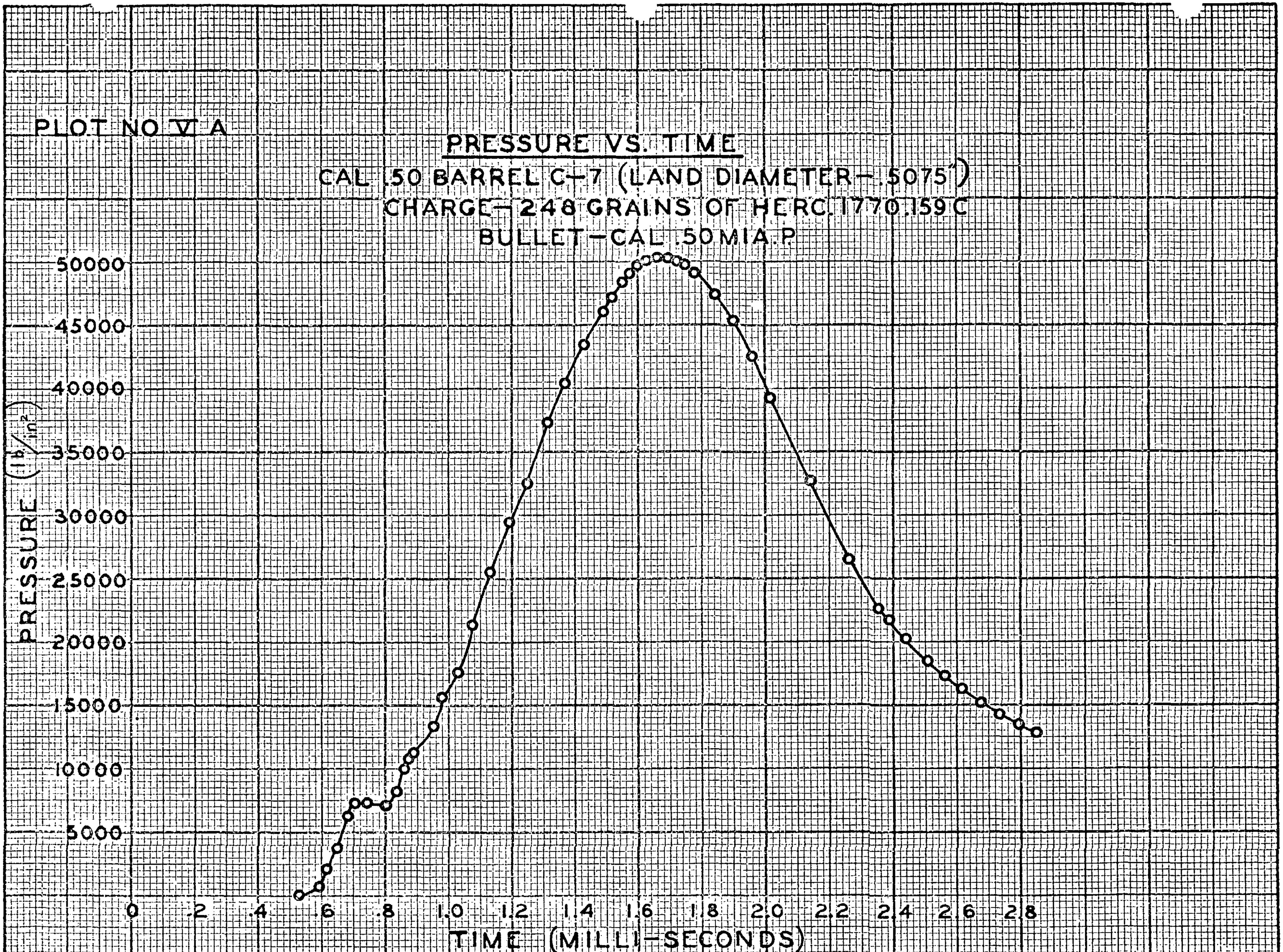

PLOT NO IV A
PRESSURE VS. TIME
CAL.50 STANDARD BARREL
CHARGE—248 GRAINS OF HERC. 1830
BULLET— CAL .50 M1 A.P.
PRESSURE (lb/in²)
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
TIME (MILLI SECONDS)


PLOT NO IV B
PRESSURE VS. TRAVEL
CAL .50 STANDARD BARREL
CHARGE—248 GRAINS OF HERC. 1830
BULLET—CAL .50 M1 A.P.
PRESSURE (lb/in)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
TRAVEL (FEET)

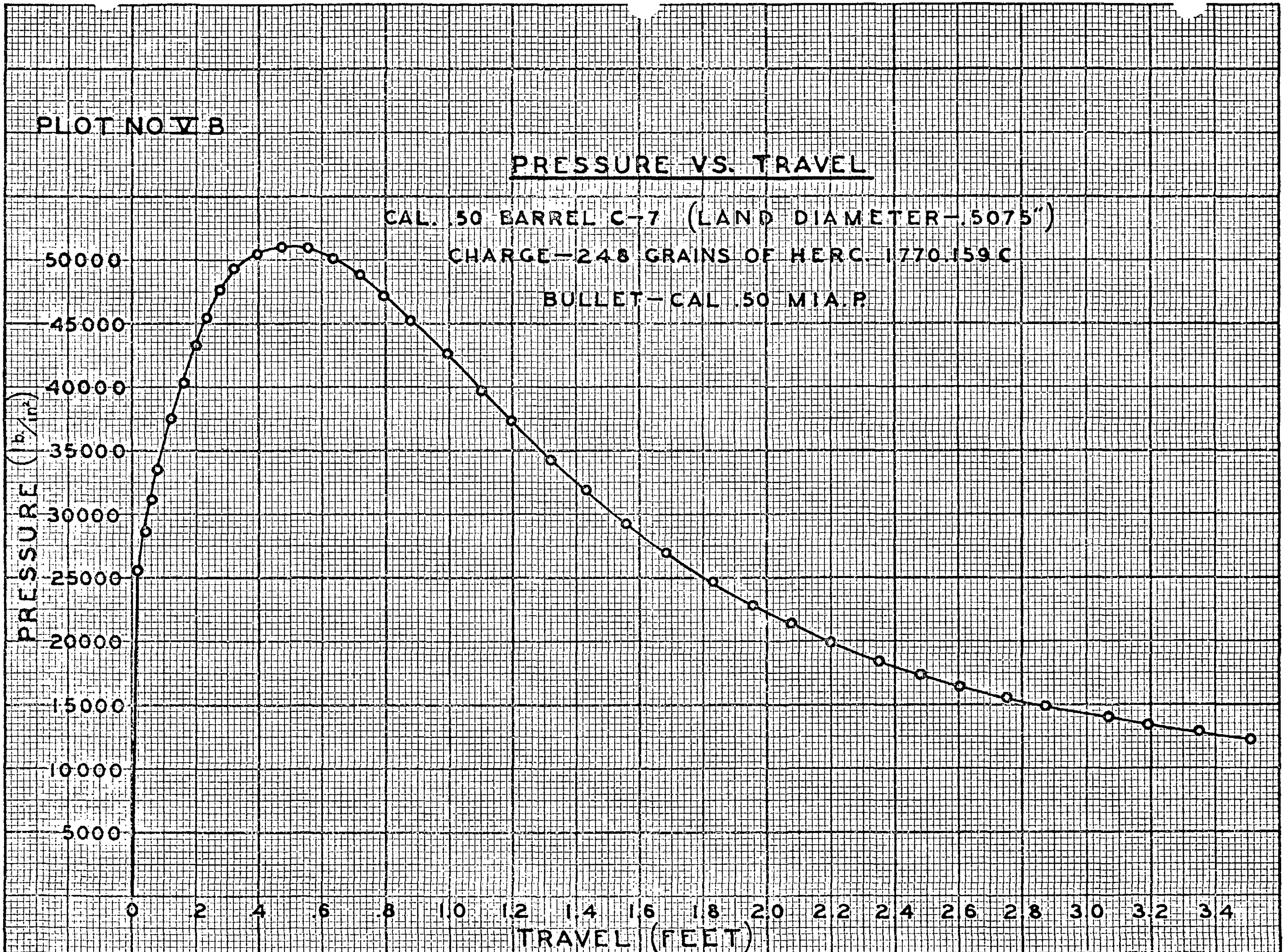


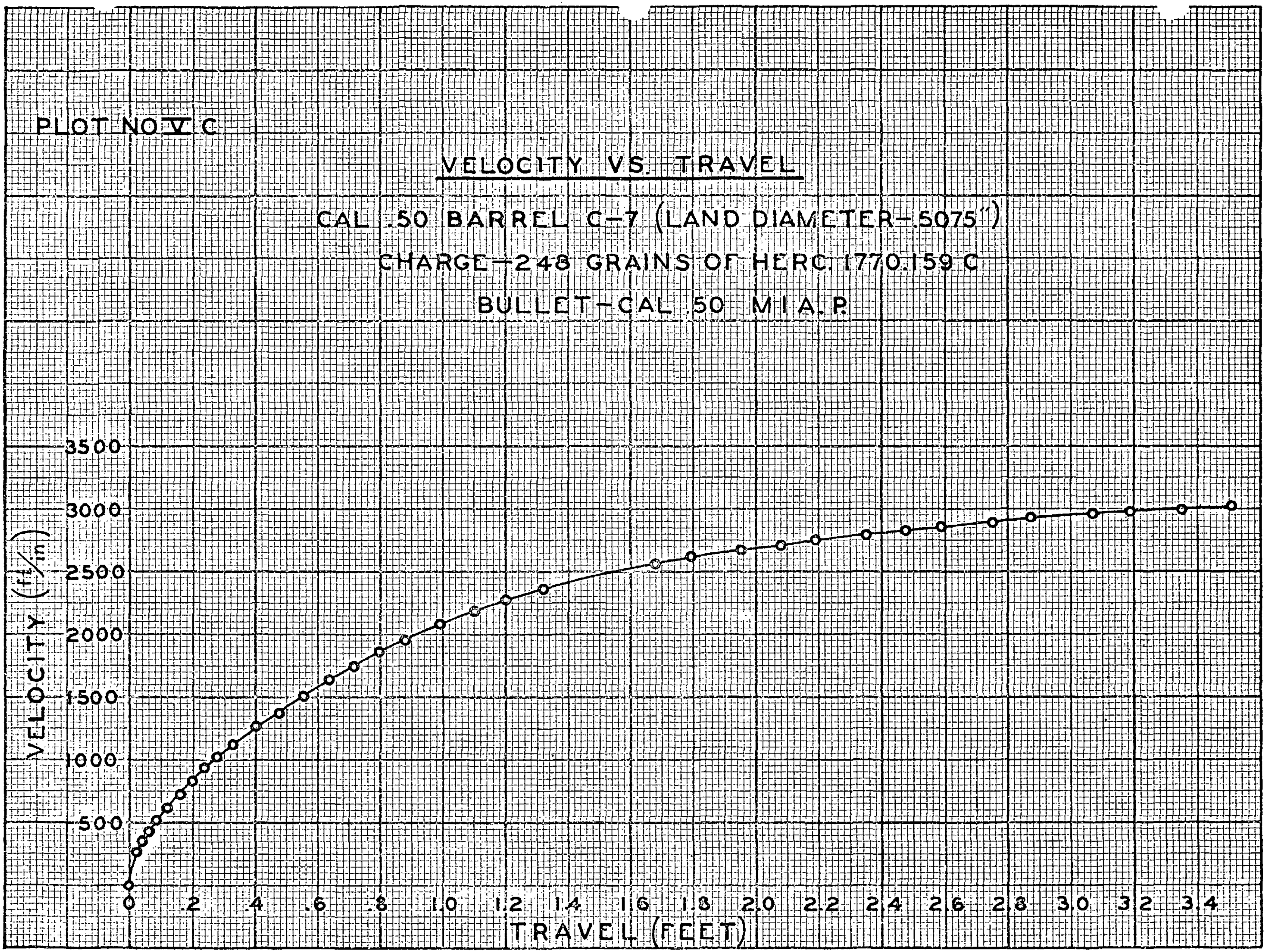
PLOT NO IV C
VELOCITY VS. TRAVEL
CAL .50 STANDARD BARREL
CHARGE—248 GRAINS OF HERC. 1830
BULLET—CAL .50 MIA.P.
3000
2500
2000
1500
1000
500
VELOCITY (ft/sec)
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
TRAVEL (FEET)


PLOT NO IV D
FRICTION VS. TRAVEL
CAL .50 STANDARD BARREL
CHARGE—248 GRAINS OF HERC. 1830
BULLET—CAL .50 M1A.P.
TOTAL
GAS
BULLET
FRICTION (lb/in²)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
TRAVEL (FEET)

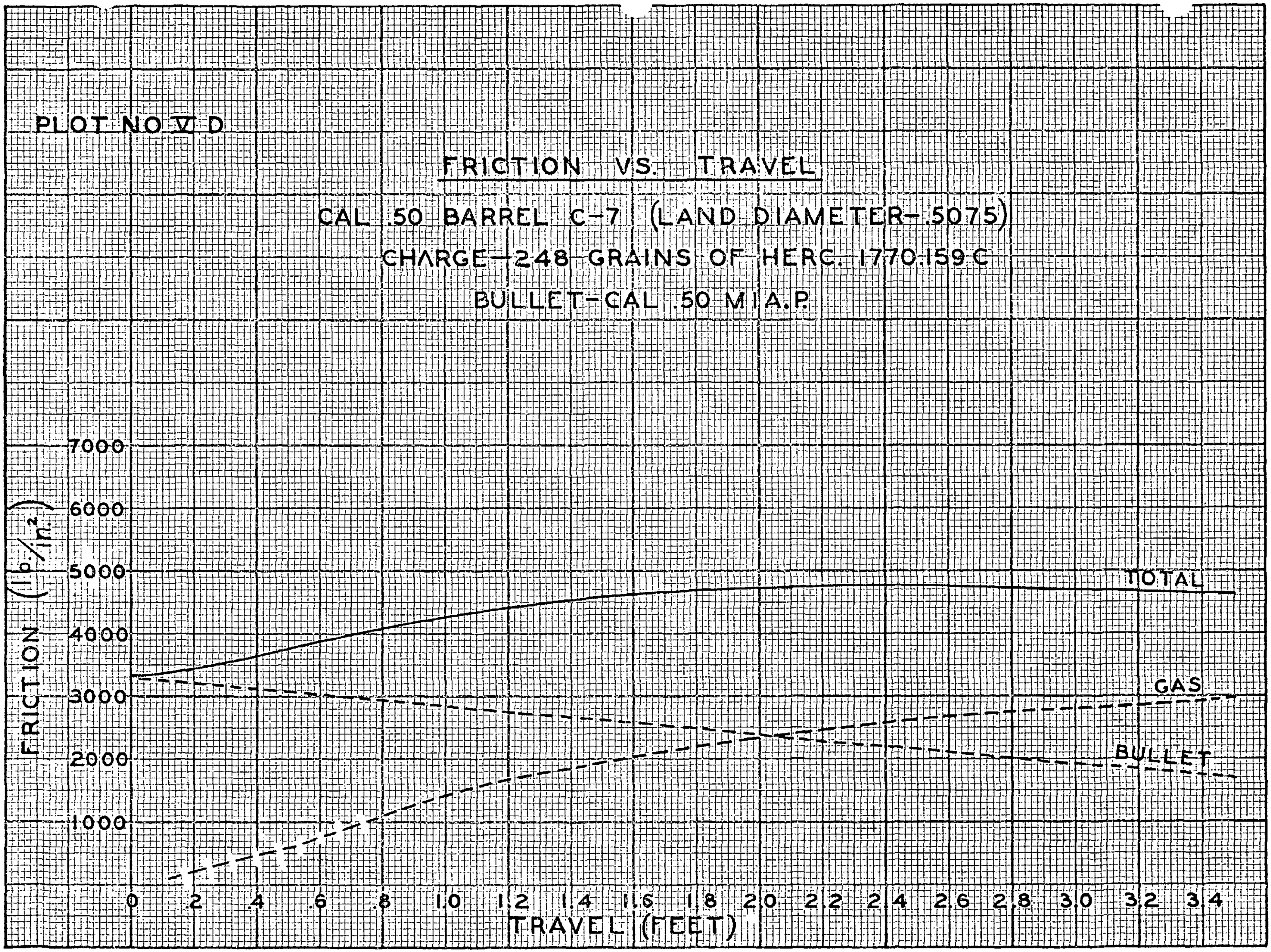


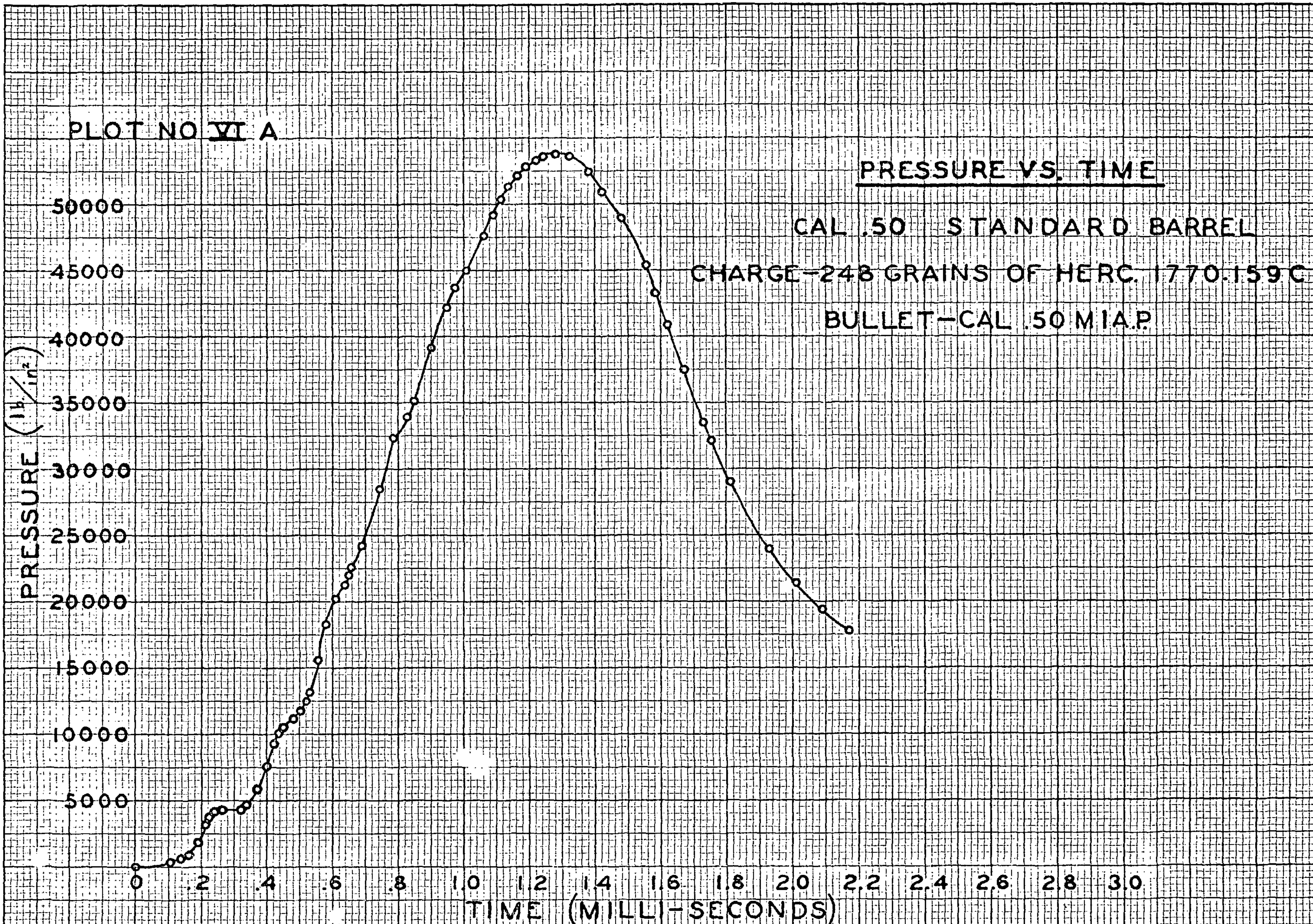
PLOT NO V A
PRESSURE VS. TIME
CAL .50 BARREL C-7 (LAND DIAMETER-.5075")
CHARGE-248 GRAINS OF HERC. 1770.159 C
BULLET-CAL .50 M1A.P.
PRESSURE (lb/in²)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
TIME (MILLI-SECONDS)

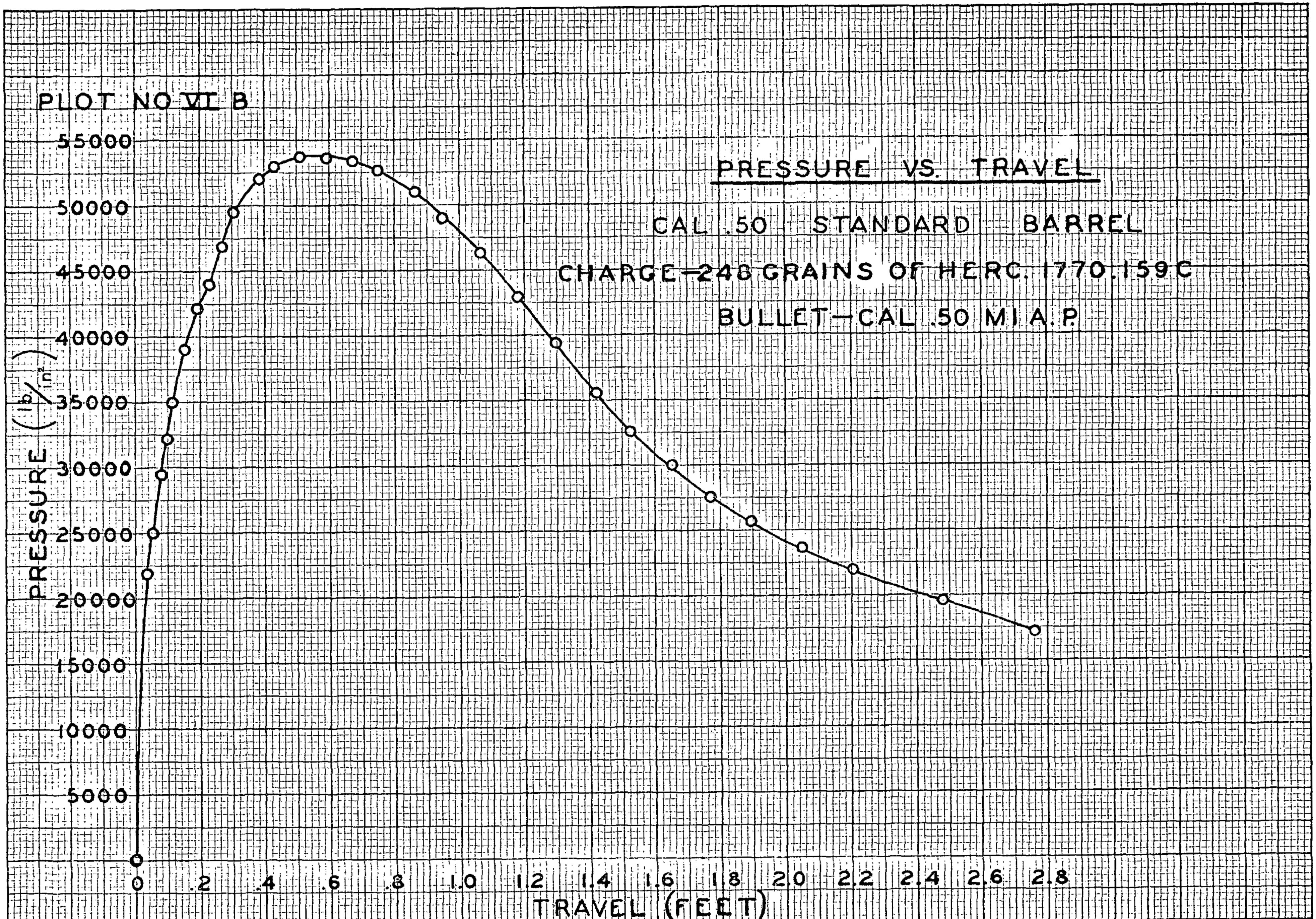

PLOT NO V B
PRESSURE VS. TRAVEL
CAL. .50 BARREL C-7 (LAND DIAMETER-.5075")
CHARGE—248 GRAINS OF HERC. 1770.159 C
BULLET—CAL .50 M1A.P.
PRESSURE (lb/in²)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
TRAVEL (FEET)

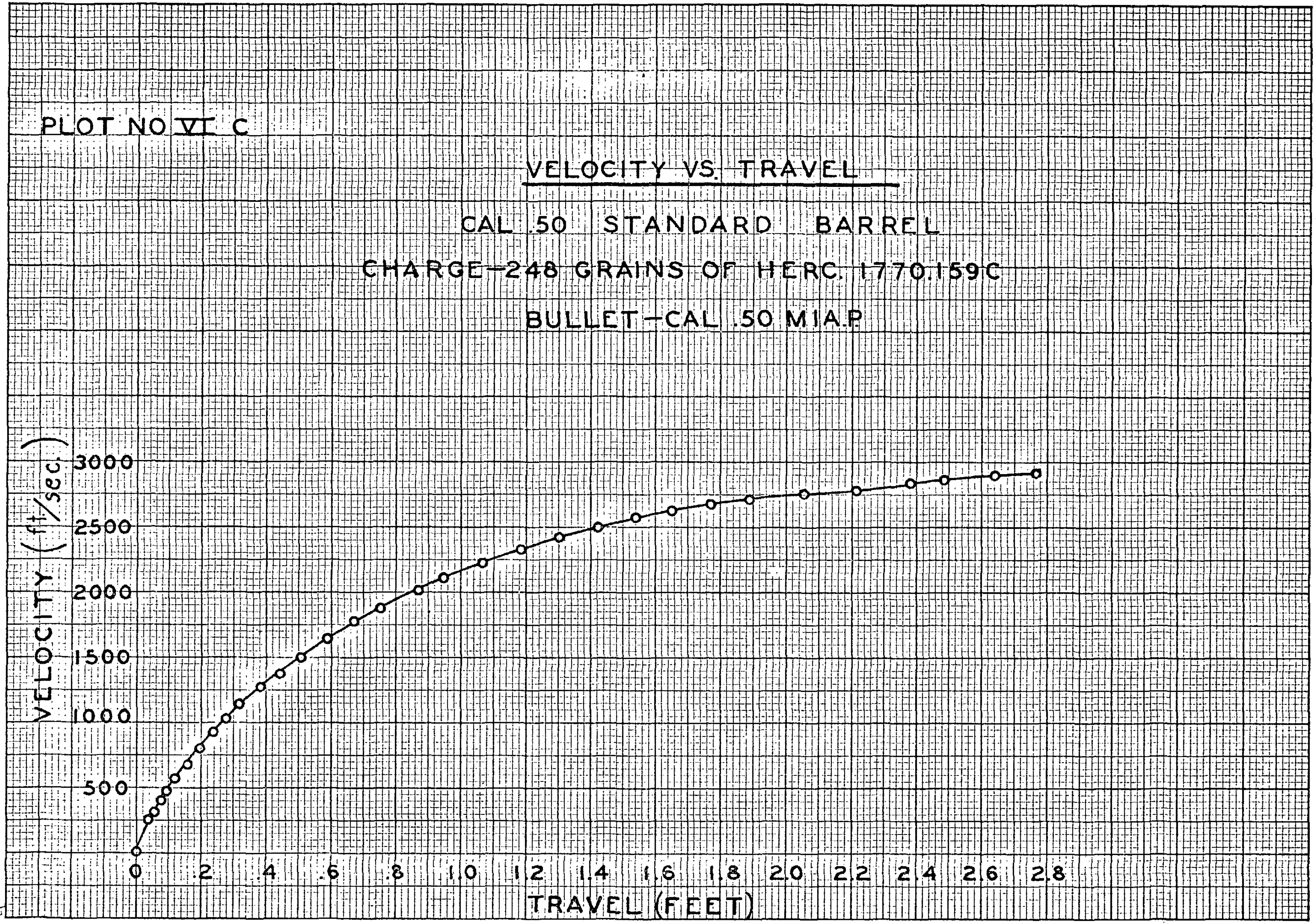


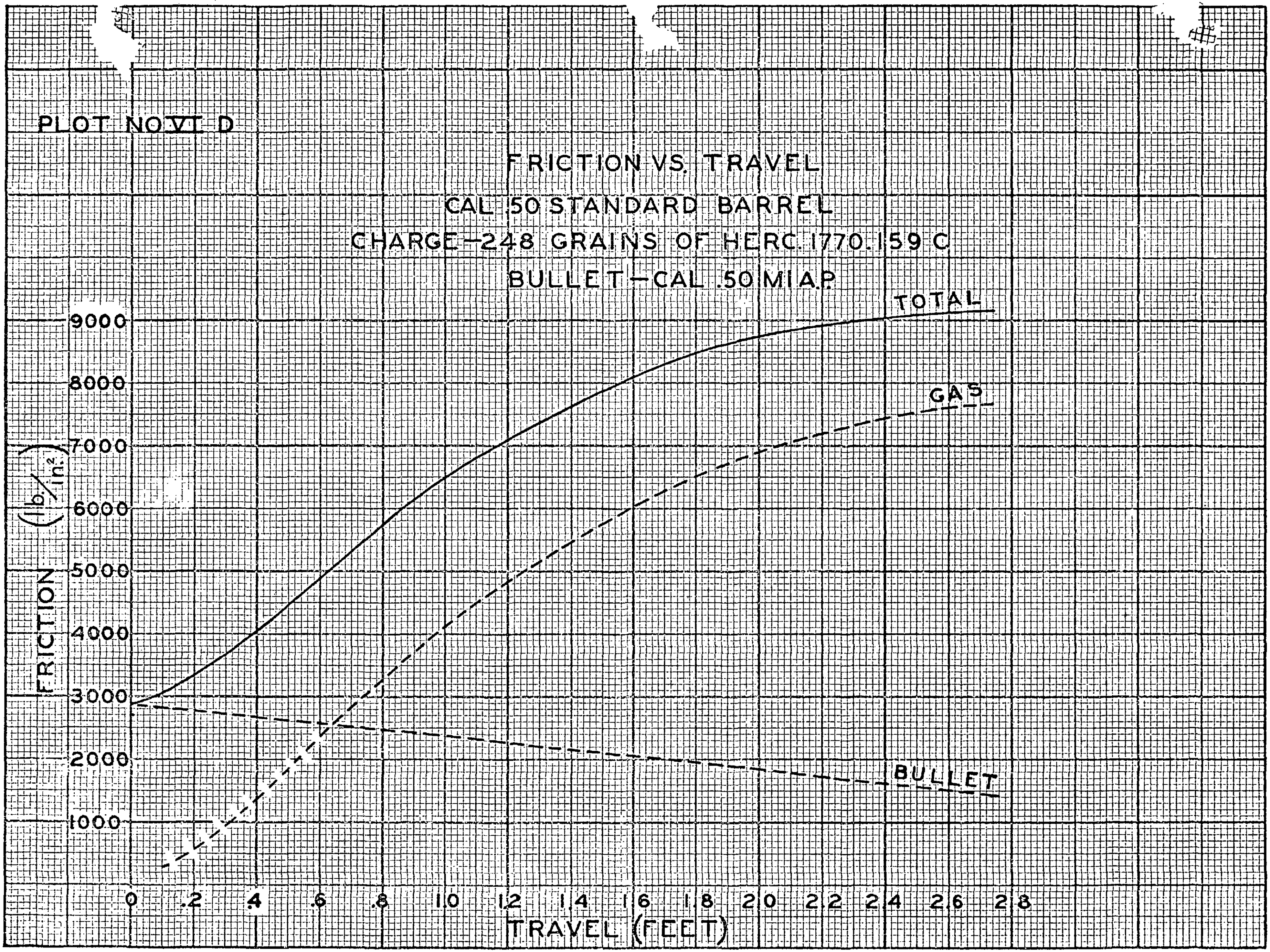
PLOT NO V C
VELOCITY VS. TRAVEL
CAL .50 BARREL C-7 (LAND DIAMETER-.5075")
CHARGE-248 GRAINS OF HERC. 1770.159 C
BULLET-CAL .50 M1 A.P.
VELOCITY (ft/m)
3500
3000
2500
2000
1500
1000
500
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
TRAVEL (FEET)


PLOT NO V D
FRICTION VS. TRAVEL
CAL .50 BARREL C-7 (LAND DIAMETER-.5075)
CHARGE-248 GRAINS OF HERC. 1770.159 C
BULLET-CAL .50 M1 A.P.
FRICTION (lb./in.²)
7000
6000
5000
4000
3000
2000
1000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
TRAVEL (FEET)
TOTAL
GAS
BULLET


PLOT NO VI A
PRESSURE VS. TIME
CAL .50 STANDARD BARREL
CHARGE—248 GRAINS OF HERC. 1770.159 C
BULLET—CAL .50 M1A.P.
PRESSURE (lb/in²)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
TIME (MILLI-SECONDS)


PLOT NO VI B
PRESSURE VS. TRAVEL
CAL .50 STANDARD BARREL
CHARGE—248 GRAINS OF HERC. 1770.159C
BULLET—CAL .50 M1 A.P.
PRESSURE (lb/in²)
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
TRAVEL (FEET)


PLOT NO VI C
VELOCITY VS. TRAVEL
CAL .50 STANDARD BARREL
CHARGE-248 GRAINS OF HERC. 1770.159C
BULLET-CAL .50 M1 A.P.
VELOCITY (ft/sec.)
3000
2500
2000
1500
1000
500
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
TRAVEL (FEET)


PLOT NO VI D
FRICTION VS. TRAVEL
CAL .50 STANDARD BARREL
CHARGE—248 GRAINS OF HERC. 1770. 159 C
BULLET—CAL .50 M1 A.P.
TOTAL
GAS
BULLET
FRICTION (lb./in.²)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
TRAVEL (FEET)

TITLE: The Test of Caliber 0.50 Barrels Having Reduced Weight of Lands	ATI- 42377
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ABSTRACT:

The analysis of the pressure-time records obtained in a standard barrel and a barrel having a land diameter of .5075" shows that the reduced height of lands result in a reduction in maximum pressure of about 5000 lb/in^2 at a pressure of over 50,000 lb/in^2. By using a large enough charge in Barrel C7 to give a maximum pressure equal to that in the standard barrel, it appears that the velocity of the reduced land barrel should be augmented by about 100 ft/sec at a velocity of about 3000 ft/sec.

DISTRIBUTION: Copies of this report obtainable from Central Air Documents Office; Attn: MCIDXD

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