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REPORT NO. 254

REPORT ON THE FIRING TEST TO DETERMINE THE LIMITS OF ACCURACY LIFE OF 4.7" A.A. GUN T2

by

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REPORT ON THE FIRING TEST TO DETERMINE THE LIMITS OF ACCURACY LIFE OF 4.7" A.A. GUN T2

2nd Report on Ordnance Program No. 5500

Dates of Test: April 26 to August 9, 1941.

ABSTRACT

The effect of the firing on various elements of the complete round and gun are noted.

During the life of the gun, the muzzle velocity decreases and the dispersion of muzzle velocity increases, affecting the probability of hitting. Assuming the rotating band continues to function, the accuracy life is estimated to be beyond 1400 rounds. It is thought that the rotating band of the projectile would be stripped before the predicted accuracy life would be reached and, therefore, that the stripping of the rotating band would determine the actual life of the gun.

Authority for Test: OO 471.91/506
APG 472.15/132

OBJECT OF TEST

The object of the test is to get the effect of the firing on the functioning of the material and to predict at what point in the life of the gun it will be most advantageous to withdraw the gun from service.

DESCRIPTION OF MATERIAL

Gun:

Six-Inch Gun M1900, No. 46, with a 4.7" Liner T2 on a 6" Wheel Mount 1917. The liner is sixty calibers in length (including chamber) and has forty-two lands and grooves with a twist of one turn in twenty-five calibers. This gun had not been previously fired.

Ammunition Components:

Projectile	- 4.7" A.A. Shell T5.
Case	- 4.7" T1 for 4.7" T2 Gun.
Fuze	- 30 Seconds Mechanical Time Fuze T31E2.
Powder	- Dupont's NH Smokeless Powder, Lot X-3684-S of 1931 for 6" Gun M1897-M1-08. It was used both loose and bagged. When bagged the charge was assembled in a silk bag with a laced charge of 8 oz. of black powder. The igniter was placed in the base of the cartridge case; then the bag of powder put into the case and jolted down, and the case closed with a cork plug T1. The charge used, 28 lbs. 8 oz., is about the maximum that can be assembled in the case.
Primer	- 300 Gr. M28A1 used with powder loaded in loose charge. 20 Gr. M23A1 used with powder loaded in bag charges.

DATA

Four hundred and sixty-three rounds were fired from the gun.

Velocity, pressure, and length of recoil were taken on all rounds. A number of rounds were fired for recovery and the shells examined. Cartridge cases were examined for fluting and obturation.

Star Gauge readings and advance of forcing cone and seating were taken during the course of firing.

Ranges were observed of those rounds fired for recovery but were not used in this report.

Over two hundred rounds were fired to get times of flight, most of which were with a five second fuze setting.

The last thirty-four rounds were fired with the lip of rotating band cut off.

Rounds 132 to 141 were fired to get the stability factor of the shell.

FUNCTIONING OF MATERIAL

I. Gun and Carriage:

The gun and carriage functioned satisfactorily and, no difficulty was experienced in firing. However, the mount was very unstable especially at low elevations.

In all the rounds the gun fired with a large yellow flash and a small amount of muzzle smoke.

II. Propelling Charge:

At the beginning of the firing the powder was packed loose in the case. At Round 46 with a propellant charge of 23 lbs. 8 oz., the average muzzle velocity was 3091 f/s and probable error in muzzle velocity was 16 f/s. The dispersion with a loose charge being so great, a change at the suggestion of Mr. Adelman, was made to bagged charges which cut down the dispersion considerably to 4 f/s. In view of this reduction in dispersion, almost all subsequent firings were made with the bagged charges.

Of the 463 rounds fired, the velocity and pressure data of 191 rounds were used in getting the curves of this report. These 191 rounds were fired with bagged charges and elevations of 4°15' or less. The low elevations allow the use of long screen distance and the velocity data obtained with the resulting longer time intervals are considered more reliable than data obtained with high angle fire.

The initial velocity of this T2 Gun with a propellant charge of 23 lbs. 8 oz. was 3125 f/s as compared with the 3224 f/s with a propellant charge of 24.7 lbs. that was recommended for a 4.7" A.A. Gun in Ballistic Research Laboratory Report No. 125, "A Comparison of Antiaircraft Guns of Various Calibers".

Figure 1 shows what was happening during the course of firing. It contains graphs of velocity, pressure, velocity dispersion, pressure dispersion, advance of forcing cone, advance of seating and erosion plotted against the number of rounds fired from the gun. The graphs of velocity, pressure, velocity dispersion, and pressure dispersion versus rounds fired were made from a statistical viewpoint to show the degree of control* with which the data was taken.

Figure 2 and Figure 3 show curves of average muzzle velocity and dispersion of muzzle velocity, respectively, plotted against number of rounds fired in the conventional manner.

Star Gauge curves are attached.

III. Cartridge Case:

In the majority of cases used, fluting was noted on the neck of the case accompanied by small amounts of unconsumed cork. In the main, fluting was only slight although it varied from slight to deep and usually the amount of unconsumed cork varied accordingly.

Throughout the firing the T1 Cartridge Case showed poor obturation.

APG Photo. No. 45644 shows fluting in cartridge cases after firing.

It is thought that these defects in the cartridge cases are caused by too much clearance between the neck of case and gun and that it could be corrected by decreasing the amount of the clearance.

IV. Projectile:

A. Body of Shell

Engraving was noted below rotating band over part of the circumference. In the early stages of firing, the engraving was deep enough to warrant investigation. (Ref. APG Photo. No. 45743). Colonel Zornig found it to be caused by eccentric loading. Upon more careful loading with barium sulphate instead of red lead and paraffine (APG Photo. No. 46318 and No. 46319), the engraving was considerably reduced (APG Photo. No. 46686).

* Simon, L. E. "An Engineer's Manual of Statistical Methods", John Wiley and Sons, 1941.

Slight engraving on bourrelet was noted on various shells over part or complete circumference.

In some cases, the diameter of the shell after being recovered was as much as .01" greater than before firing. However, there is insufficient evidence to draw any conclusion as to the cause of this upsetting.

B. Rotating Band

All shells fired for recovery appeared to be satisfactorily engraved to give full spin. However, moderate and slight shearing of rotating bands was noted. A major part of the shearing is also considered to be an effect of eccentric loading. Figure 4* is a diagram illustrating how it is thought that the centrifugal force on a shell whose center of gravity is off the axis of the shell due to eccentric loading causes the rifling to "bite" into the rotating band on one side and only partially engrave the other side.

APG Photo. No. 46478 shows instances of good engraving to moderate shearing of rotating band. APG Photo. No. 46778 shows the condition of rotating band after 420 rounds were fired.

No stripping of the rotating band was observed. There was also no fringing.

Figure 5 is a plot of muzzle velocity versus seating, for firing that was done with the lip of the rotating band cut off and the projectile seated by ramming with eight men. (Rounds 439-463). The plot indicates a dependence of dispersion of muzzle velocity upon seating, i.e., the muzzle velocities for the projectiles which were seated hard up in the gun had much less dispersion than the muzzle velocities for projectiles which were seated less firmly.**

The probable error of the muzzle velocity for the projectiles with seatings of 49" to 49-3/8" was calculated to be 6 f/s. Comparing the 6 f/s probable error at 450 rounds with lip of rotating band cut off with the 17 f/s probable error in velocity at 400 rounds with lip on, it is thought that the major part of the increase in dispersion of muzzle velocity (Figure 3) can be attributed to the "artificial" seating caused by the lip.

* Suggested by figures prepared by Colonel Zornig.

** The probability that the velocities obtained with seatings greater than 48-1/2" belonged to a universe different from that of the velocities obtained with seatings less than 48-1/2" was calculated to be greater than 0.999" using Fisher's Z - test as given on pages 434-444 in Yule and Kendall's, "An Introduction to the Theory of Statistics".

C. Base Cover

On all shells fired, the base covers remained intact and straight.

D. Stability

The stability of the shell was investigated by H. P. Hitchcock in Ballistic Research Laboratory Report No. 237, "Stability of 4.7" Shell T5". The stability factor at a muzzle velocity of 3040 f/s was found to be 2.84 and it was recommended that the twist of rifling be changed from 1/25 to 1/34 (making the stability factor 1.50) to increase the life of the gun.

E. Form Factor

The form factor was found to be 0.90 which is the same as that used for the 4.7" A.A. Gun in Ballistic Research Laboratory Report No. 125, "A Comparison of Antiaircraft Guns of Various Calibers".

V. Other Components:

A. Primer

Both the M28A1 primer (used with the loose charges) and the M23A1 primer (used with the bagged charges) appeared to give satisfactory ignition. Loosening of the primer in the case or bending in the primer body was not noted.

B. Fuze

Out of the 241 rounds fired to get time of flight, there were three failures to function and one premature.

Fuze Setting	No. of Rounds	No. of Failures
5	180	0
10	41	1
30	20	2

The premature at Rd. 429 occurred with the lip of the rotating band cut off, a filler of barium sulphate, paraffine, and a 12 oz. charge of black powder for spotting, and the shell rammed with case which did not seat the projectile on the forcing cone.

The probable error of time of flight at 30 seconds fuze setting was .23 seconds.

ACCURACY LIFE

In this report the accuracy life of a gun is defined as the number of rounds fired from the gun for which the average cost per hit* is a minimum. Average cost per hit is the cost of the complete rounds of ammunition plus a new tube averaged from first round to last round considered.

Other criteria may be set up for the accuracy life of the gun, such as the point where the rotating band is sheared or stripped, or where the muzzle velocity has dropped to such a value that the gun cannot accomplish its purpose. But, fundamentally, they are all on an economic basis. For example, the stripping of rotating band, which may not occur before accuracy life as above defined is reached, might be used to determine the accuracy life; or the stripping may come after the accuracy life is reached, in which case it is not only unprofitable to fire the gun but also very decidedly impracticable to do so.

As the gun is fired, the average muzzle velocity decreases and the dispersion of muzzle velocity increases. These factors affect the accuracy life of the gun in so far as they affect the number of rounds necessary to score a hit (reciprocal of probability of a hit).

In the following calculations to predict accuracy life, it is implicitly assumed that the rotating bands are satisfactorily engraved to give full spin to the projectiles. It is also important to note that most of the data were obtained by extrapolating from the limited data available from the firing.

The tactical situation treated is that of the gun firing at an airplane flying level at 300 miles per hour at an altitude of 10,000 yards and a slant range of about 15,000 yards.

Effect of Decrease in Average Muzzle Velocity:

Figure 2 gives the curve of the relation of average muzzle velocity to the number of rounds fired from the gun and by extrapolation, an estimate of the average muzzle velocities beyond four hundred rounds was obtained.

* This definition is called economic life by Captain Weyher in his report, "First Report on Firing Tests to Determine Limits of Accuracy Life of 155MM Gun, G.P.F." - O. P. No. 5412

As the average muzzle velocity decreases, the time of flight of the projectile increases. The probability of hitting varies inversely as the square of the time of flight.*

The time of flights were obtained from a calculated curve of time of flight versus muzzle velocity at a 45° slant range of 15,646 yards. The number of rounds considered were limited to 1400 rounds since further firing would necessitate a time of flight greater than 30 seconds, which is the maximum fuze setting.

Considering the number of rounds per hit as unity when the gun is new, the relative number of rounds per hit at various stages in the life of the gun was calculated and the results are shown graphically in Figure 6.

Effect of Increase in Dispersion of Muzzle Velocity:

Figure 3 shows the curve of relationship of probable error in muzzle velocity to number of rounds fired from the gun and by extrapolation, an estimate of the probable error beyond the four hundred rounds are obtained.

The problem is similar to that of bombing, treated in Ballistic Research Laboratory Report No. 241, "Optimum Spacing of Bombs or Shots in the Presence of Systematic Errors" by L. S. Dederick, R. H. Kent, and A. O. Smith, with an appendix by J. von Neumann. There is an imperfectly located target due to error in the fire control instruments, systematic error, and there is a dispersion of the bursts of the shells about the aiming point, accidental error, due to dispersion of velocity and time to burst of fuze. The principal errors in all of the above three -- location of target, muzzle velocity and timing of fuze -- lie along the slant range and, therefore, the problem is simplified from the three dimensions of space to the one dimension along the slant range.

The equation for the probability of hitting

$$P = \sum_{1}^{n} (-1)^{r-1} \frac{n! \qquad w^r}{(n-r)!\,r!\,(w^2 + \varepsilon_\alpha^2)^{\frac{r-1}{2}} \sqrt{w^2 + \varepsilon_\alpha^2 + r\,\varepsilon_s^2}}$$

* R. H. Kent, Ballistic Research Laboratory Report No. 127, "The Probability of Hitting an Airplane as Dependent upon Errors in the Height Finder and the Director".
R. H. Kent, Ballistic Research Laboratory Report No. 132, "The Probability of Hitting Various Parts of an Airplane as Dependent on the Fragmentation Characteristics of a Projectile".

n = number of shots fired

$2w$ = width of target

ε_α = $\sqrt{2}$ times standard deviation of accidental error

ε_s = $\sqrt{2}$ times standard deviation of systematic error

is derived in the Appendix based directly on the appendix to Ballistic Research Laboratory Report No. 241 by J. von Neumann. It may be shown from this equation that there is an optimum dispersion of the bursts around the aiming point.

The probable error of time of fuze at the setting of 30 seconds, .23 second, causes a probable error in slant range of eighty yards. The error in slant range due to dispersion in muzzle velocity was obtained from a calculated graph of slant range versus muzzle velocity. The accidental error is the $\sqrt{\text{sum of the squares of the above two errors}}$.

The probable error along slant range in locating the target (r_s) was taken to be 850 yards with the use of present height finders. (See Ballistic Research Laboratory Report No. 127, "The Probability of Hitting an Airplane as Dependent upon Errors in the Height Finder and the Director", page 8).

The number of shots the gun fired at a plane coming in to bomb was assumed to be seven and the width of the target assumed to be fifty yards.

Figure 7, Relative Number of Rounds Per Hit Versus Number of Rounds Fired from the Gun, was calculated using the above equation.

The new radio locator will reduce the systematic error, and so the calculations were also carried out assuming a probable error in locating the target along slant range of 250 yards and the results are shown in Figure 8.

Figure 7 shows that with the present directors, the dispersion of the bursts of the shells had not reached its optimum value at 1400 rounds.

Figure 8 shows that if the probable error in locating a target along the slant range is reduced by approximately one-third to 250 yards, the optimum dispersion of bursts of the shells is reached around 400 rounds.

The above analysis assumes that all the guns of a battery have the same aiming point. However, if this condition is changed so that artifical dispersion of the shots from the battery is introduced, for instance, an eight gun battery may be coordinated so that the guns fire at the corners of a cube whose center is the predicted position of the airplane, then, the optimum dispersion of the bursts from one gun around its aiming point is reduced.*

Combined Effect of Decrease in Muzzle Velocity and Increase in Dispersion of Muzzle Velocity:

The product of the relative number of rounds per hit due to each factor gives the total relative number of rounds per hit due to both factors.

Figure 9 and Figure 10 show the relative number of rounds per hit versus rounds fired for r_s = 850 yards and r_s = 250 yards, respectively.

Average Cost Per Hit:

Relative average cost per hit (Figure 11 and Figure 12) was obtained by multiplying average cost per round by relative average number of rounds per hit. Average cost per round was found by assuming the cost of the tube to be one hundred times the cost of a complete round. Relative average number of rounds per hit was found by integrating under the curve of relative rounds per hit versus rounds fired and averaging over the number of rounds fired.

Figure 11 shows that no minimum is reached up to 1400 rounds assuming the use of the gun with present height finder.

Figure 12 shows that a flat minimum occurs at 1100 rounds if the gun is used with a height finder approximately three times as good as the present instrument.

Empirical Treatment:

The above calculations estimate the accuracy life of the gun from the effects of the decrease in average muzzle velocity and increase in dispersion of muzzle velocity on the number of rounds necessary to score a hit, assuming that the rotating band continues to function. It is also desirable to base an estimate on past experience with guns.

* L. S. Dederick, R. H. Kent, A. O. Smith, Ballistic Research Laboratory Report No. 241, "Optimum Spacing of Bombs or Shots in the Presence of Systematic Errors".

In Ballistic Research Laboratory Report No. 125, "A Comparison of Antiaircraft Guns of Various Calibers", page 31, a formula for accuracy life is presented which was obtained from known or assumed accuracy lives of various guns and found to give a satisfactory fit. Using the data of this 4.7" A.A. T2 Gun in this formula,

$$L = 2.22 \times 10^{11} d^{2.93} E^{-1.51}$$

where d is the caliber in inches and E is the muzzle energy in foot-pounds, the empirically expected accuracy life is found to be approximately 800 rounds.

SUMMARY

Functioning of Material:

1. It was found advisable to load the propellant charge in silk bags rather than as a loose charge.

2. Eccentric loading was considered to cause excessive engraving of the body and moderate shearing of the band.

3. Excessive clearance between the neck of the cases and the gun was thought to cause the fluting and poor obturation of the cartridge case.

Accuracy Life:

With the present height finder the calculated accuracy life extends beyond 1400 rounds. With a height finder, three times as good as the present instrument, the calculated accuracy life is 1100 rounds.

The calculations are based on very liberal assumptions and though not much confidence can be placed on actual values, the general nature of the curves and magnitude of values are regarded as plausible.

The calculated accuracy life is much longer than the empirically expected life of the gun for such a high powered gun. It is believed probable that the actual accuracy life will be less than the calculated accuracy life and will be determined by shearing or stripping of the rotating band.

Acknowledgment:

The writer is much indebted to R. H. Kent for his advice and suggestions. Assistance was also rendered by V. H. McNeilly.

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Appendix

Effect of Accidental Error on the Probability of Effectively Damaging an Imperfectly Located Airplane.

(Based on the appendix to B.R.L. 241 "Optimum Spacing of Bombs" by J. von Neumann.)

I The problem is confined to the one dimension along the slant range. It is in this direction that the principle systematic error—due to height finder—and the principle accidental error—due to dispersion of muzzle velocity and time of flight of fuze—occur.

II The true location of the target is y with the Gaussian distribution

$$\frac{1}{\sqrt{\pi}\varepsilon_s} e^{-\frac{y^2}{\varepsilon_s^2}} dy$$

where ε_s is $\sqrt{2}$ times the standard deviation of the systematic error.

The place of burst, x, is a chance variable with the Gaussian distribution

$$\frac{1}{\sqrt{\pi}\varepsilon_\alpha} e^{-\frac{x^2}{\varepsilon_\alpha^2}} dx$$

where ε_α is $\sqrt{2}$ times the standard deviation of the accidental error.

We consider a diffuse burst such that the probability of effective damage varies according to the Gaussian

$$e^{-\frac{(x-y)^2}{w^2}} .$$

where w is a combination of the width of the target and of the burst.

With a diffuse burst the probability of effective damage assuming a certain value of y is

$$p = \frac{1}{\sqrt{\pi}\varepsilon_\alpha} \int_{-\infty}^{\infty} e^{-\frac{(x-y)^2}{w^2} - \frac{x^2}{\varepsilon_\alpha^2}} dx$$

To integrate the expression a change of variable is made in the following manner.

$$-\frac{(x-y)^2}{w^2} - \frac{x^2}{\varepsilon_\alpha^2} = -\frac{w^2+\varepsilon_\alpha^2}{w^2\varepsilon_\alpha^2}\left(x - \frac{\varepsilon_\alpha^2 y}{w^2+\varepsilon_\alpha^2}\right)^2 - \frac{y^2}{w^2+\varepsilon_\alpha^2}$$

Therefore letting $x' = x - \frac{\varepsilon_\alpha^2 y}{w^2+\varepsilon_\alpha^2}$

$$p = \frac{1}{\sqrt{\pi}\varepsilon_\alpha} \int_{-\infty}^{\infty} e^{-\frac{w^2+\varepsilon_\alpha^2}{w^2+\varepsilon_\alpha^2} x'^2 - \frac{1}{w^2+\varepsilon_\alpha^2}} dx'$$

$$p = \frac{w}{\sqrt{w^2+\varepsilon_\alpha^2}} e^{-\frac{y^2}{w^2+\varepsilon_\alpha^2}}$$

The probability of one round not damaging the target assuming a certain value of y is

$$q = 1-p$$

$$= 1 - \frac{w}{\sqrt{w^2+\varepsilon_\alpha^2}} e^{-\frac{y^2}{w^2+\varepsilon^2_\alpha}}$$

The probability of n rounds not damaging assuming a certain value of y is

$$q^n = \left(1 - \frac{w}{\sqrt{w^2+\varepsilon_\alpha^2}} e^{-\frac{y^2}{w^2+\varepsilon_\alpha^2}}\right)^n$$

The probability for n rounds not to damage for y averaged is

$$Q = \frac{1}{\sqrt{\pi}\varepsilon_s} \int_{-\infty}^{\infty} \left(1 - \frac{w}{\sqrt{w^2+\varepsilon_\alpha^2}} e^{-\frac{y^2}{w^2+\varepsilon_\alpha^2}}\right)^n e^{-\frac{y^2}{\varepsilon_s^2}} dy$$

$$= \frac{1}{\sqrt{\pi}\varepsilon_s} \int_{-\infty}^{\infty} \left(1 + \sum_{r=1}^{n} \frac{n!}{(n-r)!n!} \frac{(-1)^r w^r}{(w^2+\varepsilon_\alpha^2)^{\frac{r}{2}}} e^{-\frac{ry^2}{w^2+\varepsilon_\alpha^2}}\right) e^{-\frac{y^2}{\varepsilon_s^2}} dy$$

The probability for at least one round out of n rounds to effectively damage the target is

$$P = 1-Q$$

$$= \frac{1}{\sqrt{\pi}\,\varepsilon_s} \sum_{r=1}^{n} \frac{n!}{(n-r)!r!} \frac{(-1)^{r-1} w^r}{(w^2+\varepsilon_\alpha^2)^{\frac{r}{2}}} \int_{-\infty}^{\infty} e^{-\frac{ry^2}{w^2+\varepsilon_\alpha^2} - \frac{y^2}{\varepsilon_s^2}} dy$$

$$= \sum_{r=1}^{n} (-1)^{r-1} \frac{n!}{(n-r)!r!} \frac{w^r}{(w^2+\varepsilon_\alpha^2)^{\frac{r-1}{2}} \sqrt{w^2+\varepsilon_\alpha^2+r\varepsilon_s^2}}$$

KEUFFEL & ESSER CO., N.Y. NO. 359-11L
20 x 20 to the inch, 10th lines heavy.
MADE IN U.S.A.

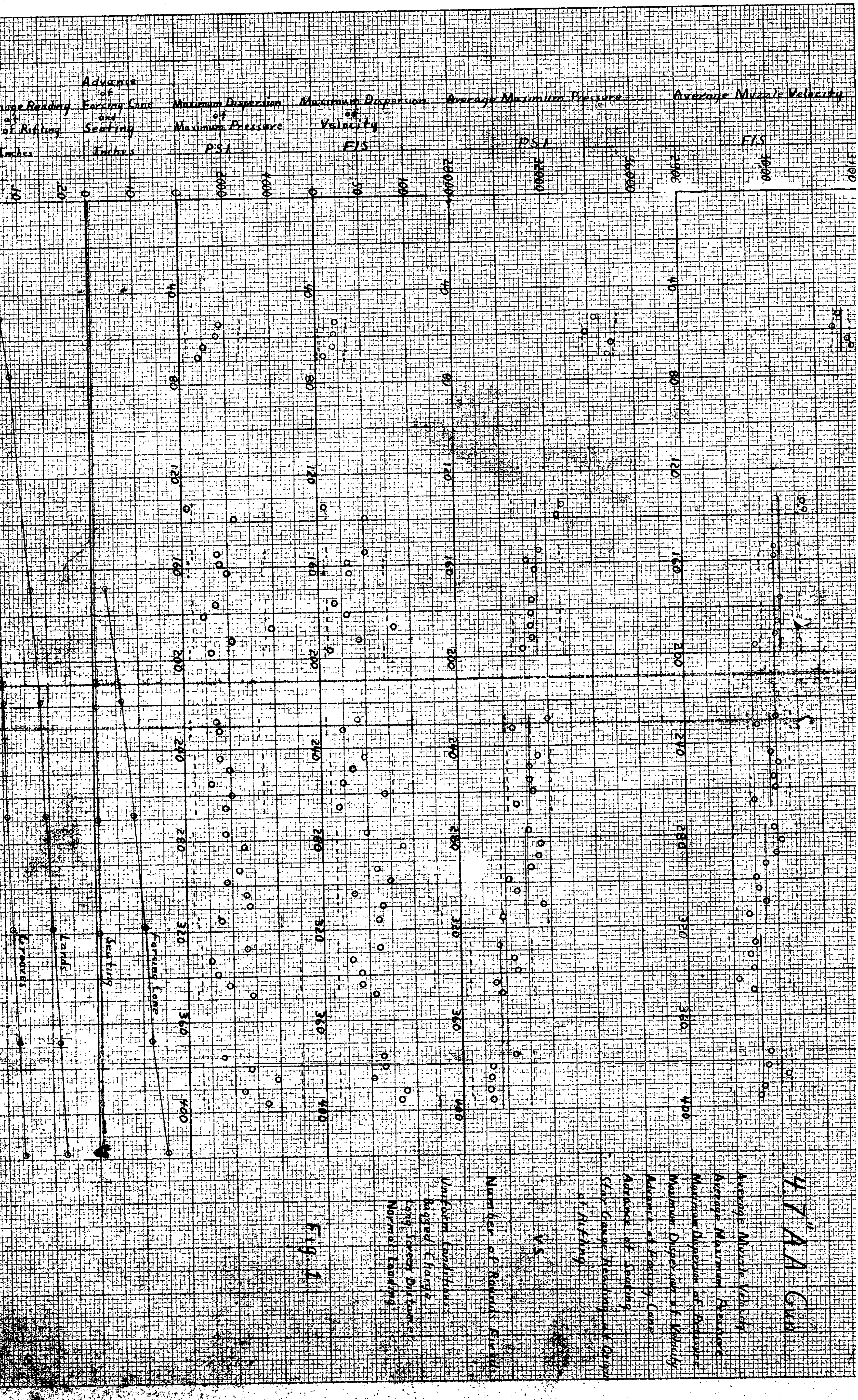
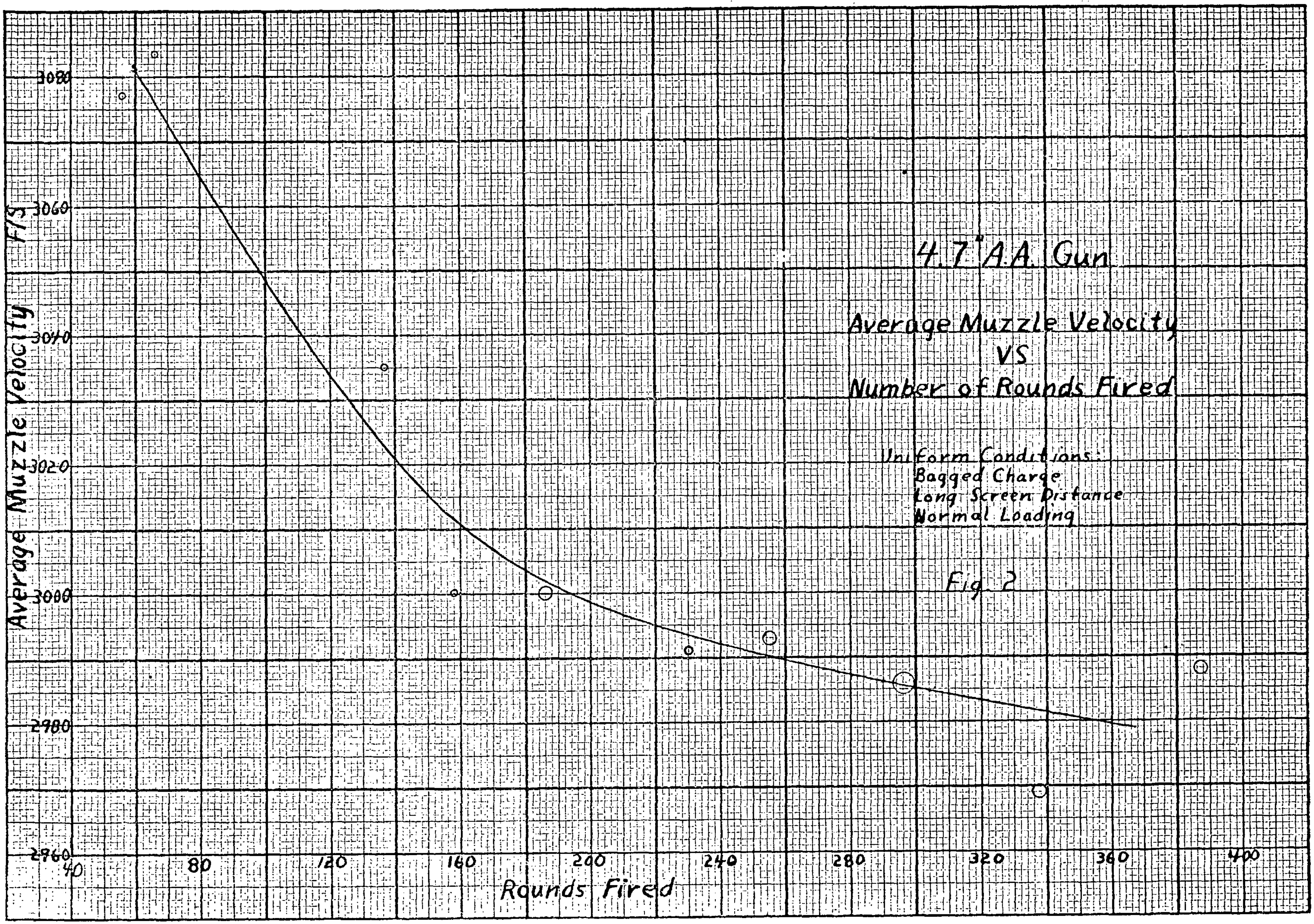


Fig. 1


4.7" A.A. Gun
Average Muzzle Velocity
VS
Number of Rounds Fired
Uniform Conditions:
Bagged Charge
Long Screen Distance
Normal Loading
Fig. 2
Average Muzzle Velocity F/S
3080
3060
3040
3020
3000
2980
2960
40
80
120
160
200
240
280
320
360
400
Rounds Fired

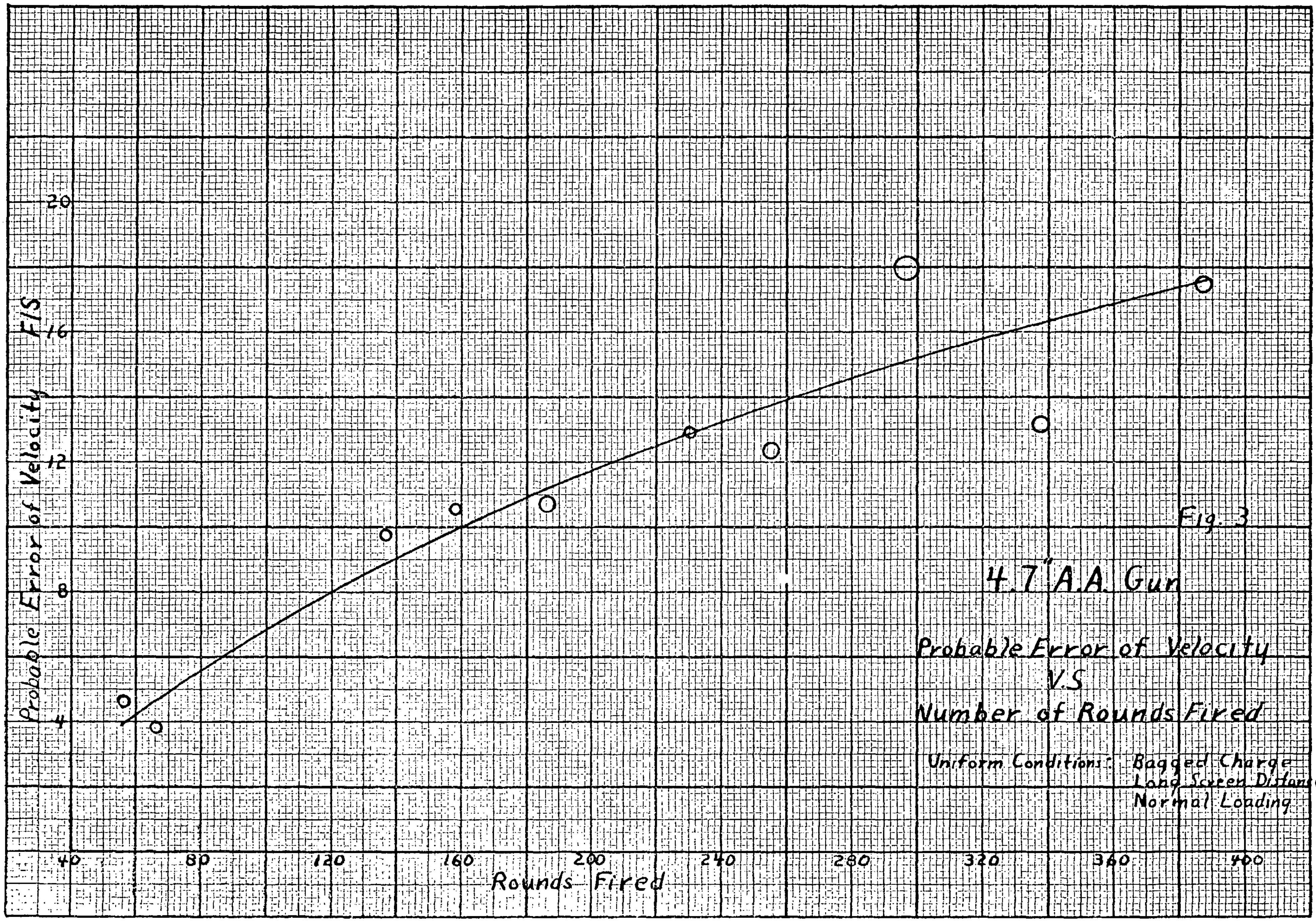


Fig. 3
4.7" A.A. Gun
Probable Error of Velocity
V.S
Number of Rounds Fired
Uniform Conditions: Bagged Charge
Long Screen Distance
Normal Loading
Probable Error of Velocity F/S
20
16
12
8
4
40
80
120
160
200
240
280
320
360
400
Rounds Fired

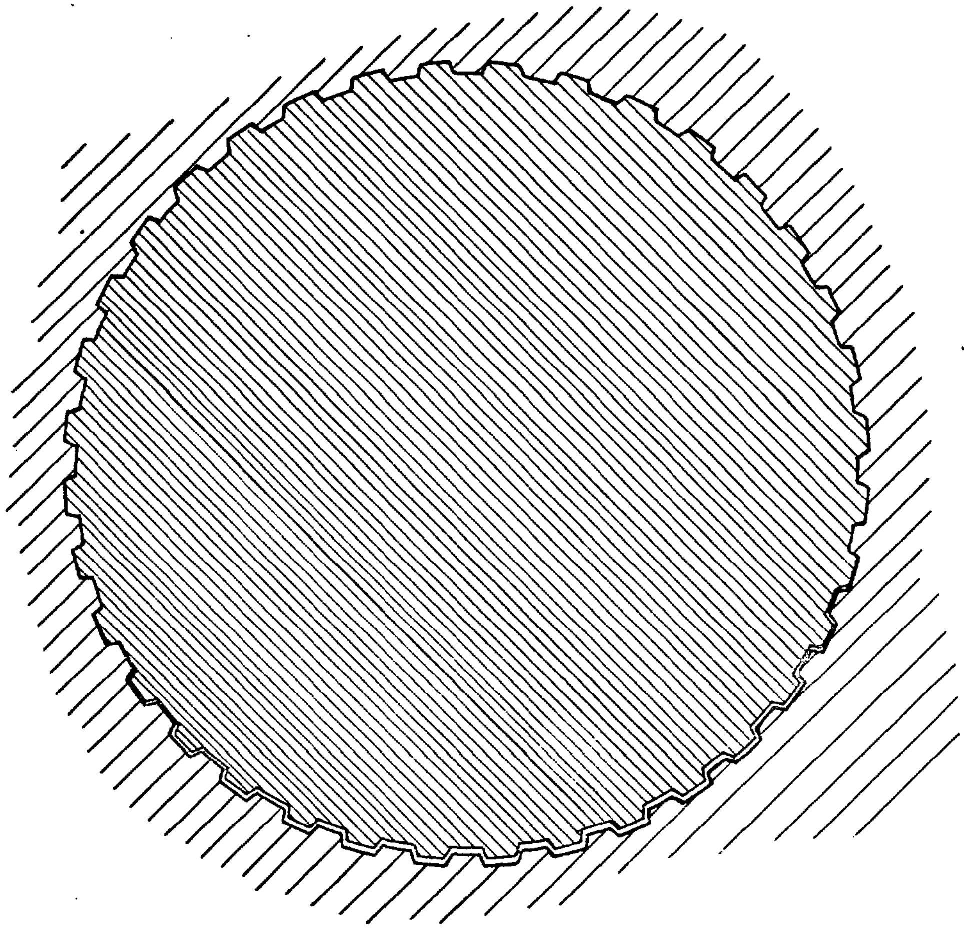


Fig. 4

Effect of Eccentric Loading on the Position of the Projectile in the Bore

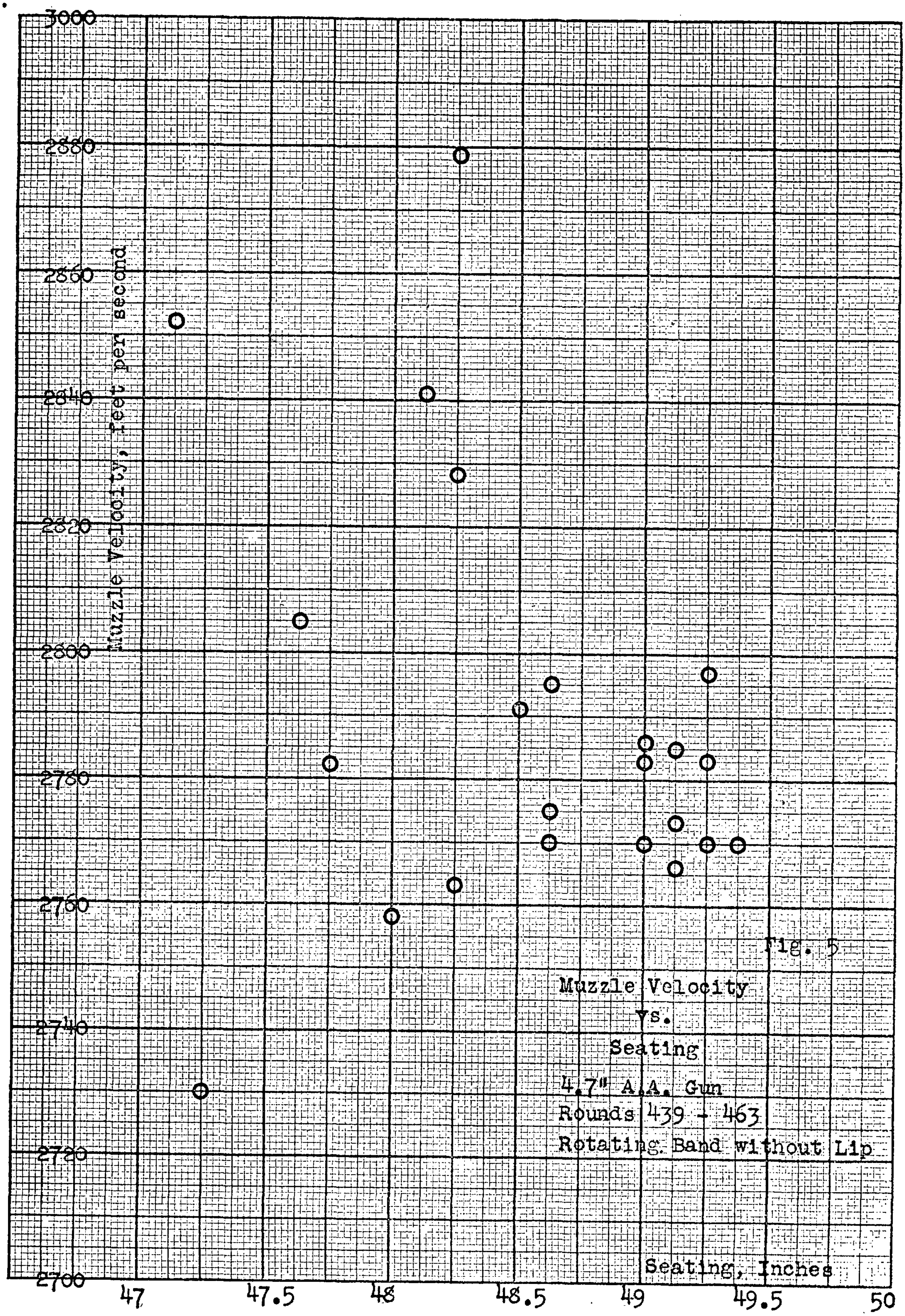
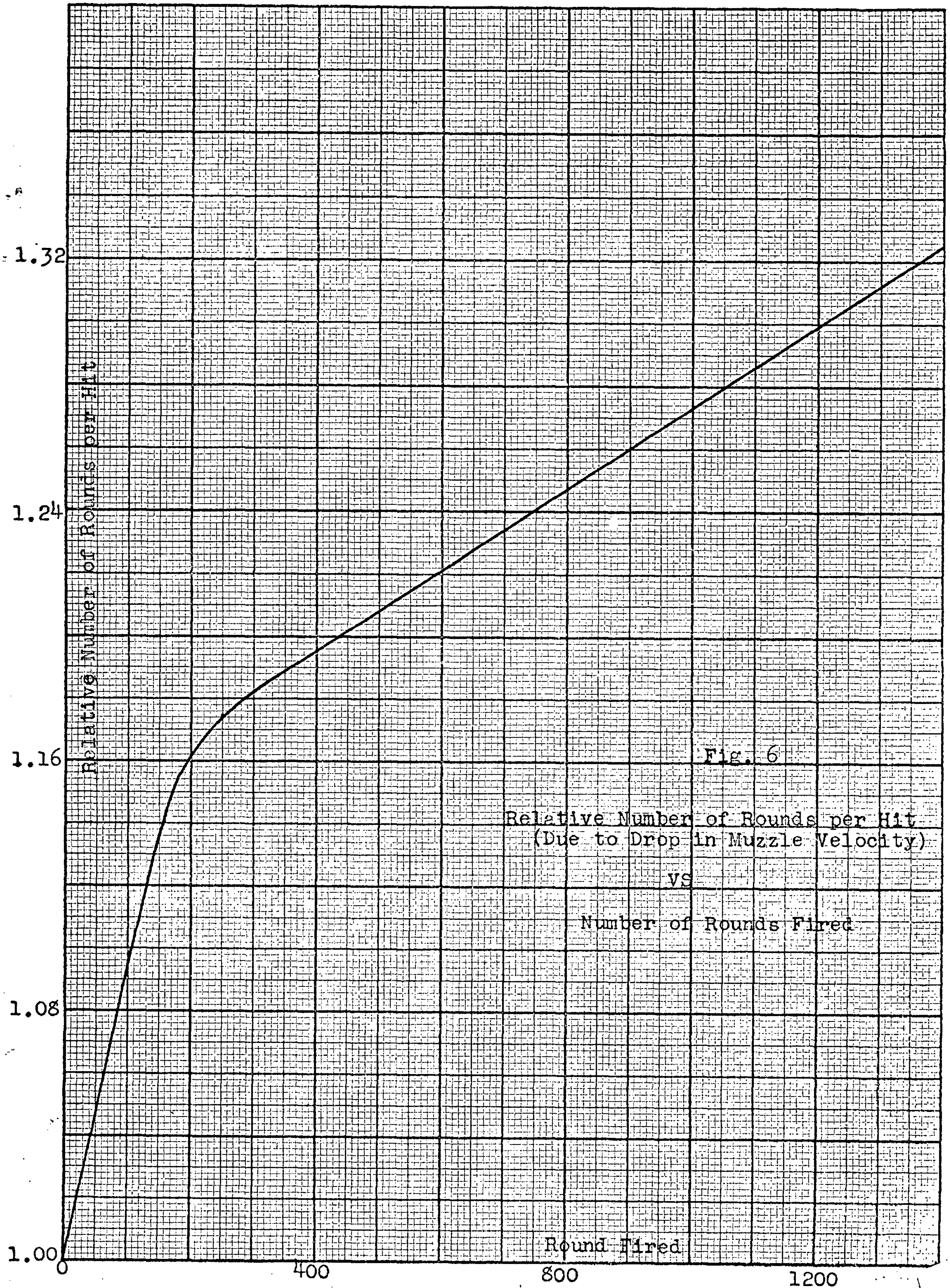


Fig. 5

Muzzle Velocity
vs.
Seating

4.7" A.A. Gun
Rounds 439 - 463
Rotating Band without Lip


1.32
1.24
1.16
1.08
1.00
Relative Number of Rounds per Hit
0
400
800
1200
Round Fired
Fig. 6
Relative Number of Rounds per Hit
(Due to Drop in Muzzle Velocity)
VS
Number of Rounds Fired

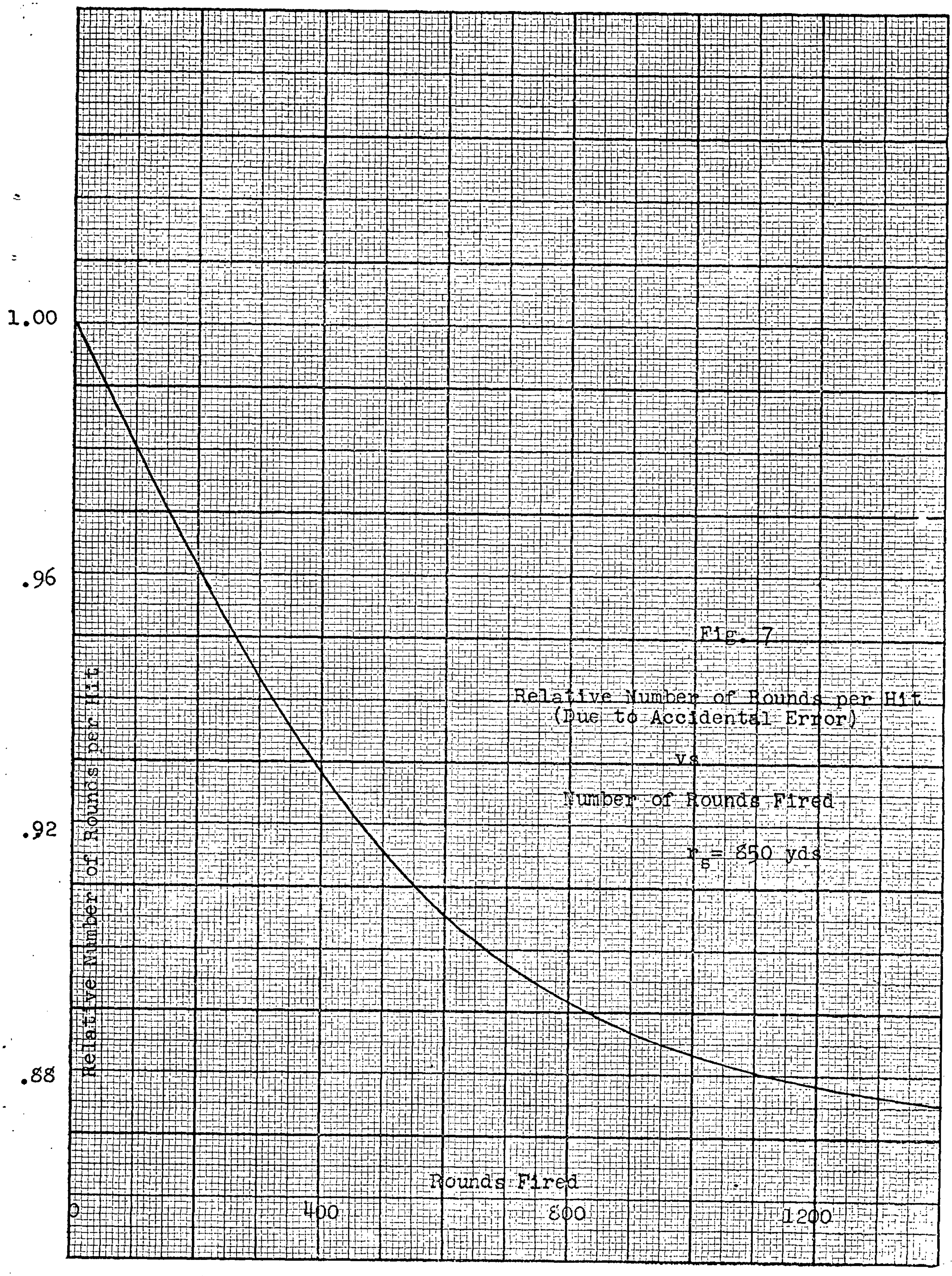


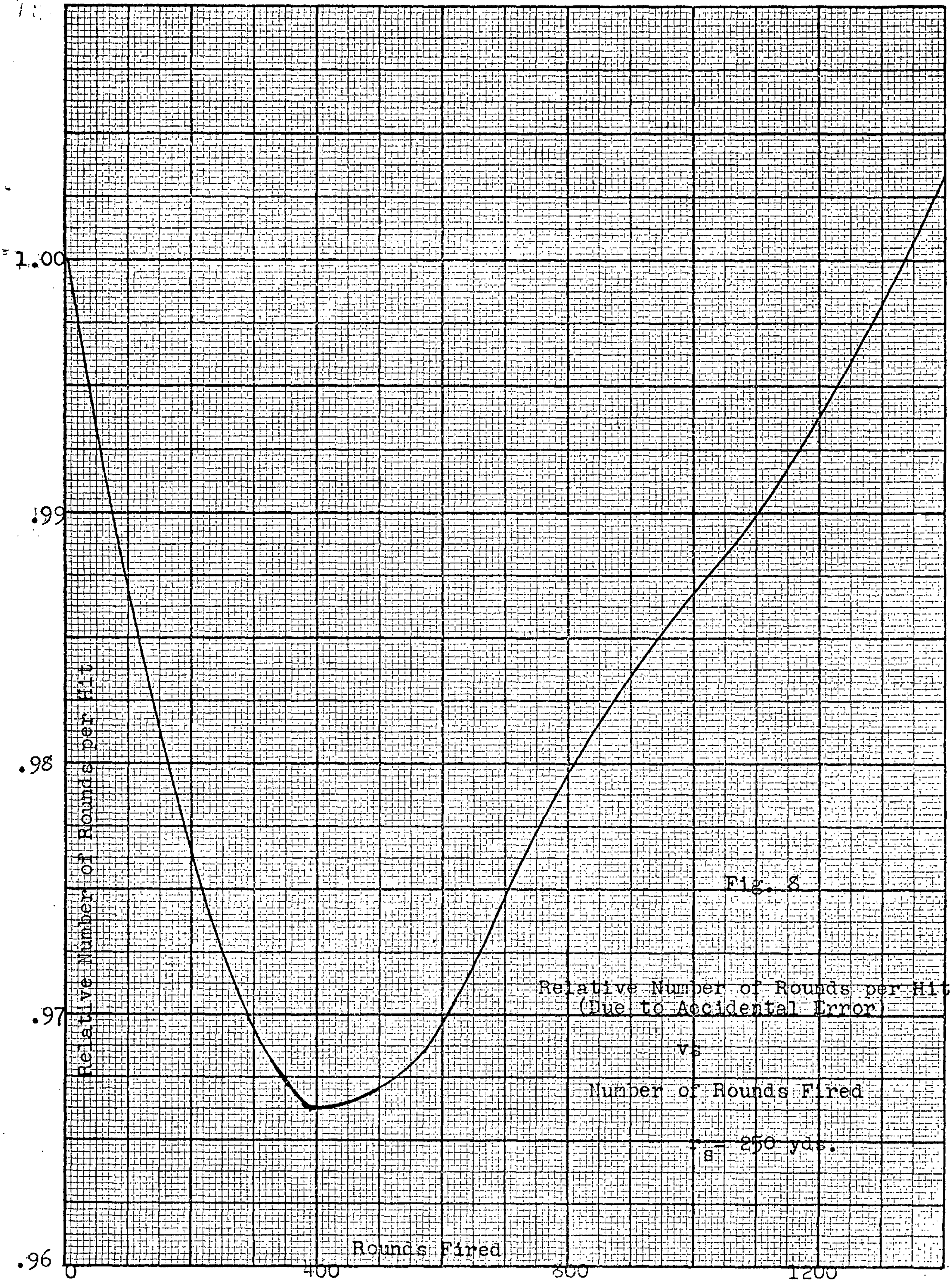
Fig. 7

Relative Number of Rounds per Hit
(Due to Accidental Error)

vs

Number of Rounds Fired

r_s = 850 yds



1.00
.99
.98
.97
.96
0
400
800
1200
Relative Number of Rounds per Hit
Rounds Fired
Fig. 8
Relative Number of Rounds per Hit
(Due to Accidental Error)
vs
Number of Rounds Fired
r_s = 250 yds.

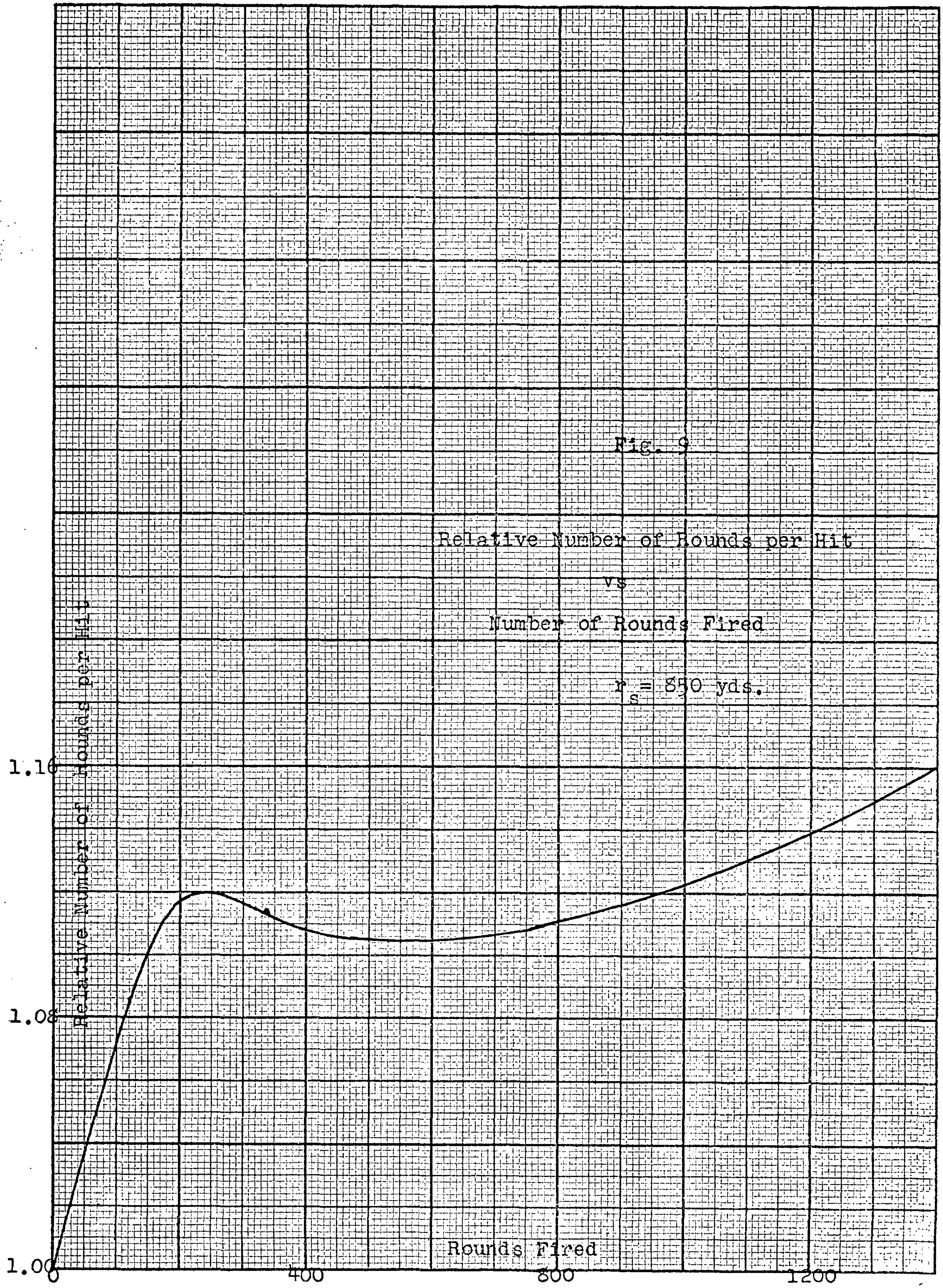
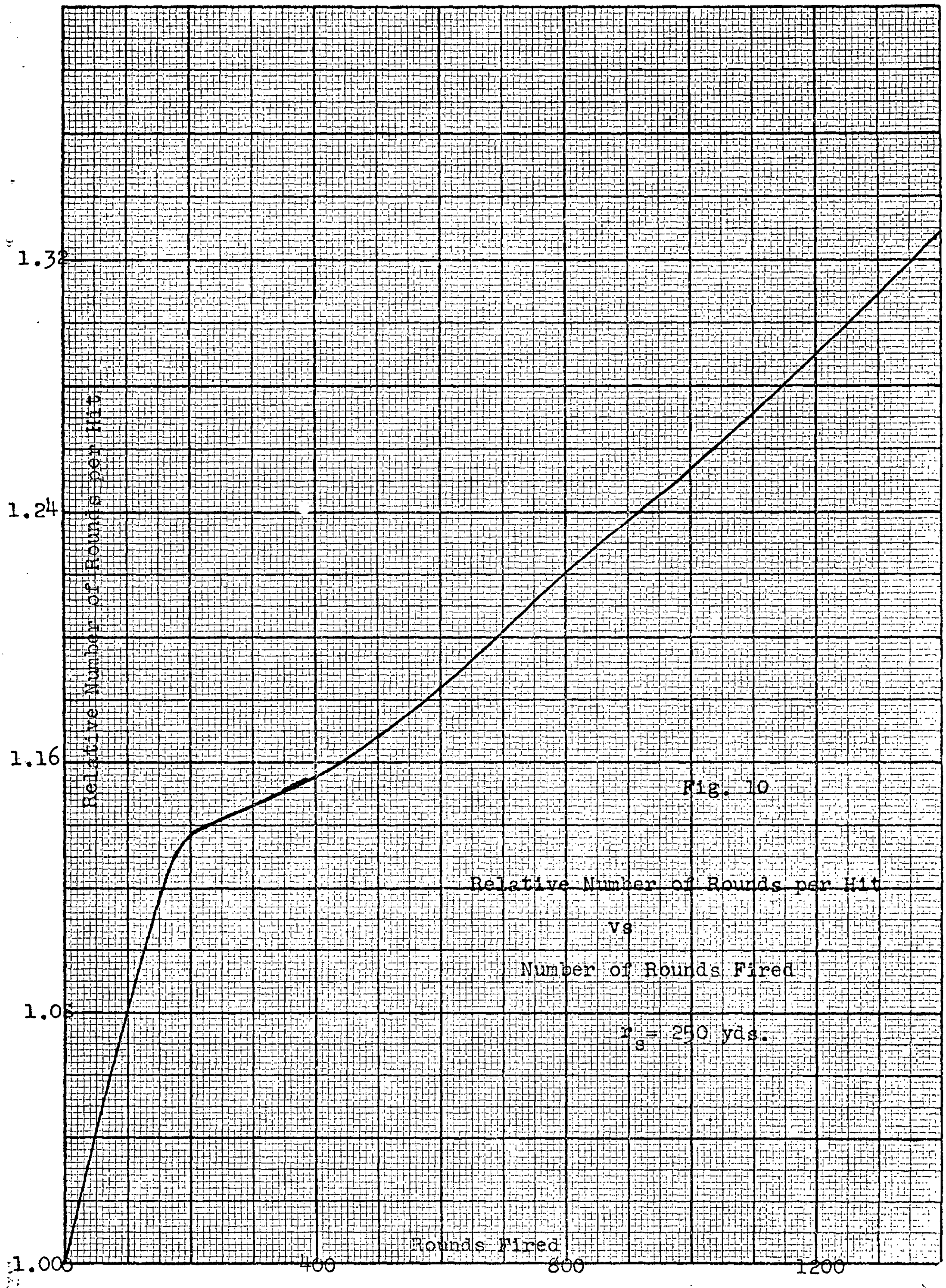


Fig. 9
Relative Number of Rounds per Hit
vs
Number of Rounds Fired
r_s = 850 yds.
Relative Number of Rounds per Hit
Rounds Fired
1.00
1.08
1.16
0
400
800
1200



1.32
1.24
1.16
1.08
1.000
Relative Number of Rounds per Hit
Rounds Fired
400
800
1200
Fig. 10
Relative Number of Rounds per Hit
vs
Number of Rounds Fired
r_s = 250 yds.

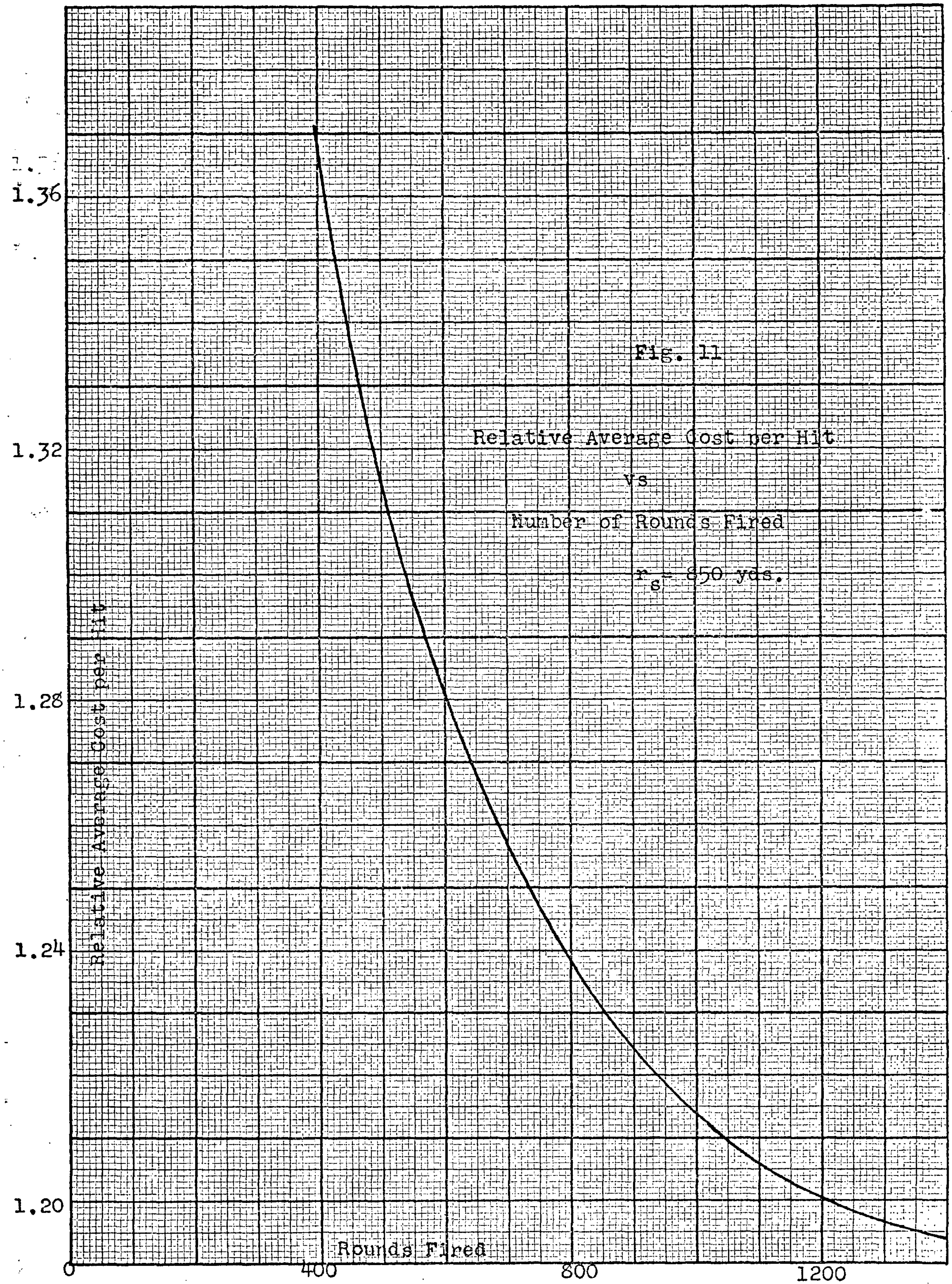


Fig. 11
Relative Average Cost per Hit
vs
Number of Rounds Fired
r_s = 850 yds.
Relative Average Cost per Hit
Rounds Fired
1.36
1.32
1.28
1.24
1.20
0
400
800
1200

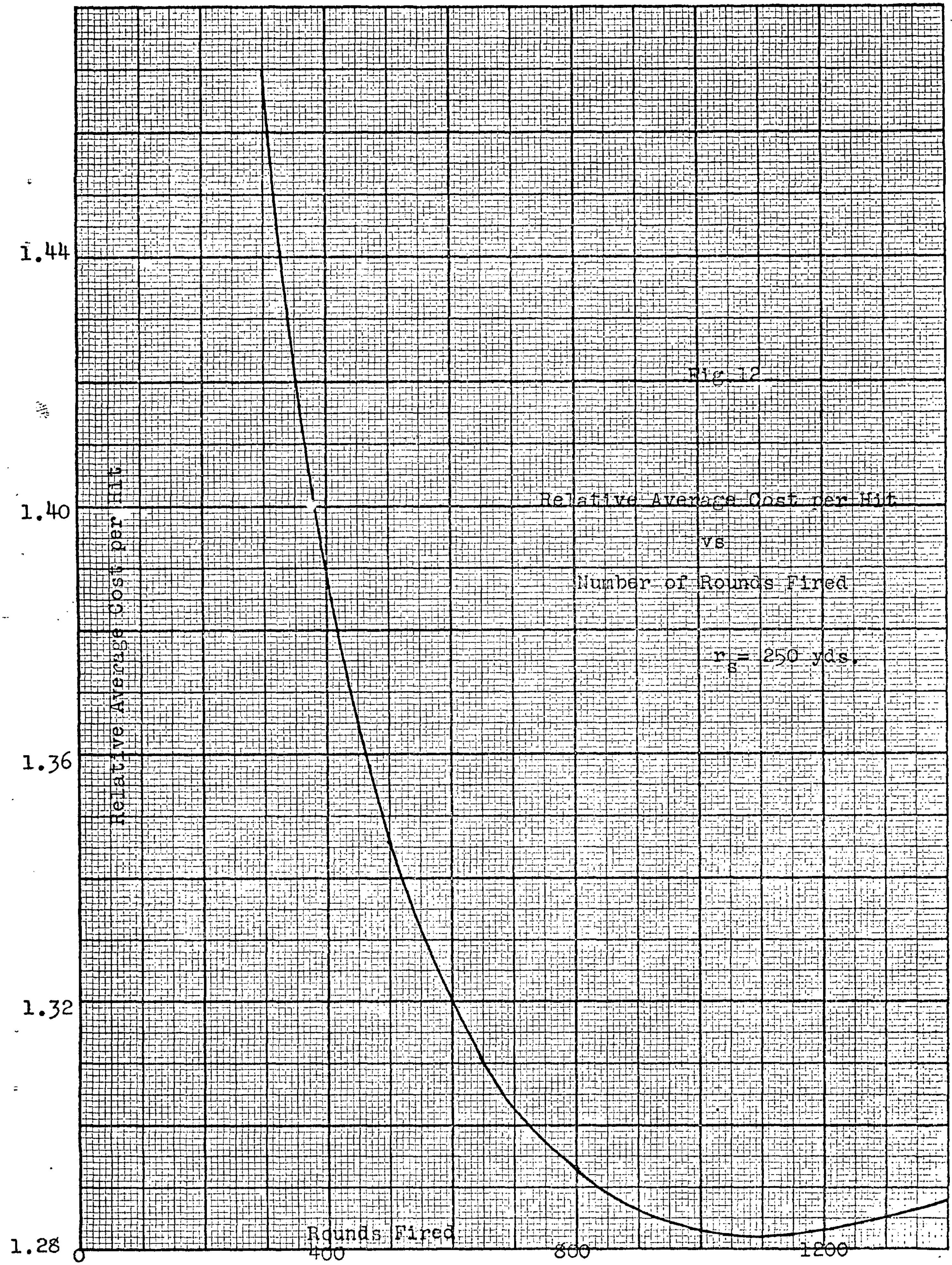
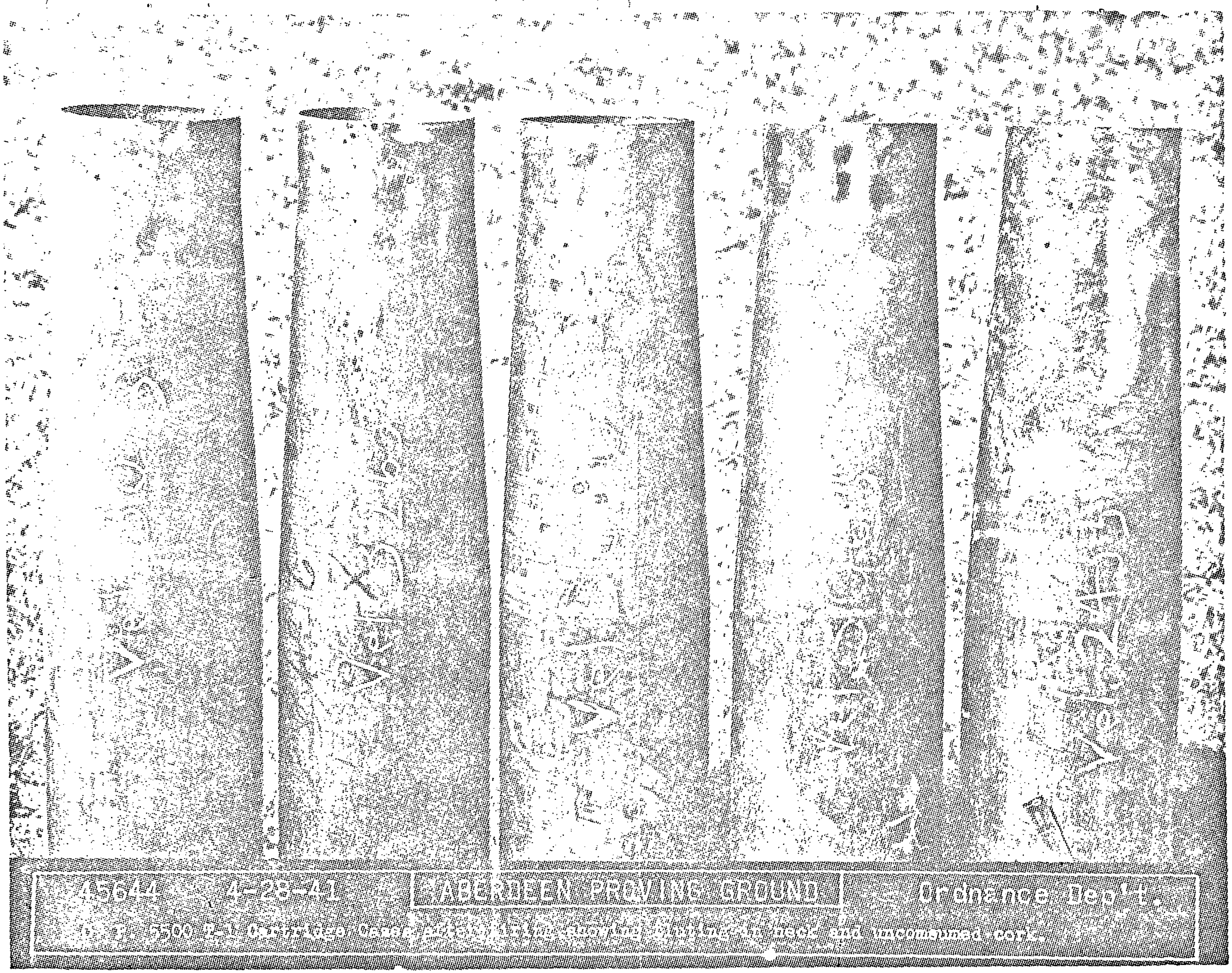
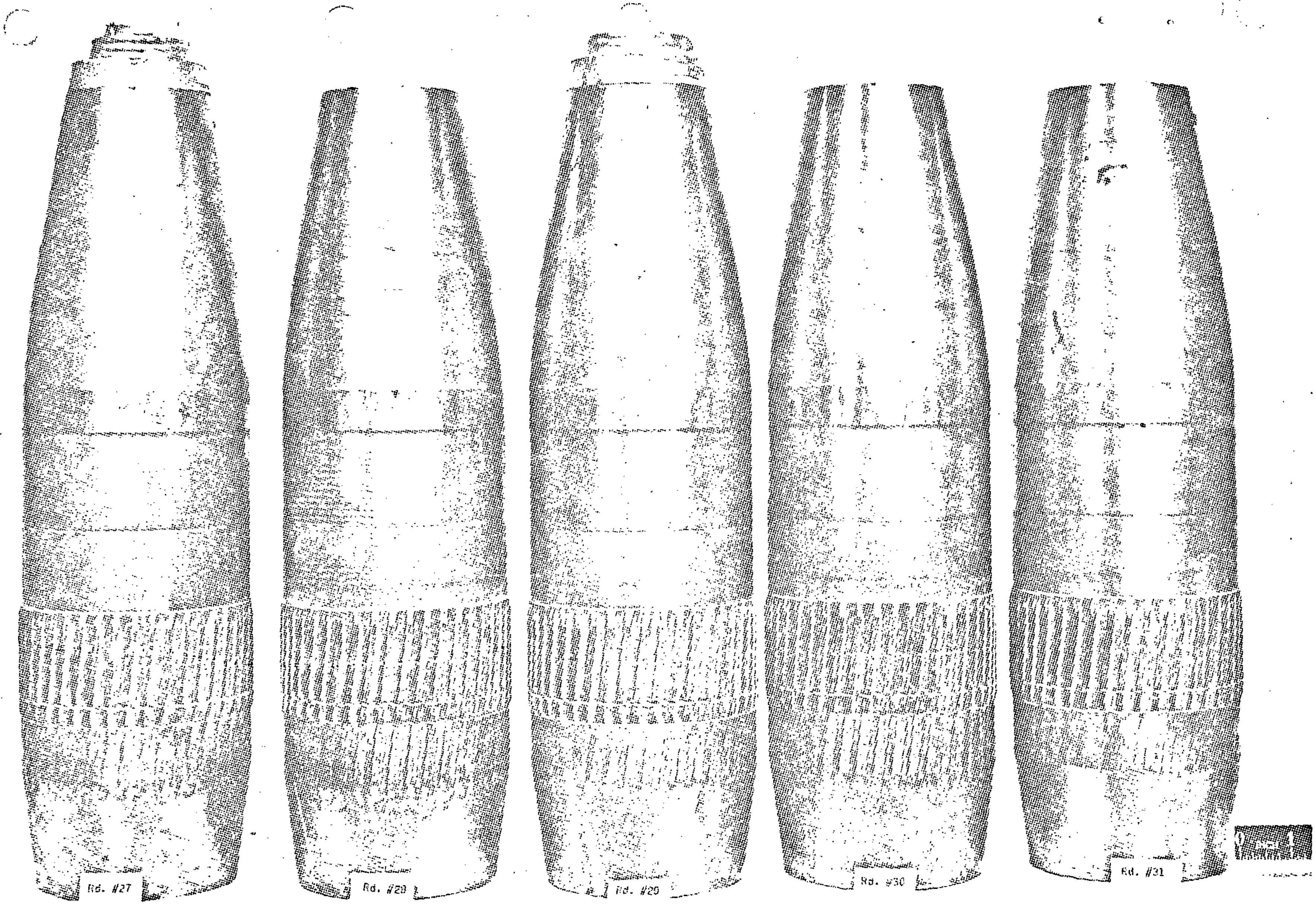
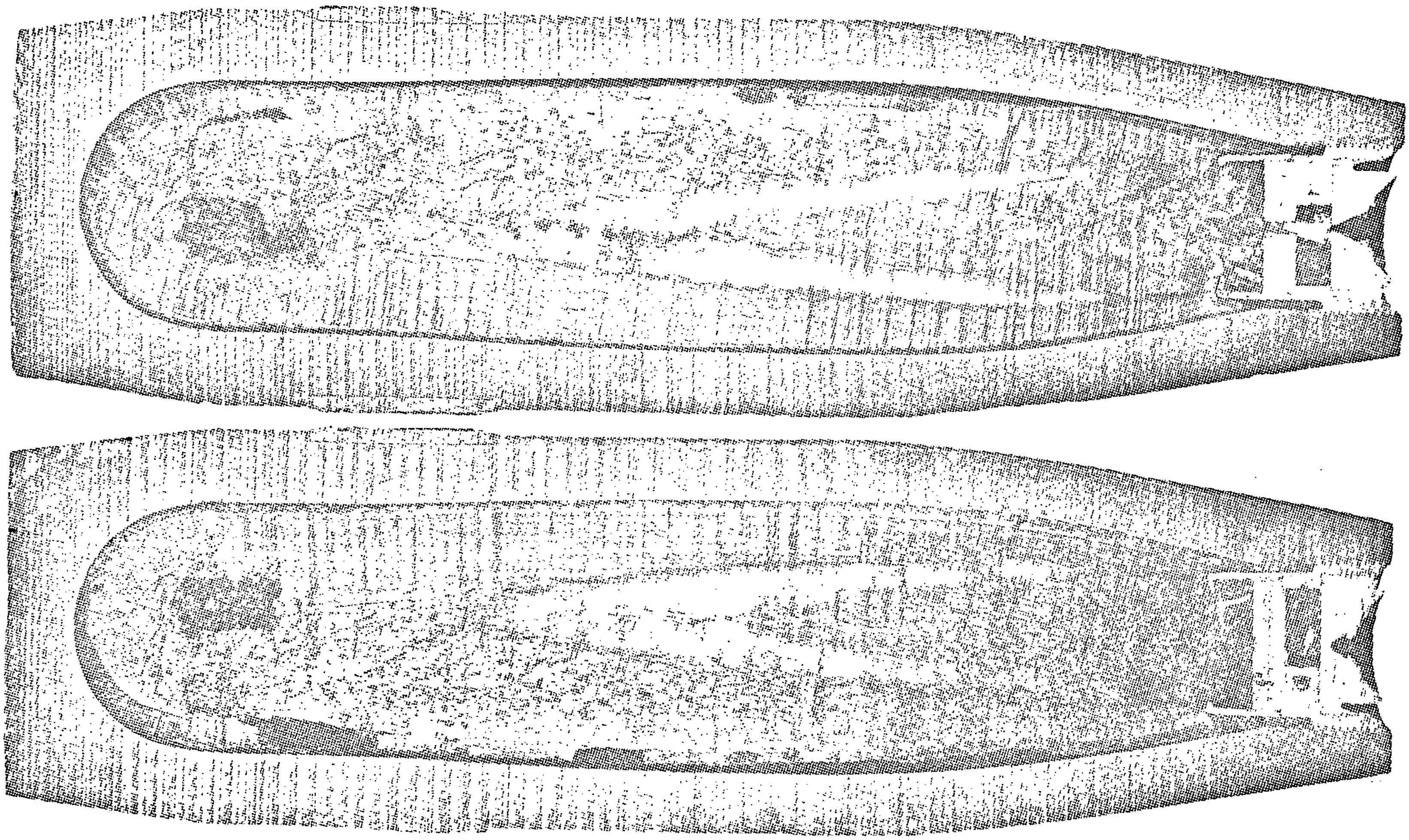


Fig. 12
Relative Average Cost per Hit
vs
Number of Rounds Fired
r_s = 250 yds.
Relative Average Cost per Hit
Rounds Fired
1.44
1.40
1.36
1.32
1.28
0
400
800
1200


45644 4-28-41 ABERDEEN PROVING GROUND Ordnance Dep't.
in neck and unconsumed cork.

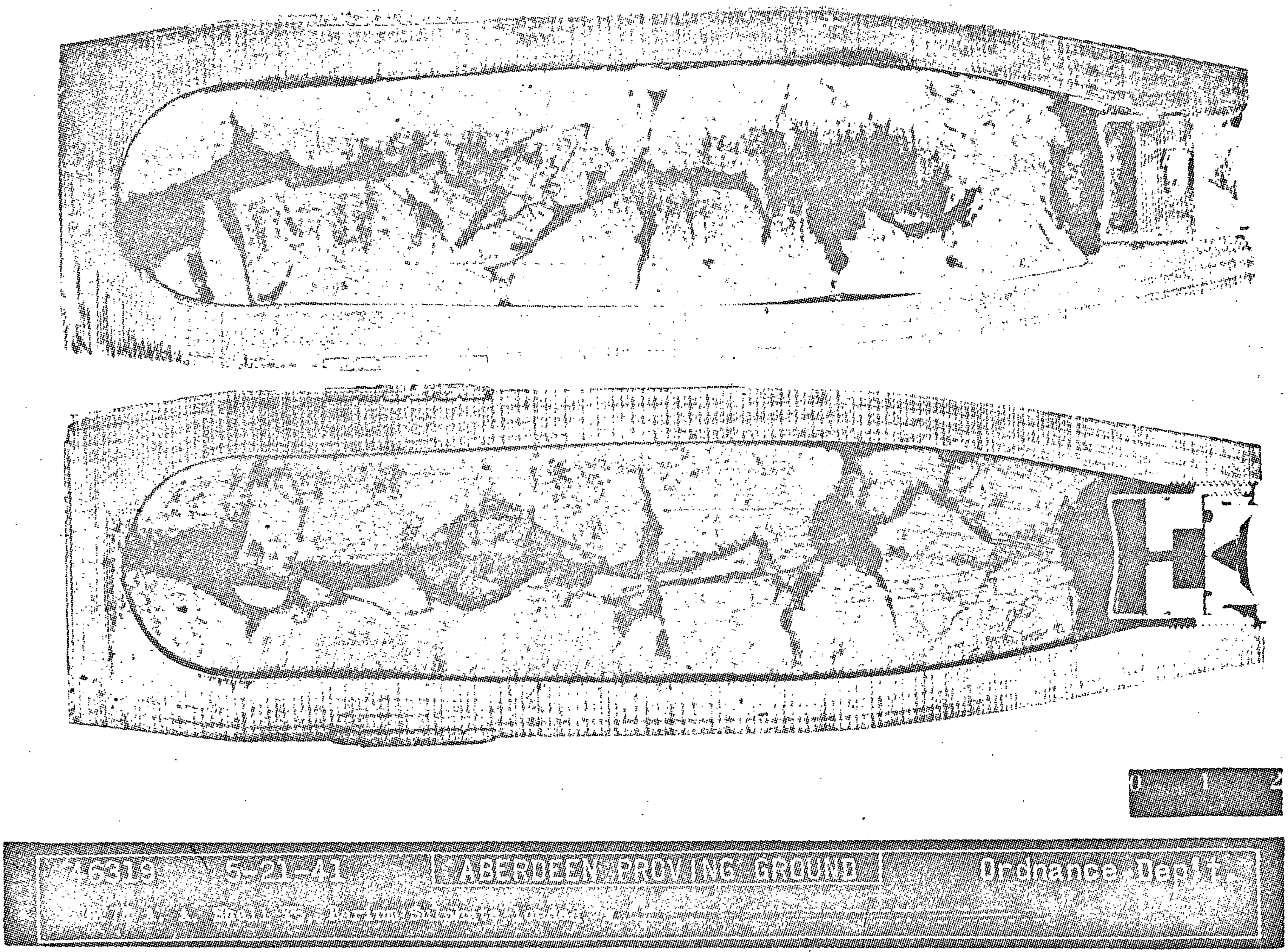


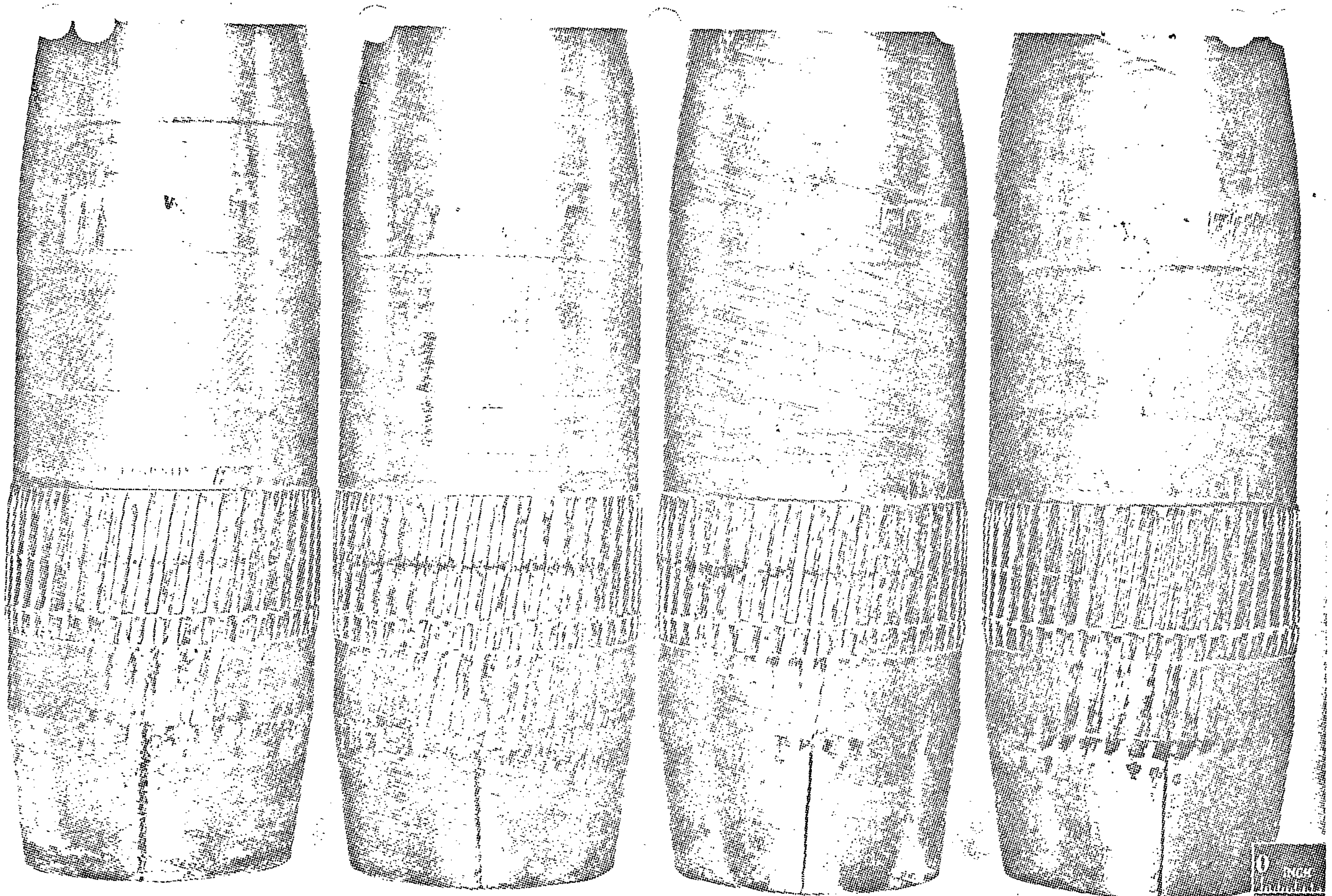
45743 5-2-41 ABERDEEN PROVING GROUND Ordnance Dep't.



46316 5-20-41 ABERDEEN PROVING GROUND Ordnance Dep't.

[illegible] red lead and paraffin loaded, sectioned, showing cavitation at base.

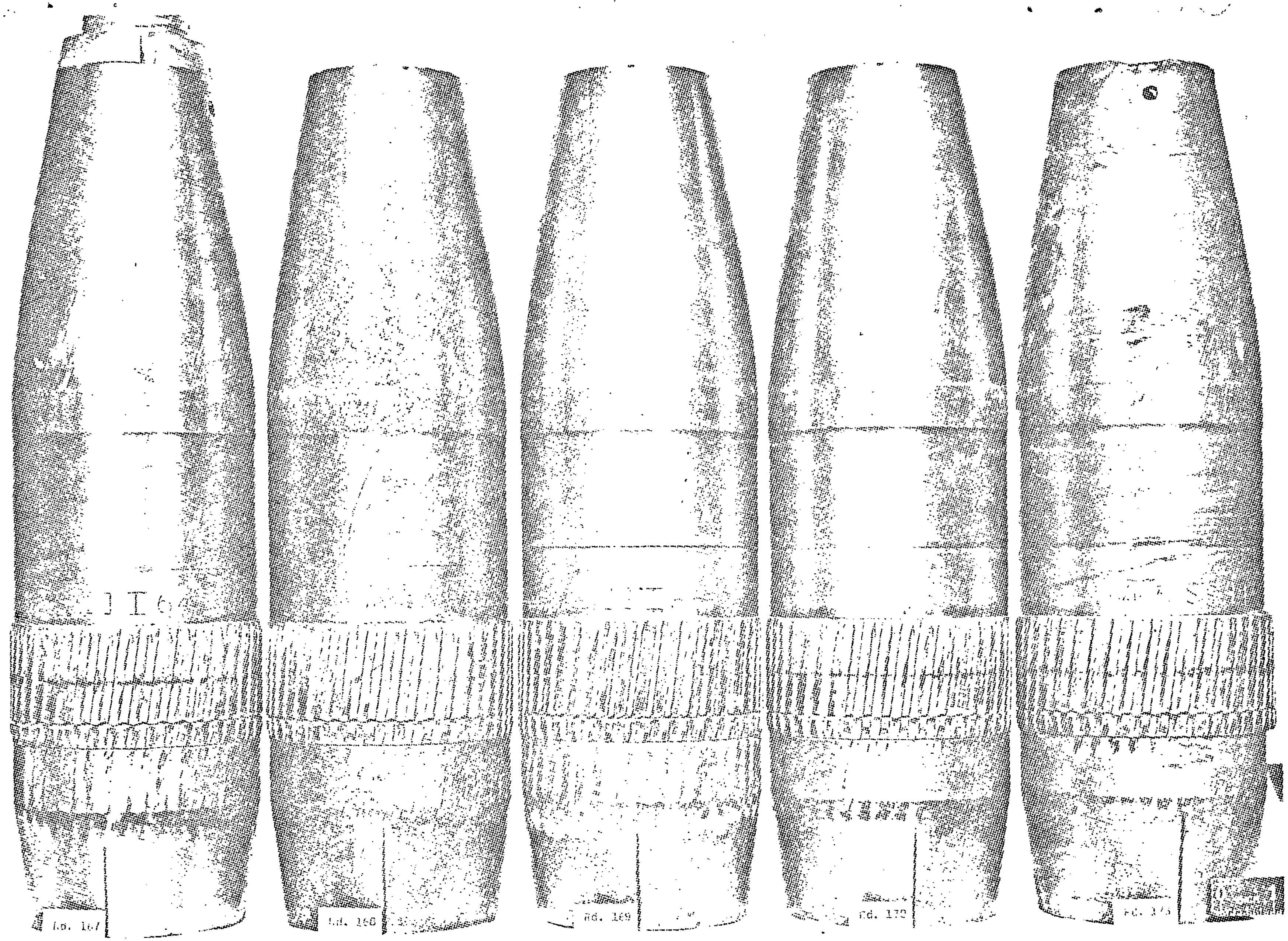

0 1 2
46319 5-21-41 ABERDEEN PROVING GROUND Ordnance Dep't



Rd. 270 Rd. 271 Rd. 273 Rd. 274

46686 6-7-41 ABERDEEN PROVING GROUND ORDNANCE DEPT.

H.E. 25, Lot 5186-1, F. A. - 1941. Engraving on Band good. No fringing. Engraving on Bourrelet [illegible] moderate; trace of engraving below band. Rds. 270-274. At [illegible] f/s.



46478 5-27-41 ABERDEEN PROVING GROUND Ordnance Dep't.

... Shell ...

... At 12:00 o'clock.

A6178 6-10-41 ABERDEEN PROVING GROUND ORDNANCE DEPT.

[illegible]