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JULY 1956

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DEPARTMENT OF THE ARMY PROJECT No. 5B03-03-001
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0108

BALLISTIC RESEARCH LABORATORIES

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LIST OF FIGURES*

* These plots, except figure 10, were inclosed with the firing records (Ref. 3). (The other figures are not needed.)

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Aberdeen Proving Ground, Md.
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ABSTRACT

The yaws of some 1070-pound projectiles, fired from a 12-inch Gun, in 1920, were determined by measuring the holes in beaver boards at a distance of 294 feet from the muzzle. Most of the rounds had yaws whose magnitude was less than the theoretical limit imposed by the maximum allowable clearance in the bore. The orientations were grouped about the theoretical value, calculated on the assumption that the front bourrelet followed the land that is at 6 o'clock at the origin. The range varies with both the magnitude and orientation of the yaw. Theoretically, the deflection also depends on the yaw, but this effect could not be detected.

INTRODUCTION

It came to Kent's notice some months ago that the British had been unaware of the fact that yaw is not completely random. This indicated that the British were unfamiliar with the work, described in this report, that Kent had done some twenty-five years ago.

THEORY

According to the small yaw theory of Fowler, Gallop, Lock and Richmond[1], the magnitude δ and orientation ϕ of the yaw of a spinning shell approximately satisfy the equations

$$\delta = (\alpha^2 \sin^2 qt + \beta^2 \cos^2 qt)^{1/2}, \tag{1}$$

$$\phi = \phi_o + \frac{AN}{2B} t \pm \tan^{-1} \left(\frac{\alpha}{\beta} \tan qt\right), \tag{2}$$

where

α is the maximum yaw,

β the minimum yaw,

t the time from the first minimum yaw,

ϕ_o the initial orientation,

A the axial moment of inertia,

B the transverse moment of inertia,

N the spin,

and $q = (AN/2B)(1 - 1/s)^{1/2}$ (3)

if s is the stability factor.

Damping is indicated by variations in α and β.

The spin is approximately

$$N = 2\pi v_o / nd, \tag{4}$$

where

v_o is the muzzle velocity,

$1/n$ the twist of rifling,

d the caliber.

For a short distance, the range is approximately

$$x = v_o t. \tag{5}$$

Then, if

$$\phi' = \pi A/Bnd \tag{6}$$

and

$$\sigma = (1 - 1/s)^{1/2}, \tag{7}$$

equations (1) and (2) may be expressed

$$\delta = (\alpha^2 \sin^2 \phi' \sigma x + \beta^2 \cos^2 \phi' \sigma x)^{1/2}, \tag{8}$$

$$\phi = \phi_o + \phi' x \pm \tan^{-1}\left(\frac{\alpha}{\beta} \tan \phi' \sigma x\right). \tag{9}$$

The stability factor may be found from the period of yaw L by the relation

$$(1 - 1/s)^{1/2} = Bnd/AL. \tag{10}$$

The curves on figure 1 are examples of the variation of δ and ϕ with x.

The minimum yaw is usually very small: about the same as the yaw in the bore ϵ, permitted by the clearance between the bourrelets of the shell and the lands of the gun. If the front bourrelet follows one land and the rear bourrelet the opposite land, the maximum yaw may be calculated by the formula[2]

$$\alpha = (2B/A - 1)\, \epsilon/\sigma. \tag{11}$$

The largest yaw to be expected at any distance may be found by using (8) and (11). Also, if it is assumed that the front bourrelet follows the land that is at 6 o'clock at the origin, the orientation of the yaw at the muzzle is known, and hence the orientation at any distance can be found by (9).

The yaw due to initial disturbances damps out rapidly if the shell is well designed. While the yaw is appreciable, however, it has two effects on the trajectory: it increases the drag and changes the direction of motion. Both of these effects influence the range; the latter also influences the deflection. In the present study, it is assumed that the range, corrected to a standard muzzle velocity and standard meteorological conditions, satisifies the formula

$$R = A + B\delta + C\delta \cos (\phi + K), \tag{12}$$

where R is the corrected range and A, B, C and K are constants. The magnitude and orientation of the yaw are measured at a given distance from the muzzle.

EXPERIMENTAL DATA

In December 1919 and January 1920, some 1070-pound Cast Iron Target Practice Projectiles (Dwg 75-10-15) were fired from a 12-inch Gun M1895 at an elevation of 18°.[3] The velocity was measured by a Boulengé chronograph with screens at 124 and 294 feet. In order to determine the yaw, beaver boards were placed on the far side of the first screen and the near side of the second screen; however, the boards on the first screen were cut by the wires so that the yaw could not be measured. On the second board, an increase in major axis from 12.1 to 13.1 inches was taken to represent a unit of yaw: this corresponds to an angle of 1.7°.

The observed ranges were corrected to a muzzle velocity of 2250 feet per second and standard meteorological conditions. The decrease in corrected range (meters) due to yaw was divided by the yaw (expressed in inches of major axis); the plot of this ratio as a function of orientation (fig 5) shows that the range varies in accordance with equation (12).

Figures 6 to 9 are plots of orientation (degrees) versus magnitude of yaw (expressed as an increase in major axis, in inches) for three groups of rounds. Plots 6 and 7 pertain to the same rounds considered in figure 5: plot 6 gives the corrected range of each round and shows curves of equal range; plot 7 gives the observed deflections. The corrected ranges of another group are given on figure 8.

The yaw in the bore was computed from the following average dimensions:

Bore Diameter	12.001 in.
Front bourrelet diam	11.982 in.
Rear bourrelet diam	11.930 in.
Bearing length	33.46 in.

The computed yaw in the bore is 0.077°.

It is estimated that the transverse moment of inertia is 10 times the axial moment of inertia, and that the stability factor is 1.51, since the observed nutational period is 430 feet (see fig. 1). Hence the maximum yaw, computed by equation (11), is 2.5°. This is equivalent to an increase of 1.5 inches in major axis.

The increase in drag due to yaw near the muzzle is equivalent to a decrease in muzzle velocity.[4] To determine this decrease for a maximum yaw of 2.5°, the following data are needed:

0.005 deg^{-2}	Yaw-drag coefficient $K_{D\delta}$ (estimated)
2250 fps	Muzzle velocity v_o (observed)
0.1625 sec^{-1}	Drag function G_6 (estimated)
8.10	Ballistic coefficient C_6 (estimated)
1.10	Cross wind force coefficient K_L (estimated)
3.52	Yawing moment coefficient K_H (estimated)
0.07513 lb/ft^3	Air density ρ (estimated)
1070 lb	Mass m (observed)
1370 $lb\text{-}ft^2$	Transverse moment of inertia B (estimated)

[illegible] computed loss in velocity is 1.16 fps. At an elevation of 1[illegible]°, the firing table for the 1070-pound Armor-piercing Projectile gives a range of [illegible] meters and an increase in range of 11.8 m for an increase of 1 foot per second in muzzle velocity. Therefore the estimated effect on range of the increase in drag due to yaw is a decrease of 13.7 meters.

The expression for the jump due to bore clearance and its orientation may be derived from an expression given by Sterne.[7] It shows that if the initial value of ϕ is 270 degrees, the jump is in the vertical plane and downwards. Its magnitude is

$$\epsilon \frac{AN}{md} \frac{K_L}{K_M} \frac{1}{v_o} \left(\frac{B}{A} - 1\right)$$

Where K_M is the overturning moment coefficient

Hence, if the actual angle of orientation of the yaw at the muzzle of the gun is ϕ_o then the actual vertical component of the jump will be

$$-\epsilon \frac{AN}{md} \frac{K_L}{K_M} \frac{1}{v_o} \left(\frac{B}{A} - 1\right) \cos\left(\phi_o - 270^\circ\right) \tag{13}$$

Hitchcock[6] has discussed the displacement caused by initial yaw. This could be used in place of Sterne's formula.**

The constants for this gun and ammunition (some repeated from page 8) appearing in equation (13) are as follows:

$\epsilon = .077^\circ = 1.37$ mils*

$A = 137$ lb ft^2

$N = \frac{2\pi v_o}{nd} = 565.5$ rad/sec

$m = 1070$ lbs

$d = 1.000$ ft

$K_L = 1.10$*

$K_M = 1.91$*

$v_o = 2250$ ft/sec

$B/A = 10$*

$\phi_o = 226^\circ$

* Estimated

** The application of Hitchcock's technique produces results almost identical to those obtained by equation (13).

$$\rho_o = .07513 \text{ lb/ft}^3$$
$$n = 25 \text{ cal}$$
$$s = 1.51$$

If the cofactor of cos $(\phi_o - 270^\circ)$ is represented by -j then the jump may be written

$$-j \cos (\phi_o - 270^\circ)$$
$$j = .23 \text{ mils} - .77'$$

It follows that the vertical component of the jump will be - .165 mils = - .56' and the horizontal component will be + .160 mils = .54'.

At an elevation of 18°, the firing table[5] for the AP Projectile gives an increase in range of 9.8 meters for 1 minute increase in elevation. Therefore, the estimated increase in range for an increase of 0.75 minute in elevation is 7.35 meters.

The combined effect of drag and jump due to yaw is plotted on figure 10.

DISCUSSION

The theoretical increase in major axis at 294 feet is 1.5 inches. Most of the measured values were less than this, although some were more; the largest was 2.75 inches. It should be noted, however, that the yaw has passed its first maximum at this distance, as the period is 430 feet; therefore, a small increase in the distance to the maximum will cause an appreciable increase in the yaw at the second screen. In other guns, when there have been enough cards to determine the actual maximum yaw, the observed value seldom exceeds the theoretical.[4]

The theoretical mean orientation at 294 feet is 35°. The observed orientations are grouped about this value although their dispersion is rather large: a few values are nearly 180° from the mean (two rounds are plotted with an orientation of 295°. but this is only 100° from the mean in the negative direction). The assumption that the front bourrelet follows the land that is at 6 o'clock at the origin is further confirmed by the fact that the lands in this region wear more rapidly near the muzzle than the others in guns which fire separate-loading ammunition (this is not true for fixed ammunition).

Since the range varies with both magnitude and orientation of yaw, the dispersion in both of these quantities should be made as small as feasible. For a given gun and ammunition, this can be done by ramming all rounds as uniformly as possible. The dispersion in deflection might also be reduced in this way, although the deflection has comparatively small dispersion anyway.

The evidence presented in this report confirming the hypothesis that in this gun and, presumably, in most guns firing separate loading ammunition, the yaw at the muzzle corresponds to an initial yaw at the breech at 6 o'clock is confirmed by observations of the muzzles of several guns that have shown erosion on the lands corresponding to 6 o·clock at the breech.

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H P Hitchcock
H. P. HITCHCOCK

REFERENCES

1. Fowler, R. H., Gallop, E. G., Lock, G. N. H., and Richmond, H. W. The Aerodynamics of a Spinning Shell. Phil. Trans. Royal Soc. London, A 221: 295 (1920).

2. Kent, R. H., and Hitchcock, H. P. The Effect of Cross Wind on the Yaw of Projectiles. APG: BRL File A-IV-31, (1928).

3. Test of Multisectional Charges for Seacoast Guns. APG: 2nd and Final Report on Ord Board Program 4062 (1920), including Supplementary Report on Jump Card Results Obtained in Connection with Firings Made on Dec 11, 16 and 31, 1919, and Jan 12, 1920.

4. Hitchcock, H. P. Comparison of Observed and Predicted Yaw and Velocity Drop Caused by Yaw. APG: BRL MR-623, (1952).

5. Chief of Ordnance. Firing Tables for 12-inch SC Gun, Model of 1895, Mounted on 12-inch Barbette Carriage, Model of 1917, Firing 1070 lb AP Projectile. Washington: FT 12-K-1 (1929).

6. Hitchcock, H. P. Integration of Equations of Motion of a Spinning Shell to Determine Displacement Due to Yaw. APG: BRL R-X95 (1922).

7. Sterne, T. E., On Jump Due to Bore Clearance. APG: BRL 491 (1944).

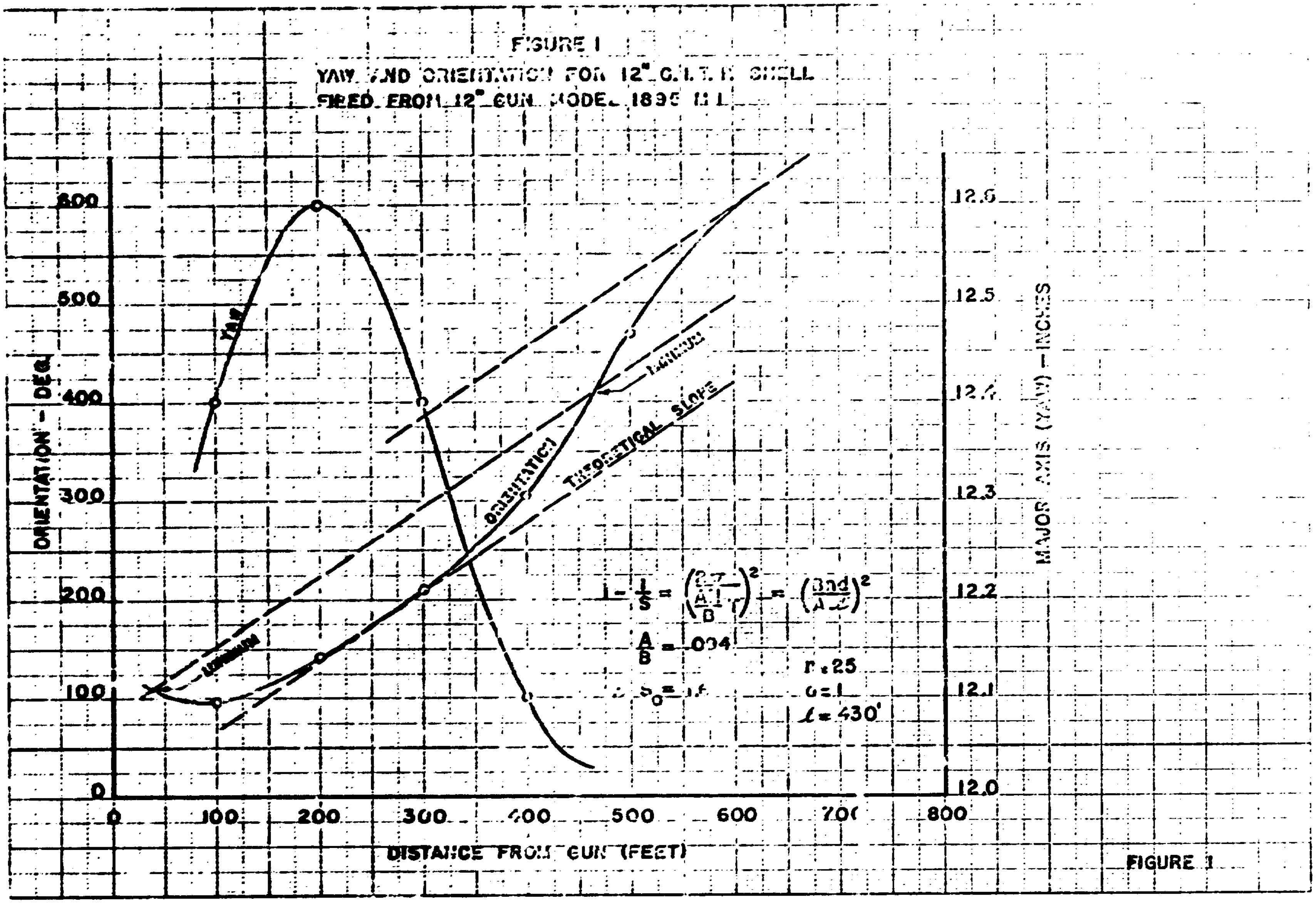
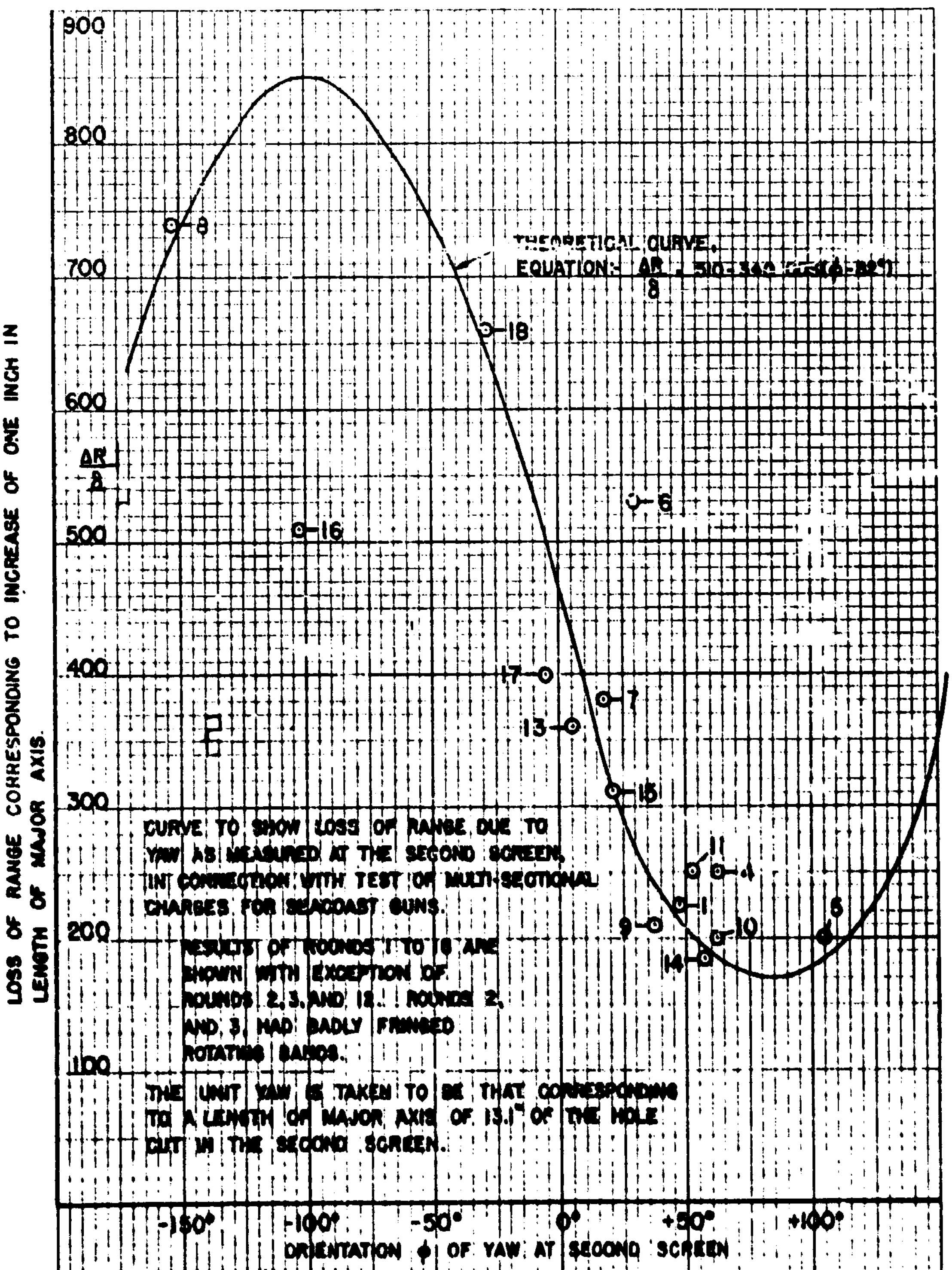
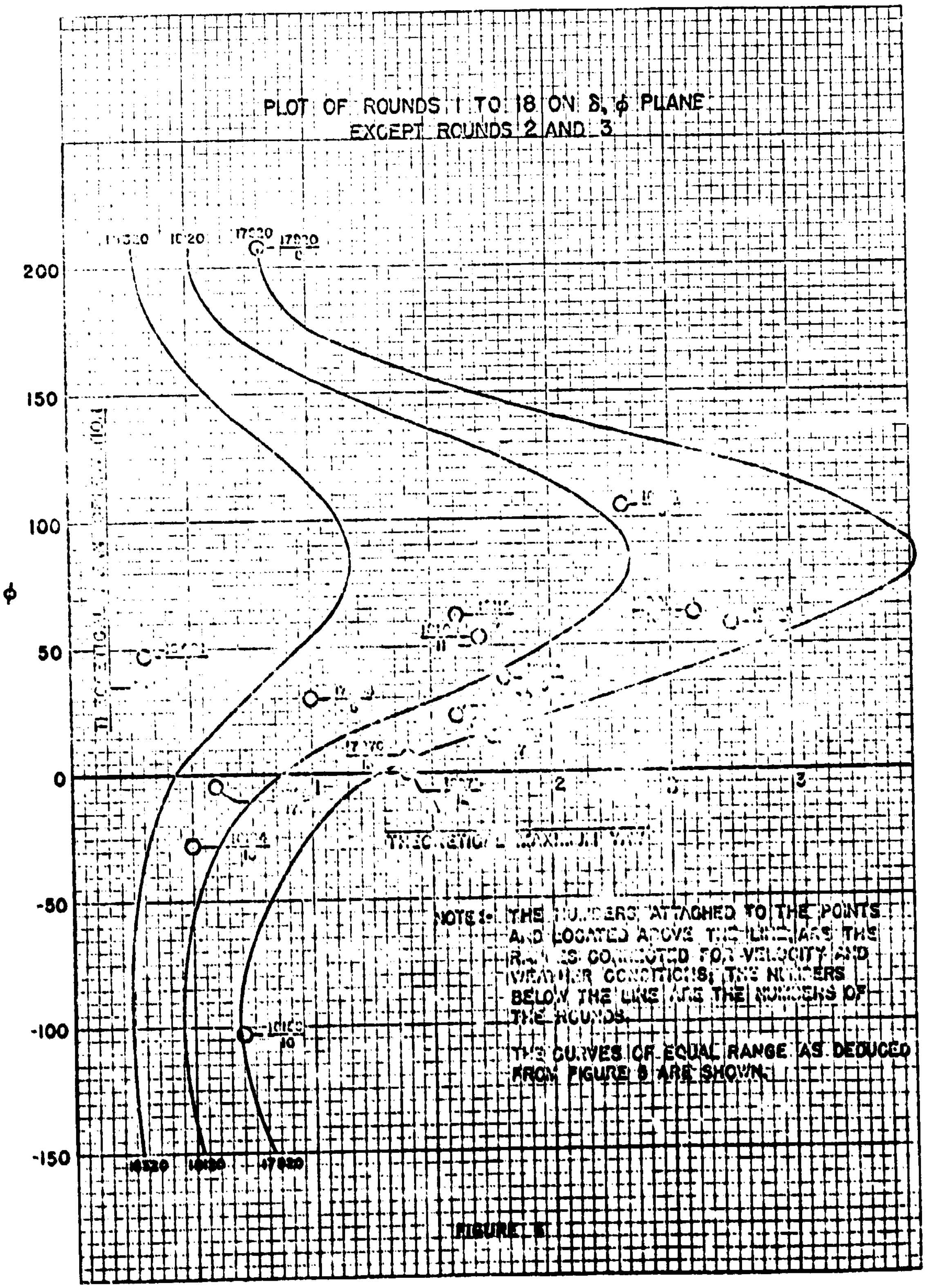


FIGURE I
DISTANCE FROM GUN (FEET)
ORIENTATION - DEG.
MAJOR AXIS (YAW) - INCHES
YAW
ORIENTATION
THEORETICAL SLOPE
0
100
200
300
400
500
600
800
12.0
12.1
12.2
12.3
12.5
$\frac{A}{B} = .004$
$r = 25$
$\ell = 430'$
FIGURE 1



900
800
700
600
500
400
300
200
100
ΔR/δ
THEORETICAL CURVE.
EQUATION:- ΔR/δ = 510-340
8
18
6
16
17
7
13
15
11
4
1
9
10
5
14
CURVE TO SHOW LOSS OF RANGE DUE TO YAW AS MEASURED AT THE SECOND SCREEN, IN CONNECTION WITH TEST OF MULTI-SECTIONAL CHARGES FOR SEACOAST GUNS.
RESULTS OF ROUNDS 1 TO 18 ARE SHOWN WITH EXCEPTION OF ROUNDS 2, 3, AND 12. ROUNDS 2, AND 3, HAD BADLY FRINGED ROTATING BANDS.
THE UNIT YAW IS TAKEN TO BE THAT CORRESPONDING TO A LENGTH OF MAJOR AXIS OF 13.1" OF THE HOLE CUT IN THE SECOND SCREEN.
LOSS OF RANGE CORRESPONDING TO INCREASE OF ONE INCH IN LENGTH OF MAJOR AXIS.
-150°
-100°
-50°
0°
+50°
+100°
ORIENTATION φ OF YAW AT SECOND SCREEN

FIGURE 5


PLOT OF ROUNDS 1 TO 18 ON δ, φ PLANE
EXCEPT ROUNDS 2 AND 3
φ
200
150
100
50
0
-50
-100
-150
1
2
3
16520
16120
17920
NOTE:- THE NUMBERS ATTACHED TO THE POINTS AND LOCATED ABOVE THE LINE ARE THE RANGES CORRECTED FOR VELOCITY AND WEATHER CONDITIONS; THE NUMBERS BELOW THE LINE ARE THE NUMBERS OF THE ROUNDS.
THE CURVES OF EQUAL RANGE AS DEDUCED FROM FIGURE 8 ARE SHOWN.

FIGURE

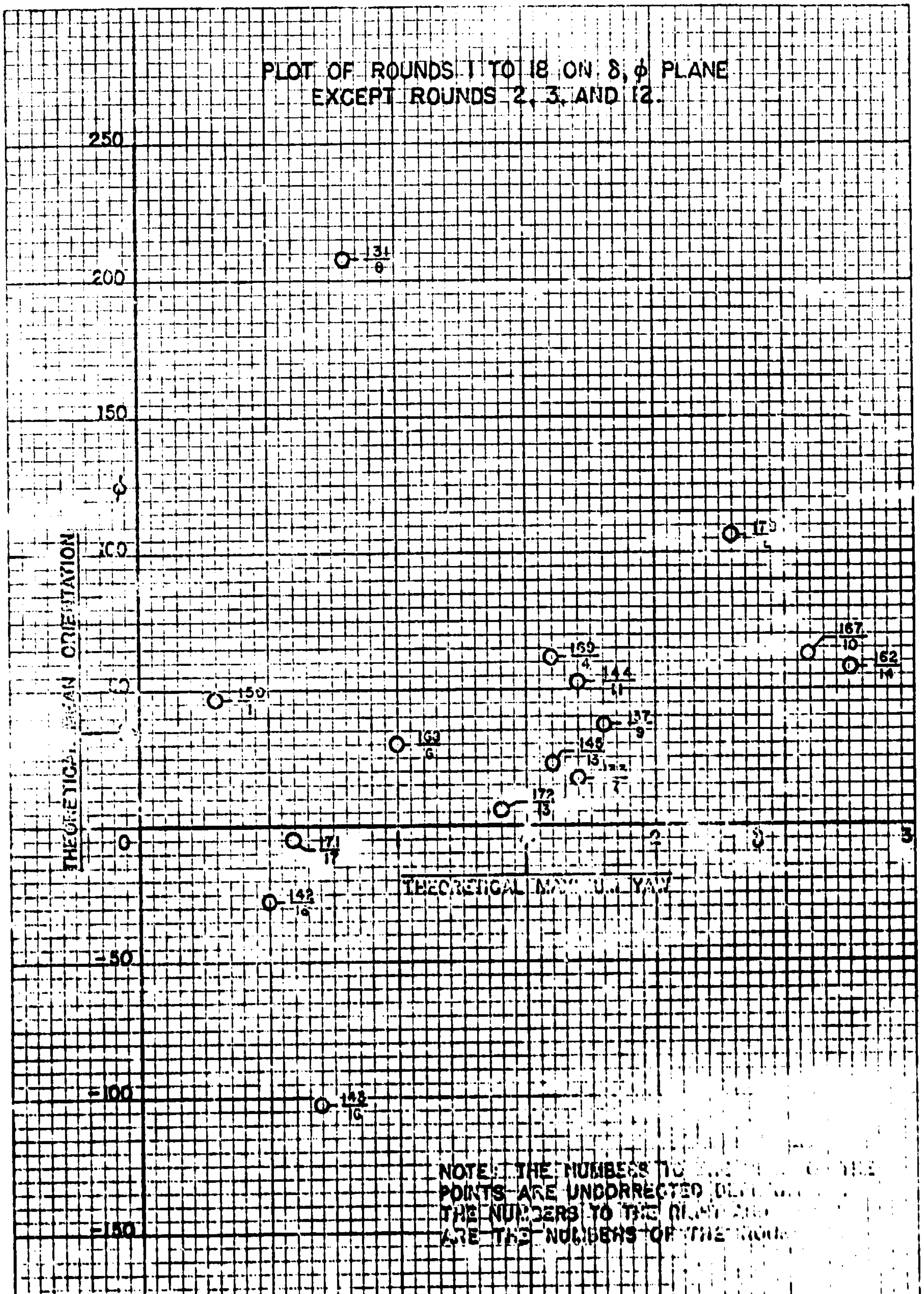
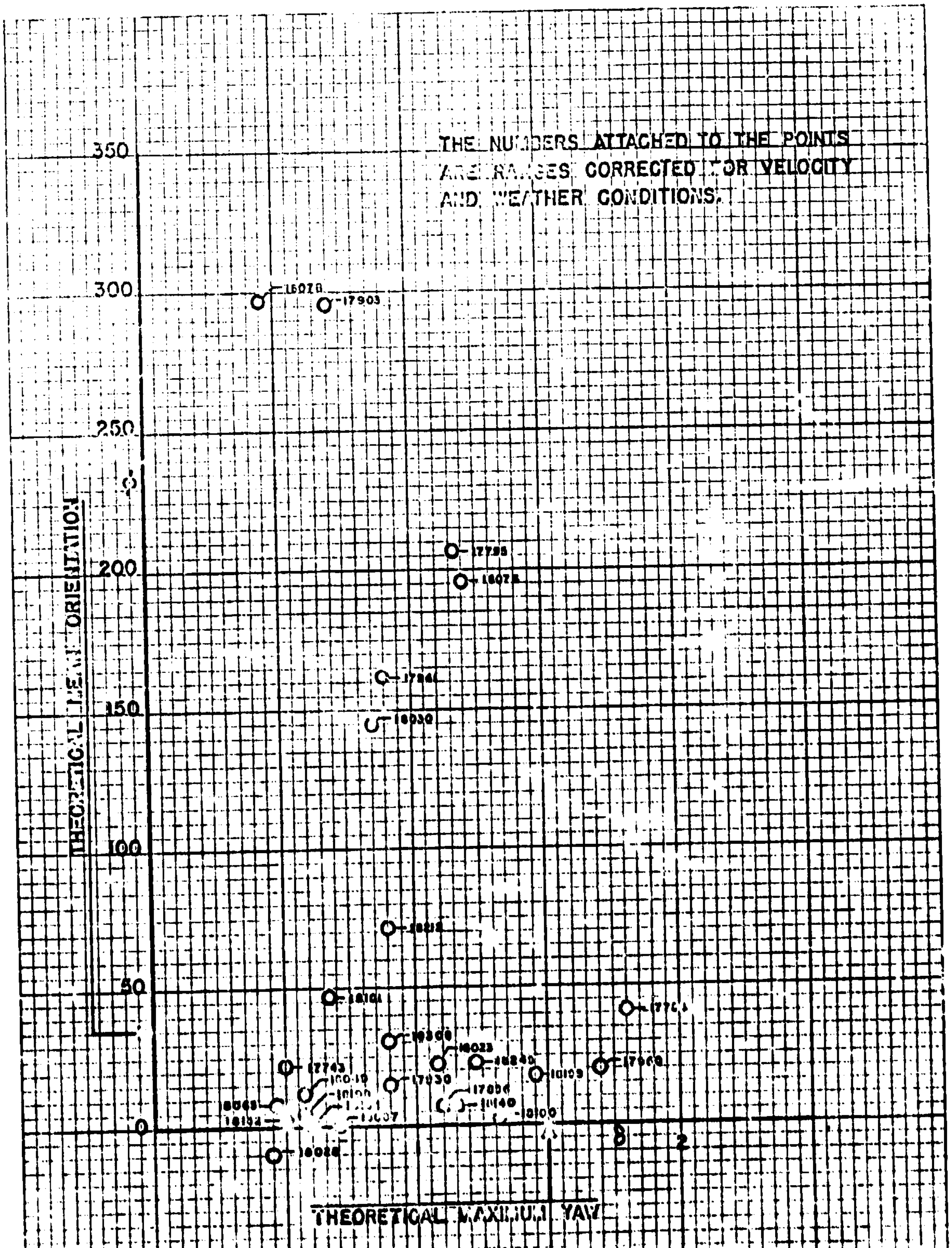

PLOT OF ROUNDS 1 TO 18 ON δ, φ PLANE
EXCEPT ROUNDS 2, 3, AND 12.
250
200
150
φ
100
0
-50
-100
-150
THEORETICAL MEAN ORIENTATION
THEORETICAL MAXIMUM YAW
NOTE: THE NUMBERS TO THE RIGHT OF THE POINTS ARE UNCORRECTED ...
THE NUMBERS TO THE RIGHT AND ... ARE THE NUMBERS OF THE ROUNDS

FIGURE 7



PLOT OF ROUNDS 19 TO 46 ON THE δ, ϕ PLANE

FIGURE 6

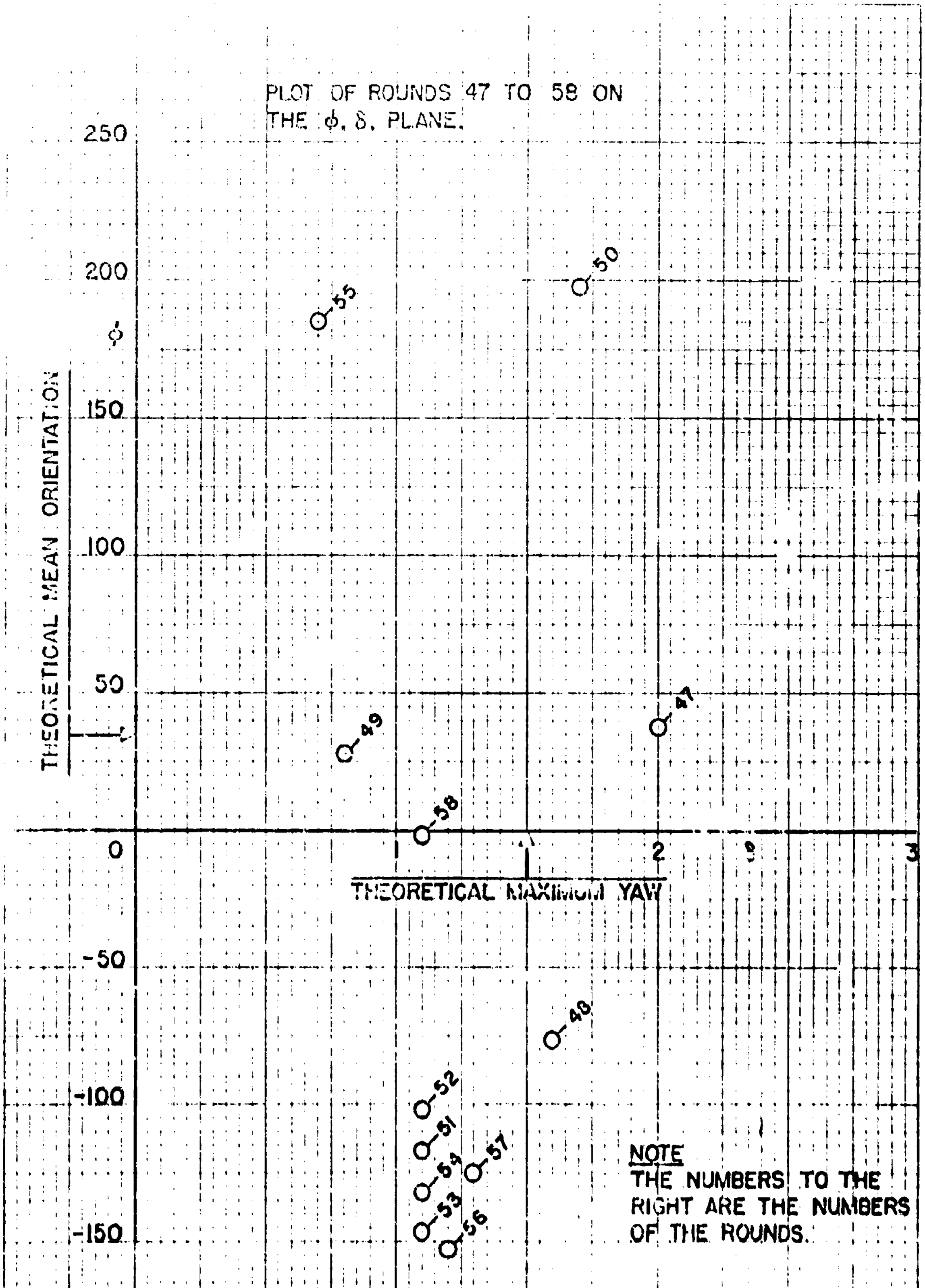

PLOT OF ROUNDS 47 TO 58 ON
THE φ, δ, PLANE.
250
200
150
100
50
0
-50
-100
-150
THEORETICAL MEAN ORIENTATION
φ
1
2
3
THEORETICAL MAXIMUM YAW
55
50
49
47
58
48
52
51
54
57
53
56
NOTE
THE NUMBERS TO THE
RIGHT ARE THE NUMBERS
OF THE ROUNDS.

FIGURE 9

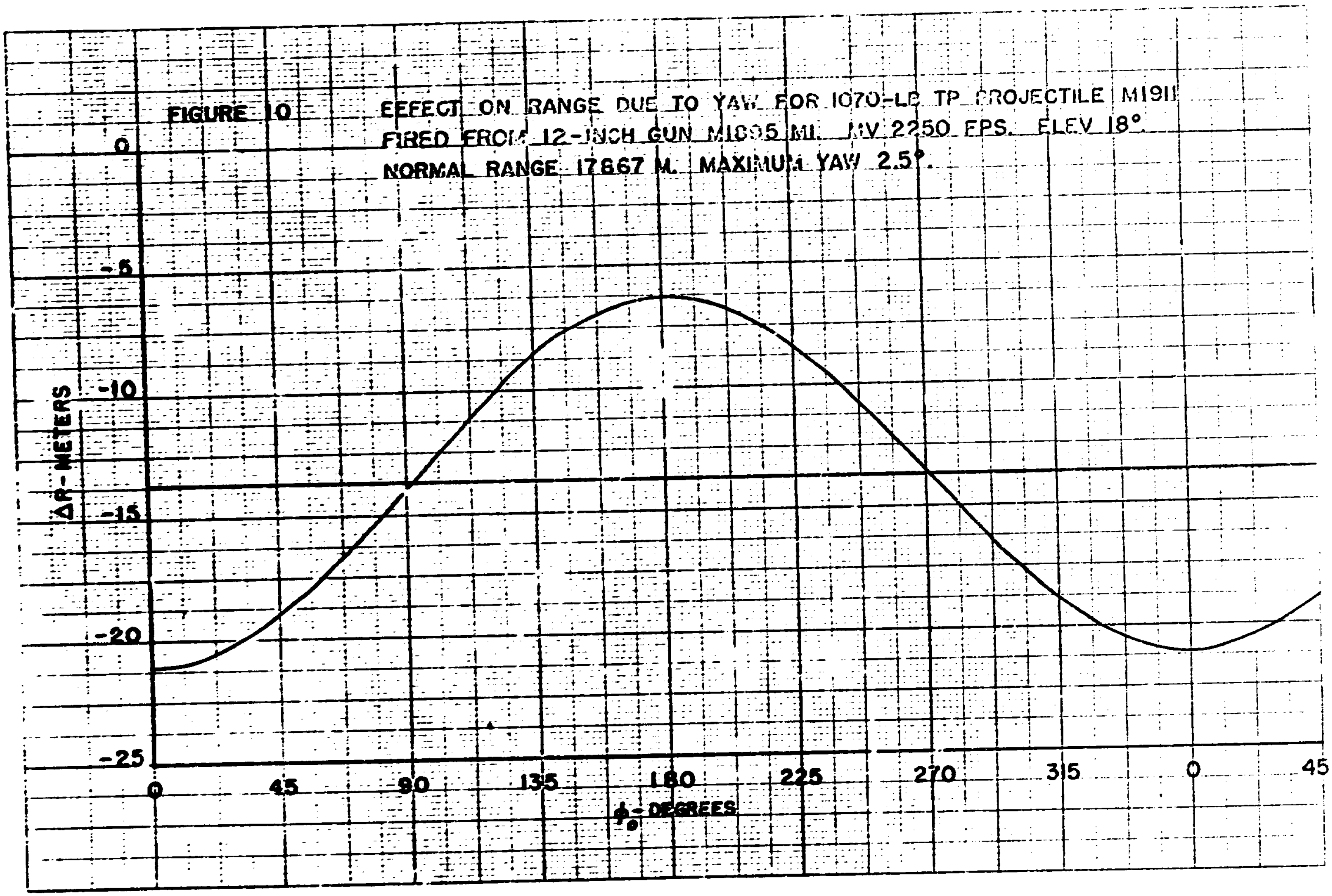


FIGURE 10 EFFECT ON RANGE DUE TO YAW FOR 1070-LB TP PROJECTILE M1911 FIRED FROM 12-INCH GUN M1895 MI. MV 2250 FPS. ELEV 18°. NORMAL RANGE 17867 M. MAXIMUM YAW 2.5°.

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