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MINISTRY OF SUPPLY

FIGHTING VEHICLES RESEARCH AND DEVELOPMENT ESTABLISHMENT

REVIEW ON June 89

REPORT No. B.R. 147

THE DETERMINATION OF THE FUNDAMENTAL CAUSES OF GUN JUMP AND DISPERSION OF JUMP.

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RESEARCH DIVISION

BASIC RESEARCH GROUP REPORT

ON

THE DETERMINATION OF THE FUNDAMENTAL CAUSES OF GUN JUMP AND DISPERSION OF JUMP

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15th June, 1959.

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ABSTRACT

This report describes an extended experimental investigation into the fundamental causes of gun jump. The work was commenced by the measurement of the vertical components of angular and linear muzzle movements (the gun axis being assumed horizontal) but, as these components of movement proved to represent only a small part of the total true jump, it was extended to the measurement of projectile yaw in the barrel and in the immediate post ejection zone. For the Q.F. 6 pr., which has a vertical bias in the orientation of yaw at ejection, it was found possible to separate the aerodynamic component of jump due to yaw conditions at ejection from (1) the component due to momentum gained in the post ejection zone and (2) that due to muzzle movement at ejection. For the 17 pr. tank mounted gun, which has a zero mean true jump and a random orientation of yaw at ejection, no such analysis could be made with an equipment measuring only one component of yaw.

It is concluded that the yaw of the projectile in the bore, the muzzle movements at the instant of ejection and the gas flow from the muzzle all make important contributions to the gun jump and dispersion of jump.

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INTRODUCTION

This report is a collection of information contained in five reports[1] issued over a period of years, two of them to the Scientific Advisory Council only, which is now made available for a wider circulation.

HISTORY OF INVESTIGATION

Investigations were first centred on the measurement of the angular displacements of a gun muzzle during the period of shot travel down the bore, the gun chosen being the Q.F. 17 pr. field piece. At the instant of ejection the measured angular displacement α in the vertical plane was found to explain only a fraction (0.3 to 0.5) of the recorded true jump ϕ_1. In the hope that the linear momentum component of jump β in the same plane would explain the remaining fraction work was extended to the measurement of the corresponding linear muzzle movements. The component β however was found to be small compared with α and an approximation to the total true jump for this gun when firing Service A.P.C.B.C. ammunition could only be explained by the rather unsatisfactory empirical relationship

$$\phi_1 = \alpha + k\beta_o$$

where β_o is the vertical yaw component of the projectile at ejection estimated from the linear muzzle movements, and k has a value somewhere within the range 10-25.

At this point the trials were transferred to the Q.F. 6 pr. in order to check an existing theory of muzzle movements for this weapon claiming full agreement with the recorded jump. This apparent agreement, however, was shown to be fallacious, the actual muzzle movements directly contributing only a small fraction of the true jump. It was further shown that the jump of this gun was increased by about -5 mins. of arc when the counterweight muzzle fitting, which results in an increased forward blast, was substituted for the muzzle brake fitting, the muzzle movements meanwhile remaining sensibly unchanged.

As at this point it was clear that for both the guns tested the muzzle movements were directly responsible for only a small fraction of the true jump it was decided to evaluate the aerodynamic component of jump (i.e. the integrated displacement on a distant target due to the precessional and nutational movements of the projectile) in terms of the initial yaw conditions.[2] Equipment was therefore devised and trials carried out to obtain information on the development of yaw both inside the barrel and in the blast zone outside. With the 6 pr. it was found the yaw in the barrel was larger than that indicated by bore clearance data but did not alter much until some 10-20 ft. from the barrel (at the end of the blast zone) where a rapid increase occurred; the yaw at ejection was found to be biased for orientation about the vertical. For the gun fitted with the counterweight a linear relationship was found between the rate of change of the vertical component of yaw δ_o and true jump, zero δ_o corresponding to a jump component (corrected for muzzle movement) of about -5 mins. of arc; now this is approximately the value of the difference between the mean jumps recorded with muzzle-ring and and muzzle brake attachments and must be assumed to be the jump component due to linear or angular momentum imparted to the projectile in the blast zone or on passing through the shock wave at the end of the zone. The theoretical coefficient of δ_o would appear to be about 25% less than that determined by experiment. A less accurate relationship was found between the yaw in the barrel near ejection and the vertical jump.

Results obtained for the 17 pr. tank proof mounting are also disoussed. This gun has a zero muzzle movement at ejection and zero M.P.I. The smaller yaw of the twin banded projectile (less than the maximum estimated on bore clearance data) and a random orientation of yaw at ejection made it impossible with an equipment measuring one component of yaw only to detect any relationship of yaw with true jump.

The project was closed before completion due to reduced interest in the problem of dispersion of tank and anti-tank guns. It is clear however from the work accomplished that the yaw of the projectile in the bore, the exact conditions (of yaw and muzzle movement) at ejection and the gas flow from the muzzle will all modify the subsequent motion of the projectile. As these effects may be expected to be accentuated under the extreme ballistic conditions of modern guns their further study is of prime importance.

Theoretical work organised by the Gun Jump Panel of the W.R.C. has advanced in hand with the experimental. As a result the experimental observations on the barrel movements of the Q.F. 17 pr. are now adequately described on elastic vibrational theory. Theoretical work on the intermediate ballistic zone tends to confirm the trends of the experimental work but is however unable to explain the magnitude of the effects noted.

PART 1

THE MEASUREMENT OF MUZZLE MOVEMENTS

PRELIMINARY RESULTS WITH Q.F. 17 PR.

(COMPILED FROM REPORT R.W.103 AND MEMO 7/51)

ABSTRACT

A photo-electric method of remote recording of angular movements of the order 0 to 12 ± 0.1 mins. arc, and capable of adaption for the remote recording of linear movements in the range 0 to 1 ± 0.002 in., has been developed for the study of the muzzle vibrations of a Q.F. 17 pr. gun over the period shot-start to shot-ejection. Successful measurements of angular muzzle movement have been made in the vertical plane containing the barrel axis.

The recorded muzzle displacements at the instant of ejection* were found to show some correlation with true jump† for A.P.C.B.C. ammunition, but none for A.P.D.S. ammunition. Investigations were later extended (R.W.103) into the simultaneous measurement of the vertical components of the angular and linear muzzle movements.

The sum of the components of jump assumed imparted to the projectile by these two movements does not agree with the shot dispersion recorded at 200 yds. where there is no evidence of yaw. Considerable yaw must occur earlier in the trajectory, however, to explain the discrepancy, and it is concluded this is developed after ejection by muzzle blast.

For Service charge A.P.C.B.C. ammunition results can be explained approximately by the relationship

$$\phi_1 = \alpha + k\,\beta_o$$

where ϕ_1 is the true jump,

α the recorded angular movement of the muzzle,

β_o the yaw at ejection developed by the recorded linear movement of the muzzle,

k is a constant of the order 10.

*Defined as "the instant the shot base coincides with the plane of the muzzle surface".

†Defined as "the angular displacement of the point of strike on the target from the direction of the bore axis at the muzzle before firing, corrected for drop of shot".

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1. INTRODUCTION

The object of the investigation was to find the extent to which the lateral movements of the muzzle section of the barrel are responsible for the shot dispersion, special attention being given to angular and linear movements in the vertical plane. A field mounting with its unbalanced recoiling masses was chosen for preliminary work with the hope that results would show similarity with those calculated for such a system on the theory of Lee, Sneddon and Parsons.[4] The measurements were initiated at the request of the Ordnance Board.[2]

As far as is known previous successful experimental work in this field has been the direct optical recording of the muzzle movements of small arms fired in the laboratory,[3] no successful recording with large calibres having been achieved. Calculations of lateral movements have been made, however, for the 6 pr. anti-tank gun.[4]

Methods suggested in O.B. Procs.[5] are:-

(1) A direct recording of angular movements by means of an optical lever method, light reflected from a mirror rigidly attached to the barrel being brought to a focus on the drum of a recording camera (Prof. S. Chapman).

(2) A photo-electric recording of linear movements, in which a signal is generated by variation in the obstruction of a beam of parallel light by means of a straight edge rigidly attached to the barrel.

Mention is also made of an accelerometer method tested by A.R.E. and abandoned due to the difficulty of preventing components of the relatively high recoil acceleration from obscuring the small lateral signals under observation.

The method described in the present report uses a mirror attachment as for method (1), but avoids the mechanical difficulties of both methods (1) and (2), resulting from ground shock and gun recoil, by incorporating an optical unit with photo-electric signal conversion mounted remotely to the rear of the gun, and giving an output suitable for electro-magnetic oscillographic recording. Both angular and linear movements can be recorded simultaneously from a single mirror attachment on the barrel. The method is insensitive to recoil movements of the barrel.

2. DESCRIPTION OF EQUIPMENT

2.1 The Optical System for Angular Movements (Fig. 1)

For vertical movements light from a horizontal ribbon filament lamp* (S) is projected in a parallel beam, from a site directly behind the gun, on to a right-angle mirror prism (P) mounted rigidly on the gun barrel at a distance approximately 50 ft. from the projection lens (L_1). Some of the incident light is reflected back along a path making a small angle with the incident beam, and is collected by a lens of large surface area (L_2) mounted on the same rigid framework as, and immediately below, the projection lens (L_1).

A vertical Vee slit (V) is adjusted to the image distance of the horizontal ribbon filament from the lens L_2, so that any angular movements of the reflected beam will affect the amount of light passing the slit (Fig. 2).

Any stray sky light entering the system is blocked by a circular stop (O) mounted at the image distance of the prism mask (circular or square). The remaining light passing the slit-stop system is dispersed by means of a simple lens (L_3) on to the photo cathode of an electron multiplier (M), suitable neutral filters being interspersed to ensure correct working conditions for the multiplier. The multiplier output is D.C. coupled to a cathode follower output stage (C), matched approximately to the output cable impedance, and feeds into one strip* of an electro-magnetic oscillograph installed in the laboratory some 50 ft. distant.

The total angular movement to which the equipment can respond is controlled by the diameter of the collecting lens and the distance of this lens from the muzzle prism. With the set-up as described the maximum recordable movement is about 12 mins. arc.

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*Edison Microscope Illuminator 6V. 18A.

2.2 Method of Mounting the Prism on the Barrel (Figs. 3, 4)

For vertical angular movements the right angle prism is mounted with its "axis" (the direction of the three parallel edges) in a vertical plane containing the barrel axis, and the refracting surface approximately perpendicular to the barrel axis; the reflected beam is thus unaffected by angular movements in the perpendicular plane. A few degrees inclination of the prism axis with the plane normal to the barrel axis is necessary for adequate clearance of the operational light beam over gun and mounting.

The prism mount which is of steel, is welded to the barrel at a distance 6.5" from the muzzle surface, use of the muzzle brake not permitting any reduction of this distance. The prism is cemented into the mount with bitumen thus making a rigid assembly of high natural frequency.

For movements in line the prism is mounted with its axis horizontal and with the refracting surface still approximately perpendicular to the barrel axis, a few degrees inclination again being necessary to clear obstructions. The image of the ribbon filament is now made vertical before projection by means of a prism system (the lamp cannot be used with the filament vertical) and the Vee slit is mounted with its axis horizontal.

For linear movements an inclination of the prism axis with the plane normal to the barrel axis is not permissible, or a sine component of the barrel recoil movement will be added to the required signal. Inclination of the light beam for clearance purposes must now be restricted to the plane containing the barrel axis which is perpendicular to the required movement.

2.3 Mounting and Alignment of the Optical Projection and Signal Conversion Unit

The existing optical unit for vertical angular movements which has approximate overall dimensions of 6' 6" x 2' x 2', is mounted on a 12 pr. gun pedestal mounting so that the elevation and traverse mechanisms are available for sighting the unit on to the muzzle prism. The gun is adjusted in elevation and approximate line so that the reflected beam enters the collecting lens L_2 centrally, successive adjustments of gun and optical unit being necessary to ensure the best adjustment. A viewing screen and cross wires are fitted (not shown in figure), light being deviated from the photo-sensitive surface of the multiplier during the adjustments by means of a right angle prism.

2.4 Calibration Devices for Angular Movements

Two calibration devices have been constructed to date both automatic and both applying known axial movements to the Vee slit. The first of these (Fig. 5) provides a satisfactory 4-step movement of 2 m.m. per step, corresponding to 2.4 mins. arc per step, in an operation time of $\frac{1}{5}$ sec. This is too slow for automatic calibration at the start of a record of total exposure of the order $\frac{1}{25}$ sec., and necessitates a separate exposure at a lower camera drum speed.

The second of these devices (Fig. 6) has an operation time of $\frac{1}{40}$ sec. and provides mechanically an approximate damped sinusoidal displacement of two positive and two negative maxima, followed by a zero with negligible residual vibration. The use of this calibration device reduces danger of error due to:-

(a) variations in beam intensity caused by atmospheric absorption or filament current fluctuation,

(b) drift in the photo-multiplier and amplifier system,

(c) any mechanical disturbance of the gun or optical unit.

2.5 Optical System for Linear Movements (Figs. 7, 8)

For vertical linear movements the optical system for angular movements is modified by replacement of the Vee slit by a horizontal straight knife edge at the image position of the muzzle prism mask (now preferably rectangular).

Vertical linear movements calculated for the 6 pr. anti-tank gun[4] are negative in sign and of the order 0.03 in. at the instant of ejection (Fig. 12). Assuming this movement for the 17 pr. then an image movement of only 0.002 in. will be obtained. This can be increased

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[M] Siemens & Halske Type 2; N.F. 10 KC/S.

conveniently to 0.008 in. by an additional lens (L_4) when the image of the 1 in. prism mask is 0.27 in. Further magnification is undesirable on account of the limited area of the photo sensitive surface of the multiplier tube (approximately 1 x $\frac{1}{2}$ in.).

The expected linear muzzle movement is thus small and of negative sign. This fact permits that the knife edge may have an initial adjustment blocking off most of the image (Fig. 8), and giving the low level illumination to the photo-cathode (achieved by the use of filters in the angular movement equipment) necessary for satisfactory operation of the photo-multiplier.

As the linear movement signal is proportional to the total reflected light from the prism collected by the lens (L_2), care must be taken that vertical angular movements of the beam do not cause variation in cut-off. A vertical parallel slit system at the lens (L_2) surface or at the filament image would guard against this possibility.

The conversion of the system for measurement of linear movements in line would be as described for angular movements (see 2.2).

2.6 Calibration for Linear Movements

The development of an accurate and purely mechanical step-like calibrator for the small total linear movements involved (0.002-0.008") was considered impracticable. The method finally adopted is given at para. 7.

2.7 Optical System for Combined Angular and Linear Movements in One Plane

A single optical unit giving signals of both angular and linear movement in one plane, and operating from a single muzzle prism, was constructed. Light from the single collecting lens of the unit is split into two parallel beams by a semi- and fully-silvered mirror system, angular and linear signals being separated as described in para. 2.1 and 2.5. (See para. 7.)

3. ACCURACY OF MEASUREMENTS

The sensitivity of the system for angular measurement is such that a 1 in. deflection in the oscillograph trace is approximately equivalent to 6 mins. arc movement.

Neglecting errors due to fluctuation in beam intensity, drift in the electronic equipment, and mechanical disturbance to the equipment (permissible when the calibration is automatic or taken at a short interval prior to recording) the essential remaining errors are those introduced by the calibration device and those of record measurement.

Errors of the two types of calibrator (2.4) have been investigated by a direct optical recording method and are negligible for the $\frac{1}{5}$ sec. type (mean error 0.01 min. arc), but have a mean value of 0.08 min. arc for the $\frac{1}{40}$ sec. type. Errors of record measurement using a plane graticule and lens are of the order 0.06 min. arc (corresponding to $\frac{1}{100}$" displacement). The total probable error is thus of the order 0.06 min. arc using the $\frac{1}{5}$ sec. type calibrator, and 0.1 min. arc using the $\frac{1}{40}$ sec. type.

For linear movements the normal sensitivity will be of the order 1 in. record deflection per 0.06 in. barrel movement. Calibration errors and random vibrations will probably be the limiting factors to accuracy. It is hoped however to record to better than 0.002 in.

4. SUBSIDIARY MEASUREMENTS

4.1 Shot Dispersion

Recording is by jump card at 200 yds. range, and sighting by F.V.R.D.E. type muzzle boresight, the accuracy of which has been improved by the use of a special breech telescope of magnification X25 to better than 0.1 min. arc (Fig. 9).

In order that the final angle of lay should be known to high precision after the inevitable disturbances to the barrel on removal of the sight and on loading, the angular positions of a prism mounted rigidly on the breech block (Fig. 9) are observed by theodolite situated to the rear of the gun. The normal procedure is to take a theodolite observation for each of 5 lays of the gun on the target by muzzle boresight, and

also for the final lay (by Clino and Gun Sight) after loading. The deviation of the final lay from the mean muzzle boresight lay is then known to an accuracy (d_1) better than 0.1 min.

Drop of shot is estimated from the measured time of flight to the target (by S.V.A.). For A.P.C.B.C. ammunition the T.O.F. at 200 yds. = 0.208 secs. and an error of measurement of 1 in 300 would give an error in the angular drop as observed from the gun d_2 = .03 min. arc. For H.E.R.C. which is the worst case for the 17 pr., with T.O.F. 0.347 secs., the same fractional error 1 in 300 would result in an error d_2 of .07 min. arc, and for A.P.D.S. (T.O.F. = .15 secs.) d_2 = 0.013 min. arc.

The accuracy of the jump card measurement (d_3) is of the order 0.03 min. arc ($\frac{1}{16}$ in. at 600 ft.). Hence the probable error in true jump estimation is

$$\sqrt{d_1^2 + d_2^2 + d_3^2}$$

or 0.11 min. arc for A.P.C.B.C., 0.12 min. arc for H.E.R.C. and 0.10 min. arc. for A.P.D.S. ammunition.

4.2 Ejection Signal (Fig. 4)

For ejection signal a record is made of the discharge current of the condenser when circuit is completed through two insulated contact pins, situated at the muzzle, by the 1st driving band of the projectile. The pins ($\frac{1}{10}$ in. dia. hardened steel rod with pointed ends) are clamped in screwed plug-form holders mounted in diametrically opposite drillings in the muzzle brake, so that the pins just clear the muzzle surface. The pins are positioned accurately with the aid of a special feeler gauge, so that the pointed ends are midway between land and groove surfaces. In evaluation of the record for ejection time, a small correction is made for the distance point of contact to base of shot. An auxiliary method of indicating ejection, viz. the recording of hoop strain near the muzzle (6 in. from muzzle surface) by wire strain gauge, is used to cover the event of failure of the contact pin system, and is the only ejection signal available when the gun is fired without the muzzle brake. The hoop strain signal is more complex than the contact pin signal, and is accurate only if related to the contact pin signal.

4.3 Chamber Pressure Measurement

The hoop strain at the forward end of the chamber is recorded by wire strain gauge, and gives an approximate pressure-time curve to indicate shot start, maximum and muzzle pressures.

4.4 The Measurement of Lateral Bending of the Barrel by Wire Strain Gauge

Some recordings of mean lateral bend in the vertical and perpendicular planes have been made on a 9 in. parallel walled section of the barrel of mid-point $11\frac{1}{4}$ in. from the muzzle surface.

5. TIMING OF EVENTS AND SIMULTANEOUS RECORDING OF SIGNALS

The oscillograph and drum camera used for the recording was a German 6-8 channel ballistic electro-magnetic type (Rheinmetall Borsig and Von Ardenne). Events were timed from the 6 commutators of the oscillograph in the following sequence:-

1. Gun firing via special release switch (Fig. 10).
2. Shutter opening.
3. Calibration release for optical units.
4. Calibration (when used) for strain gauge circuits.
5. Shutter closing.

The recording drum is 1 m. circumference, takes 7 or 20 cm. paper, and will run up to a speed of 50 r.p.s. A maximum of 7 signals can be recorded simultaneously, the 8th strip being reserved for a 1,000 c/s timer.

Muzzle velocity and time of flight to the target were recorded (by S. of E. Shoeburyness) with separate equipment.

6. PRELIMINARY EXPERIMENTAL RESULTS

6.1 Comparison of Calculated Movements for the 6 Pr. Anti-tank Gun with Q.F. 17 Pr. Anti-tank A.P.C.B.C. Recordings

The only available guide on expected results is the calculation for the 6 pr. Anti-tank gun made in an A.R.D. Theoretical Report[4] previously mentioned, in which flexural vibrations in the vertical plane are considered as due to the reaction of the recoiling masses, the centre of gravity being below the bore axis. These results are reproduced in Figs. 11 and 12 and should apply to the general form of the 17 pr. movements on firing A.P.C.B.C. ammunition. It will be seen that both angular and linear muzzle displacement at ejection is negative. The linear displacement is small (0.028 in.) but gives rise to a lateral linear velocity at ejection of 1.9 ft./sec. and a negative jump of the order 2.25 mins. arc for a mean shot velocity to the target (as in the present 17 pr. trials) of 2,900 ft./sec.

To date only angular measurements in the vertical plane have been made, although preparations are well advanced for the measurement of linear movements as described at 2.6. In general the experimental curves obtained are of the same form as those calculated for the 6 pr. i.e. the angular movement at ejection is negative following a positive rise (see Fig. 13). A feature not shown in the calculated curve is the initial negative movement starting soon after shot start (1 to 2 x 10^{-3} secs.) and continuing until about 6.4 x 10^{-3} secs. after, with a maximum of about 1 min. arc at 4 x 10^{-3} secs., and superimposed upon which is an approximate sinusoidal vibration of about 1,000 c.p.s. The maximum positive signal (of the order 2 mins. arc) occurs at a mean 8.4 x 10^{-3} sec., a zero signal at a mean 9.2 x 10^{-3} secs. and the negative ejection signal (upon which the curves are synchronised) of the order 3 mins. arc at 10 x 10^{-3} secs. On the 3 curves of Fig. 13 ejection occurs when the muzzle has small angular velocity. The signal after ejection has no significance as it is confused by smoke and flash.

A sharp negative impulse at 8.2 x 10^{-3} secs. after shot start is a common feature of all three rounds and may be caused by impact of the slipper on the gun cradle after initial clearance has been taken up by flexure of the barrel.

6.2 Radial Vibrations of the Muzzle (Figs. 14, 15, 16, 17)

Early records of vertical angular movement were obtained with the prism mounted at 12 o'clock on the barrel. Rounds were fired with A.P.D.S., H.E., and A.P.C.B.C. ammunition, and in all cases the records obtained were complicated by vibrations of a constant frequency, viz. 3,300 c.p.s.

The sample results given (Fig. 14) for these 3 types of ammunition show a maximum double amplitude of this frequency near or at ejection of 5.4, 3.8 and 3.6 mins. arc respectively.

It was considered that these vibrations were either due to the flexibility of the prism mount, or to radial barrel vibrations. The frequency recorded however does not correspond to a simple hoop vibration of the barrel such as given by the formula

$$f_h = \frac{1}{2\pi} \cdot \frac{1}{R} \sqrt{\frac{E}{\rho}} \qquad \ldots \ldots \ldots \ldots \quad (1)^6$$

(R = mean radius, ρ = density, E = Young's Modulus)

which gives a natural frequency of the order 20,000 c.p.s. (for R = 1.825").

The fundamental mode of radial flexural vibration of a ring g given by the formula

$$f_n = \frac{1}{2\pi} \sqrt{\frac{n(n^2 - 1)}{n^2 + 1}} \cdot \sqrt{\frac{EI}{\mu_1 R^4}} \qquad \ldots \ldots \ldots \quad (2)^7$$

(μ_1 = mass per unit length of ring, EI = bending stiffness)

gives the closer approximation of 5,500 c.p.s. The loading effect of the muzzle brake may account for the lower observed frequency (3,300 c.p.s.).

(N.B. Hoop strain records seem to indicate a natural frequency of the order 4-5,000 c.p.s. at the prism position (Fig. 15), and 5,460 c.p.s. when measured 3 ft. from the muzzle surface and after ejection (Fig. 17).)

Further records of vertical angular movement were taken with the prism mounted at 3 o'clock (as observed from the breech - Fig. 3) so that any radial component would be eliminated from the measurement. The improvement in this respect is marked as can be observed in Figure 16.

6.3 Lateral Bending of the Barrel by Wire Strain Gauge (Fig. 17)

Records obtained for vertical bending near the muzzle by wire strain gauge have approximately the same form as those obtained with the optical system, while the corresponding bending in the perpendicular plane is smaller and of different form.

6.4 Effect of Muzzle Brake on Vertical Angular Movement (Fig. 18)

The two examples given are a comparison of vertical angular movement for A.P.D.S. ammunition with and without the muzzle brake. It will be seen that the two curves are closely similar, indicating that the muzzle is near a node of the lateral vibration. The comparison has not yet been made for other ammunitions.

6.5 The Effect of Ground Shock on the Optical System for Angular Movements

Insufficient ground - about 25 ft. of moist sand - separated the spades of the gun carriage from the optical unit mounting to ensure complete safety from ground-shock up to the instant of ejection.* Therefore a test was made in which the optical unit was rotated through an approximate 180° in azimuth and sighted on to a prism mounted on a tripod 50 ft. distant i.e. 75 ft. distant from the spade of the gun carriage. The gun was fired on the normal line and an oscillograph record made. No disturbance was recorded either before or after ejection and it was concluded that no error was introduced by ground shock in the normal recording of angular muzzle movement.

6.6 Correlation of Point of Strike on the Target with Recorded Angular Movements at the Instant of Ejection

The vertical angular displacement from the sighted axis of the gun muzzle as indicated on the target (ϕ) is assumed to be built up of the following components:-

(i) Angular equivalent of gravitational drop of shot, neglecting air resistance,

$$\gamma = \tfrac{1}{2} g t^2/b$$

(t = T.O.F., b = target distance).

(ii) Angular displacement of the muzzle at the instant of ejection, α.

(iii) Ratio of the vertical linear velocity of the muzzle at ejection to the average velocity of the projectile in its flight to the target,

$$\beta = \frac{1}{V} \cdot \left(\frac{dy}{dt}\right)_{t_o} \text{ /}$$

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*Vel. of compression wave in damp sand = 2,000-6,000 ft./sec.

/N.B. The existence of a vertical linear muzzle displacement results in an initial motion of the c.g. of the projectile making an angle

$$\beta_1 = \frac{1}{V_1} \cdot \left(\frac{dy}{dt}\right)_{t_o}$$

(V_1 = Muzzle Velocity)

to the axis of the bore at the muzzle, and indicates an initial yaw of this amount. This yaw would contribute to the precessional error ψ.

(y = vertical displacement
V = mean projectile velocity to target
t_o = instant of ejection).

(iv) Component due to momentum imparted to projectile at or after the instant of ejection, θ.

(v) An aerodynamic component ψ due to precessional and nutational movements of the projectile in its flight to the target, and resulting from initial yaw β. Possible components of yaw are as follows:-

(a) δ_o due to clearance in barrel.

(b) δ_ω due to angular momentum imparted to projectile by the barrel at the instant of ejection.

(c) δ_β due to lateral linear momentum imparted to the projectile by the barrel at the instant of ejection.

(d) δ_1 yaw due to blast gases in post ejection period. Any initial yaw would be exaggerated by this blast region and thus δ_1 should be a function of this yaw. Say

$$\delta_1 = A(\delta_o + \delta_\omega + \delta_\beta) \qquad (3)$$

Assuming first that the precessional component of jump ψ can be neglected when no yaw is evident on the jump card at 200 yards, as was the case for the majority of A.P.C.B.C. rounds, then a measure of β would complete the analysis, residual errors being considered as due to θ.

i.e. $\phi = \gamma + \alpha + \beta + \theta + \psi$

or true jump

$$\phi_1 = \phi - \gamma$$

$$= \alpha + \beta + \theta + \psi \qquad (4)$$

A 100% correlation of ϕ_1 with α cannot therefore be expected unless the remaining terms β, θ and ψ are negligible. It has already been shown at 6.1 that β (calculated) for the 6 pr. is not negligible. The factors θ and ψ are unknown but should be small for an accurate gun and ammunition.

Rounds were first fired without theodolite observation of final lay as described at 4.1, and recorded results were as follows:-

(1) A.P.D.S. Service charge (Fig. 19) - no apparent correlation between ϕ_1 and α presumably due to relatively high combined components of β, θ and ψ.

(2) A.P.C.B.C. Service charge (Fig. 20) - a spread of ϕ_1 of -5 to +0.4 mins. arc corresponding to an α of -2.5 to +1 min. arc and giving a mean ratio $\alpha:\phi_1$ of approximately 0.5 assuming a straight line relation through the origin. The maximum deviation from the straight line is about 1.5 min. arc. It was considered that the low value of the mean ratio $\alpha:\phi_1$ was due to a large component β and possibly θ, and that random errors were due chiefly to the unknown components β and θ, and to disturbance of the gun on loading, the final laying check being by gun sighting telescope and clino of 1 min. arc accuracy. For these rounds there was little evidence of yaw on the target card to indicate a possible precessional component ψ.

Laying accuracy was now improved by theodolite observation to better than 0.1 min. arc and further rounds were fired as follows:-

(3) A.P.C.B.C. Service charge (Fig. 21) - a group of 7 rounds giving close agreement as follows:-

Mean ϕ_1 = -8.2 mins. arc, M.D. = 0.25 mins. arc.

Mean α = -3.0 mins. arc, M.D. = 0.28 mins. arc.

A warmer round gave

ϕ_1 = -5 min. arc; α = -2.25 min. arc.

A mean ratio $\alpha:\phi_1$ for this group is 0.37. There was little evidence of yaw for these rounds.

It should be noted that the mean jump ϕ_1 for this group is greatly in excess of figures obtained at (2) above, and of the mean true jump for the ammunition (-3 mins. arc). This discrepancy can be attributed only to different trail lodgements for the different series.

(4) A.P.C.B.C. reduced charges (Figs. 22, 23) - a group of 13 rounds* covering the M.V. range of 1,920-3,100 ft./sec. in 6 charges were fired to determine if a constant mean ratio $\alpha:\phi_1$ existed for varying M.V.s and presumably varying α.

Such did not prove to be the case however, nor did ϕ_1 have any apparent relationship to the M.V., but α appears to vary continuously with M.V., showing that the bulk of the random errors are in the combined factors β, θ and ψ. The two Service rounds fired in this group (Rd. Nos. 69 and 70) showed on the target a considerable yaw and a displacement to the right of over 4 mins. arc.

6.7 Effect of Variations in Muzzle Velocity on Vertical Angular Muzzle Movements for the A.P.C.B.C. Projectile (Fig. 24)

The figure gives five recordings of vertical angular movements, over the period shot start to ejection, for five of the charges reported at 6.6(4). Gradual transition features with varying M.V. can be observed in addition to that already noted for α (Fig. 23) and are given in Table 1. Of particular interest is the sharp negative impulse previously observed for the Service charge (Fig. 13 para. 6.1) and attributed to impact of the slipper on the gun cradle, which recedes in time from the instant of ejection with progressive reduction of M.V. For the bottom two charges B and A an additional negative maximum is attained close to the instant of ejection.

Table 1

Charge			Recorded M.V.	Time of Events in 10^{-3} Secs.				
				Maxima		Zero Signal	-ve Impulse Measured from Ejection	Ejection
Type	Weight	Propellant	ft./sec.	-ve	+ve			
E	8 lb. 2 oz.	N.H. .055	3038	6	-		1.7	10
D	7 lb. 3 oz.	N.H. .055	2747	6	7.6	7.6	1.9	11
C	4 lb. 12 oz.	NF/S .116 - .036	2459	6	8.7	8.7	2.1	12
B	4 lb. 1 oz.	NF/S .116 - .036	2164	8.8) 13.6)	11	11.0	2.5	14
A	3 lb. 5 oz.	NF/S .116 - .036	1917	8.6) 14.5)	10.6	10.6	3	14.5

7. METHOD FOR LINEAR MOVEMENTS

Measurements were first attempted with a modified angular equipment in which an image of a rectangular mask framing the muzzle prism (in distinction to the image of the ribbon filament) was focussed on to a horizontal knife edge. Automatic calibration was achieved by attachment of the knife

*Ammunition made up by S. of E. Shoeburyness.

edge to a quartz bimorph element, of natural frequency of the order 200 c.p.s., and damped in silicone oil. A sudden change in potential of the order 1 K.V. gave an adequate deflection, 2×10^{-3} ins., the amplitude of which was checked by microscope; the equivalent movement at the gun muzzle being 30×10^{-3} ins.

Both angular and linear systems were incorporated in a dual equipment using common lenses, source of illumination, and muzzle prism. The reflected beam was aligned accurately parallel with the axis of the barrel at the muzzle so as to avoid components of recoil movement showing in the linear system, use being made of a special reflecting rhomb to deviate the beam past obstructions.

The linear displacements at ejection recorded with this system were larger than expected; no relationship between $\alpha + \beta$ and ϕ_1 was evident.

Sources of error were investigated and it was found that:-

(i) For large angular movements some light was obstructed by the lens aperture.

(ii) Torsional movements of the barrel (>12 mins. arc) could produce a mean linear movement of the prism greater than the linear movement of the barrel axis.

The equipment was therefore redesigned to overcome these difficulties, the angular unit being separated from the linear and lined up with the existing prism some 3° to the side of the barrel axis; the linear unit was sighted on to an independent light source mounted at 12 o'clock on the muzzle section of the barrel by means of a 6 inch stem, this being necessary to obtain an unobstructed line of sight parallel to the barrel axis. (The light source was an overrun 60 watt motor head lamp with an opal diffusing screen suitably masked to give a rectangular area of uniform brilliancy.) With this arrangement angular movements of the lamp support and barrel, including the torsional movements, do not give rise to appreciable errors in recorded linear movement.

Stray light into the linear system was reduced to a minimum by providing a black background to the source and by fitting a tubular sun shield over the collecting lens. Under the worst conditions calibrations carried out with a blacked out source showed that stray light was responsible for less than 10% of the total signal. Overall sensitivity is of the order 1 inch deflection per 15×10^{-3} ins. muzzle displacement.

8. RESULTS OBTAINED FOR LINEAR MOVEMENTS (Figs. 28 and 29 and Table 2)

Records obtained with the Service charge A.P.C.B.C. in general show similar features consisting of a gradual positive displacement commencing at 6×10^{-3} secs. before ejection, reaching a maximum of between 3×10^{-3} and 30×10^{-3} ins. at about 2.5×10^{-3} secs and a gradual drop to and beyond ejection.

Except for one round (Rd. 182) exhibiting a large amplitude high frequency angular vibration at ejection the Service charge (Charge F) gave negative or zero values for the vertical velocity at ejection; the equivalent angular movement to the target, β, is small, varying from 0 to -0.6 mins. of arc for a true jump ϕ_1 varying in the range -1.2 to -7.5 mins. of arc; the reduced charge (Charge A) gave small positive values for β.

9. RELATIONSHIP OF RECORDED ANGULAR AND LINEAR MOVEMENTS AT THE INSTANT OF EJECTION WITH TRUE JUMP

The correlation plot (Fig. 26) of α and β versus ϕ_1 for 23 rounds of the Service charge (Charge F) shows a wide scatter in observations, giving a mean ratio $\alpha:\phi_1$ of 0.46 and $\beta:\phi_1$ of 0.024.

The reduced charge (Charge A) for the 4 rounds fired gave higher values of α (mean -7 mins.) resulting in a mean ratio $\alpha:\phi_1$ of unity, the mean ratio $\beta:\phi_1$ being -0.04 (see Fig. 27). An earlier recording for Charge A (Rd. 75) gave α = -0.1 min. (see Table 3); it is thought the increase in α for the present series is due to the out of balance inertia of the light-source attachment mounted on the muzzle.

It is clear from the results that:-

(1) The linear muzzle movement provides a negligible direct contribution to jump.

Table 2

Simultaneous Measurements of Angular and Linear Movements in the Vertical Plane

Rd. No.	Charge	M.V. ft./sec.	ϕ_1 mins. of arc	α mins. of arc	$\dot{\alpha}$ mins. of arc per sec.	Linear Displacement x 10^3 ins.		β mins. of arc
						Max.	At Ejection	
156	F	2,870	-3.3	-1.6	-1,900	+8	+3.8	-0.25
157	"	2,852	-5.6	-1.6		+25	+20	-0.27
158	"	-	-4.8	-1.4		+32	+15	0
159	"	2,848	-7.5	-1.4		+22	+11	-0.57
161	"	2,851	-1.2	-2.2		+3	-1.5	0.
162	"	2,865	-3.8	-2.8		-12	-12	-0.51
163	"	-	-2.8	-2.4	-6,200	+5	+1	0
164	"	2,809	-6.8	-2.4	-1,200			-0.1
165	"	2,844	-5.0	-1.4	-3,500		0	0
166	"	2,836	-2.3	-0.25	-2,800			0
180	"	2,894	-2.7	-0.2	-2,200	+9	+3	-0.22
181	"	2,874	-3.7	-0.3	-1,000	+4	+2	0
182	"	2,886	-2.4	-0.6	-500	+2	-1	+0.24
183	"	2,838	-3.9	-0.85	0	+12	+12	-0.6
185	"	2,819	-4.0	-0.9	-500	-5	-5	0
188	"	2,860	-3.5	-2.9	-3,900			0
191	"	2,881	-3.2	-2.2	0			0
192	"	2,880	-6.3	-1.2	0			0
194	"	2,880	-4.8	-1.4	+2,800			0
196	"	2,864	-4.3	-2.4	0			0
197	"	2,897	-3.1	-1.35	0			0
199	"	2,853	-2.1	-2.6	+7,400			0
203	"	2,874	-3.2	-0.5	-1,900	+5	-3	-0.22

Table 2
(Con'd)

Rd. No.	Charge	M.V. ft./sec.	ϕ_A mins. of arc	α mins. of arc	$\dot{\alpha}$ mins. of arc per sec.	Linear Displacement x 10^3 ins.		β mins. of arc
						Max.	At Ejection	
186	A	1,940	-7.9	-6.5	0	+4	+4	+0.66
187	"	1,913	-8.1	-5.7	0	-3	-1	+0.30
176	"	1,874	-7.3	-8.3	+3,300	+7	+7	+0.22
177	"	1,880	-6.2	-7.9	+11,600	+6	+5	+0.08
178	E	2,994	-1.4	-0.5	-600	+17	+19	-0.04

Charge E " " " 8 lb. 2 oz. NH .055

Charge F " " " 7 lb. 10 oz. NH .055

Charge A " " " 3 lb. 5 oz. NF/S .116-.036

(2) The sum of the angular muzzle movement α and the linear velocity component of jump β does not represent the total true jump ϕ_t.

(3) The poor correlation of α with ϕ_1 for the Service charge must be due to aerodynamic jump resulting from an initial yaw of the projectile which is increased considerably by blast in the post ejection zone; the better correlation for the reduced charge would correspond to a much reduced value of yaw induced in the post ejection zone by the reduced gas flow and shock wave for this charge.

The components of yaw which can contribute to an aerodynamic component of jump ψ are listed at (v) in para. 6.6. On the assumption that the measured muzzle movement at ejection is that of the projectile and that the δ_o and δ_ω components of yaw are negligible, we are left with the measured $\delta\beta$ component, subsequently increased in the blast zone, to account for the aerodynamic jump component ψ and we may write

$$\phi_1 = \alpha + k\beta \qquad \text{(5)}$$

when k is a function of β.

The experimental results for the Service round are explained if k has a value somewhere between 10 and 25. For the reduced charge k is approximately zero.

10. EVIDENCE OF YAW COMPONENTS δ_o, δ_ω and δ_1

10.1 δ_ω Component (Angular Momentum)

This component is unlikely to be negligible except for rounds showing small angular velocity ($\dot{\alpha}$) at ejection. These vertical component valves of $\dot{\alpha}$ are listed in Table 2; although a large proportion are small or zero the extreme range is +7,400 mins./sec. to -6,200 mins./sec. The yaw δ_ω induced in the projectile should be of opposite sign to that of $\dot{\alpha}$.

10.2 δ_o Component (Barrel Clearance)

Some records show an increased angular vibration of the order 2,000-3,000 c.p.s. towards the end of shot travel (Fig. 28). This may be taken as evidence of unstable shot travel in the barrel giving rise to a large value of δ_o. This feature became more frequent as barrel wear proceeded. The worst state of barrel wear during the trial was 92×10^{-3} ins.; assuming no engraving of the shoulder of the projectile this would correspond to a maximum possible δ_o yaw component of 40 mins. of arc.

10.3 δ_1 Component (Blast)

For Rounds 163-167 yaw was measured by yaw cards at 19 and 40 ft. from the muzzle and was found to have mean values of 6 and 4 degrees respectively for the two positions. This is larger than could be expected from the sum of the initial yaw components δ_o, $\delta\beta$ and δ_ω and may in part be attributed to blast. Some part of this yaw must however be the normal yaw increase upon relief of barrel constraint.[10]

A rough calculation for the 17 pr. projectile shows that a 6° maximum yaw could be produced by 24 mins. yaw at the muzzle assuming no blast disturbance. Further, the 24 mins initial yaw would give rise to an aerodynamic jump component at right angles to the initial yaw of about 3 mins.

[Calculation of Aerodynamic Jump Component from Maximum Yaw for 17 Pr. Projectile

Initial yaw $|\varepsilon_c| = \sigma \cdot \varepsilon_{max.}/(2B/A - 1)$

A = Axial moment of inertia = 0.132 lb. ft.^{2}

B = Transverse moment of inertia = 0.774 lb. ft.^{2} } (For proof shot.)

$\sigma = \sqrt{1 - \frac{1}{S}}$ S = Stability factor

= about 0.7 say

for 6° maximum yaw

$\therefore |\varepsilon_o| = 0.7 \times 360/10.5 = \underline{24 \text{ mins.}}$

Aerodynamic Jump (Kent's Formula)

$$j = -i \frac{NA}{mdu} \cdot (B/A - 1)$$

u = Shot velocity

N = Spin in radians/sec. = 0.84 u for 17 pr.

m = Shot weight = 17 lb.

d = Calibre = 0.25 ft.

whence

$j = -i \times 0.124 \times 24$ mins.

$= -i \times \underline{3 \text{ mins.}}$]

11. CONCLUSIONS

(1) An accuracy of better than $\frac{1}{10}$ min. arc. can be attained in the measurement of lateral angular muzzle movement.

(2) The angular muzzle displacement at ejection of the 17 pr. Q.F. does not give a complete correlation with true jump.

(3) A.P.C.B.C. ammunition gives a better correlation than A.P.D.S. ammunition.

(4) The vertical linear velocity of the muzzle at ejection directly contributes only a small fraction of the total true jump; its measurement permits the assessment of the residual aerodynamic and momentum components of jump.

(5) There is some evidence of radial flexural vibrations which may affect accuracy.

(6) Accuracy may be affected by an impulse present in the vertical angular movements, possibly due to impact between the gun cradle and the slipper.

12. FURTHER ACTION

(1) Deduction of residual errors $(\theta + \psi)$ and direct measurement of yaw at ejection and in blast zone.

(2) Possible measurement of breech movement.

(3) Repetition of measurements (1)-(3) with 17 pr. barrel mounted on a concentric tank mounting.

13. ACKNOWLEDGEMENT

Acknowledgement is due to C.S.X.R. for range facilities and assistance.

Table 3

17 Pr. Muzzle Vibration Trial

Tabulated Results

Prism mtd. at 12 o'clock for first 15 rds. Thereafter mtd. at 3 O'clock.

Jump measured for rds. 24 onwards.

Shot velocities measured for rds. 38 onwards.

Rd. No.	Date of Firing	Type	Charge lb. oz.	Propellant	M.V. ft./sec.	T.O.F. milli-sec.	True Jump mins.	Vertical Angular Movement of Muzzle at Ejection (mins.)	Remarks
1	5.4.48	A.P.C.B.C.	8 2	NH 055	--	-	-	-	Prism off. No record.
2	"	"	"	"	-	-	-	-	Record of vertical and horizontal bend.
3	4.5.48	"	"	"	-	-	-	-	Part of record missed.
4	"	"	"	"	-	-	-	-	
5	"	"	"	"	-	-	-	-	
6	"	H.E	6 11	NH 050	-	-	-	-	
7	"	"	"	"	-	-	-	-	Record obtained.
8	5.5.48	A.P.D.S.	"	NH 033	-	-	-	-	" "
9	"	"	"	"	-	-	-	-	" "
10	"	H.E.	"	NH 050	-	-	-	-	" "
11	"	A.P.C.B.C.	"	"	-	-	-	-	" "
12	"	H.E.	"	"	-	-	-	-	" "
13	"	A.P.C.B.C.	8 2	NH 055	-	-	-	-	" "
14	"	H.E.	6 11	"	-	-	-	-	" "
15	21.5.48	A.P.C.B.C.	8 2	"	-	-	-	-	Check for ground shock. Prism on tripod.
16	1.7.48	A.P.D.S.	6 10	NH 033	-	-	-	-	Record obtained.
17	"	"	"	"	-	-	-	-	" "
18	"	-	-	-	-	-	-	-	No record.

Table 3
(Con'd)

Rd. No.	Date of Firing	Type	Charge lb. oz.	Propellant	M.V. f't./sec.	T.O.F. milli-sec.	True Jump mins.	Vertical Angular Movement of Muzzle at Ejection (mins.)	Remarks
19	1.7.48	A.P.C.B.C.	8 2	NH 055	-	-	-	-	Record obtained.
20	"	"	"	"	-	-	-	-	" "
21	"	H.E.	6 11	"	-	-	-	-	No record.
22	"	"	"	NH 050	-	-	-	-	Record obtained.
23	"	A.P.D.S.	6 10	NH 033	-	-	-	-	" "
24	15.7.49	"	"	"	-	-	+2.01	+1.4	
25	"	H.E.	6 11	NH 050	-	-	+0.75	0	
26	"	A.P.C.B.C.	8 2	NH 055	-	-	-	-	No record.
27	"	"	"	"	-	-	-0.98	-0.8	
28	"	A.P.D.S.	6 10	NH 033	-	-	+1.75	+2.4	
29	"	H.E.	6 11	NH 050	-	-	+0.27	-0.59	
30	"	A.P.C.B.C.	8 2	"	-	-	-	-	No record.
31	"	"	"	NH 055	-	-	-1.87	-0.55	
32	28.7.48	H.E.R.C.	1 10	WM 017	-	-	-	-	No record.
33	"	"	"	"	-	-	-	-	" "
34	"	"	"	"	-	-	-	-	" "
35	29.7.48	"	"	"	-	-	-	-	" "
36	"	A.P.C.B.C.	8 2	"	-	-	-	-0.66	
37	"	A.P.D.S.	6 10	NH 033	-	-	-	+0.426	
38	1.9.48	A.P.C.B.C.	8 2	NH 055	2,902	-	-0.96	0	
39	"	H.E.R.C.	1 10	WM 017	-	-	-	-	
40	"	A.P.D.S.	6 10	NH 033	4,060	-	+3.8	+2.15	
41	"	"	"	"	4,077	-	+5.3	+1.78	Without muzzle brake.
42	16.9.49	A.P.C.B.C.	8 2	NH 055	2,972	204.0	+0.48	+1.1	
43	"	"	"	"	-	-	-	-	No record.
44	"	"	"	"	3,008	-	-0.94	-0.55	
45	"	"	"	"	-	-	+0.06	-0.24	
46	20.1.49	"	"	"	-	204.23	+2.02	-1.32	
47	"	"	"	"	2,958	204.43	-0.97	-1.92	
48	"	"	"	"	2,951	204.83	-4.6	-2.34	

Table 3
(Con'd)

Rd. No.	Date of Firing	Type	Charge lb. oz.	Propellant	M.V. ft./sec.	T.O.F. milli-sec.	True Jump mins.	Vertical Angular Movement of Muzzle at Ejection (mins.)	Remarks
49	20.1.49	A.P.C.B.C.	8 2	NH 055	2,861	211.3	-4.97	-2.56	Bore sighting correction of +1.22 mins. made from here onwards.
50	17.3.49	"	"	"	2,811	214.4	-8.34	-2.74	
51	"	"	"	"	2,867	210.2	-7.96	-2.88	
52	18.3.49	"	"	"	2,808	214.5	-8.86	-3.1	
53	"	"	"	"	2,814	213.9	-8.08	-2.74	
54	"	"	"	"	2,804	214.9	-8.4	-3.57	
55	"	"	"	"	2,792	215.6	-8.02	-2.7	
56	"	"	"	"	2,801	215.1	-7.94	-3.36	
57	"	"	"	"	2,794	215.6	-	-	No record.
58	21.4.49	"	"	"	2,812	216.0	-4.57	-	No ejection signal.
59	"	"	"	"	2,823	215.5	-4.7	-	No calibration.
60	"	"	"	"	2,832	214.6	-5.38	-0.92	
61	"	"	4 12	NF/S 116-036	2,456	247.8	-5.44	-2.37	
62	"	"	"	"	2,460	247.5	-7.32	-1.79	
63	"	"	7 3	NH 055	2,728	223.0	-5.87	-1.78	
64	"	"	"	"	2,709	224.6	-7.22	-1.93	
65	"	"	3 5	NF/S.116-036	-	-	-	-	No record.
66	22.4.49	"	7 10	NH 055	2,770	219.7	-6.4	-	" "
67	"	"	7 3	"	2,715	224.0	-7.03	-1.95	
68	"	"	"	"	2,714	224.2	-7.77	-1.69	
69	"	"	8 2	"	3,043	200.1	-4.13	0	
70	"	"	"	"	3,029	200.9	-4.65	+0.126	
71	"	"	4 12	NF/S 116-036	2,443	249.3	-3.97	-2.18	
72	"	"	"	"	2.420	251.6	-3.94	-1.79	
73	"	"	4 1	"	2,159	282.2	-6.36	-	No record.
74	"	"	"	"	2,164	281.5	-7.15	-1.73	
75	"	"	3 5	"	1,917	318.2	-9.65	-0.09	

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PART 2

MUZZLE MOVEMENTS OF Q.F. 6 PR. MK. 4

(COMPILED FROM REPORT B.R.102)

ABSTRACT

Angular movements, in the vertical plane containing the barrel axis, of the muzzle of a Q.F. 6 Pr. Mk. 4 have been recorded over the period of shot travel down the bore and compared with calculated movements. At ejection the recorded displacement (-2 minutes) is at variance with that calculated (-12 minutes) and also with the recorded true jump (-7 minutes). A change from the muzzle brake to counterweight fitments make a difference of 5 minutes in recorded true jump (-7 minutes and -12 minutes respectively), the recorded angular displacement at ejection being little affected. It is concluded that aerodynamic jump components exist of value -5 and -10 minutes respectively, the measured linear velocity component of jump being negligible.

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1. INTRODUCTION

The measurements were undertaken by D/F.V.R.D.E. at the request of the Weapon Research Committee (Gun Jump Panel) of the Advisory Council on Scientific Research and Technical Development.

2. OBJECT

(i) To record angular and linear muzzle movements and angular breech movements in the vertical plane containing the barrel axis of the Q.F. 6 Pr. Mk. 4, and to compare with the calculated movements for this gun given in A.R.D. Theoretical Report No. 9/45.[4]

(ii) To determine what proportion of true jump is due to the recorded angular displacement at the instant of ejection.

3. METHOD OF MEASUREMENT

The technique used is that developed for Q.F. 17 Pr. trials.[1a,1b] The muzzle prism, previously of glass, pitch-mounted to the barrel, was however replaced by an improved type made of stainless steel and welded to the barrel, this effectively eliminating any movement between the barrel and prism occasionally experienced with the glass type. A glass prism was found adequate for recording the angular breech movement.

4. RESULTS

4.1 Details of Firing

Some 50 rounds of Service charge A.P.C.B.C. ammunition have been fired to date for recordings of angular muzzle displacement, half of this number before a muzzle bore sight was available and used to check correct operation of the equipment. The rounds were fired with both muzzle brake and counterweight fitments. A short reduced charge series was included using the muzzle brake fitment. The muzzle attachment necessary for recording linear muzzle displacement[1a,1b] was not fitted for the above firings. Further series were fired to determine (i) the value of the linear velocity component of jump, and (ii) the vertical angular displacement of the breech.

4.2 Recorded Movement for Service Charge A.P.C.B.C. and Comparison with Calculated Movements

The recorded displacements are shown in Figs. 30 and 31 for the muzzle-brake and counterweight fitments respectively. It will be seen that the displacement is little disturbed by the type of muzzle fitment. Records commence with an indefinite movement at about 4.5×10^{-3} seconds before ejection, followed by a shallow minimum at some 2.5×10^{-3} seconds before ejection, a definite maximum of +1 to +2 minutes at 1×10^{-3} seconds before ejection, dropping to -2 to -3 minutes at ejection. In only one case was the value of -3 minutes exceeded (Round 49, $\alpha = -3.7$ minutes) and in no case was the theoretical figure of -12 minutes approached (Fig. 32). It will be observed that the form of the theoretical curve bears no relationship to that experimentally determined except perhaps in the time of commencement (4.5×10^{-3} seconds before ejection).

4.3 Angular Displacement at Ejection (α) Compared with True Jump (ϕ_1) for Muzzle Brake and Counterweight Fitments

Table 4 gives the recorded angular displacement at ejection (α) and the true jump (ϕ_1). Series A is a 10 round series with the muzzle-brake fitment, while Series B is an 8 round series with the counterweight fitment. It will be seen that the mean true jump is affected by the type of muzzle fitment, being numerically 4·9 minutes greater with the counterweight; while the mean angular displacement is relatively unaffected, viz: numerically 0·6 minutes less with the counterweight.

The ratio $\alpha:\phi_1$ is 0·36 with the muzzle-brake (close to that found for the 17 pr. fitted with muzzle-brake) and 0·16 with the counterweight. Other possible components of true jump are:

(i) β, due to vertical linear velocity;

(ii) θ, due to linear momentum imparted to the projectile by blast gases after ejection;

(iii) ψ, due to aerodynamic phenomena and dependent on initial yaw enhanced by post ejection blast.

If β and θ can be neglected* then we can put the aerodynamic jump component $\psi = \phi_1 - \alpha$, whence ψ = -4.5 minutes and -10 minutes with muzzle brake and counterweight respectively.

Evidence of yaw for rounds fired with the counterweight was found on the target at 200 yards but not for rounds fired with the muzzle-brake.

4.4 Recorded Angular Movement for Reduced Charges (A.P.C.B.C.)

Figure 33 shows the recorded angular displacements for a reduced charge series A.P.C.B.C. (Rds. 26-28) compared with those for the Service charge (Rd. 25). It will be observed that ejection, which occurs at or before a minimum for the Service charge, occurs after the minimum for the reduced charges and α can acquire a positive value. The value of the minimum is of the order -3 minutes and it therefore seems unlikely that the theoretical value for α of -12 minutes for the Service charge can be attained in this weapon by the process of charge adjustment.

4.5 Recorded Linear Movement for Service Charge (A.P.C.B.C.)

The muzzle attachment for this measurement (a lamp housing mounted on a 9 inch stem at 12 o'clock - total weight 3 lb.) was found seriously to change the previously determined angular movements - a negative drift being added - and to increase the total jump; the linear velocity component of jump β was found to be of the order -3 minutes. It was found possible to reduce the length of the stem to some 3 inches and to fit a counterpoise on the barrel at 6 o'clock. With this arrangement angular movements and jump reverted to normal, while β was found to be negligible. Recorded results for ϕ_1, α and β are given in Table 5. A typical linear movement record is given in Fig. 34.

4.6 Recorded Angular Movement λ of the Breech

As the calculated muzzle displacements of the A.R.D. report are given as a sum of the displacements of the breech part of the gun (assumed rigid), and the vibratory components of the more flexible parts of the barrel, it is important to compare theoretical and measured breech displacements. This is done in Fig. 35 and Table 6. It will be seen that the measured displacement at ejection (+14 minutes mean value) is in excess of that calculated (+9 minutes) and would thus account for approximately half of the discrepancy between the theoretical and measured muzzle displacements.

5. CONCLUSIONS

5.1 Discrepancy Between Recorded and Calculated Movements

The theoretical angular movements at the muzzle are at variance with the measured movements in spite of a numerical agreement between true jump (-12 minutes) for a gun fitted with a muzzle counterweight and the calculated angular displacement at ejection. The measured muzzle displacement for this condition is a fraction of this value (-1.9 minutes). When the gun is fitted with a muzzle-brake there is no longer a numerical agreement, the true jump being smaller (-7 minutes) while the angular displacement is relatively unchanged (-2.5 minutes). The measured breech displacement at ejection is 5 minutes in excess of that calculated.

5.2 Value of the Aerodynamic Jump Component

The aerodynamic jump component ψ is sensitive to muzzle blast and appears to account for the major part of the discrepancy between the measured angular displacement at ejection α and the recorded true jump ϕ_1, viz ψ = -4.5 and -10 minutes for the muzzle-brake and counterweight respectively. Accuracy does not appear to be improved by the reduced jump occurring with the muzzle-brake.

5.3 Summary

It appears that the theory is incorrect in (a) that it assumes the angular displacement of the muzzle at ejection is equal to true jump and (b) in the value of the calculated movement.

6. PROPOSED FURTHER ACTION

(i) To attempt an experimental comparison between the angular displacements in the vertical plane, of shot and muzzle, from the instant of shot start until shortly after ejection.

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* See para. 4.5.

(ii) To investigate the development of yaw in the post-ejection blast region.

(iii) To investigate the accuracy of the gun when the aerodynamic jump component is small, e.g. when the muzzle pressure is low.

Table 4

Angular Displacement at Ejection (α) and True Jump ϕ_1

A. Muzzle Brake (Wt. 22 lb.)

Round No.	ϕ_1 Mins./arc	α Mins./arc
25	-8•5	-2•2
41	-8•4	-2•8
42	-7•1	-2•1
43	-5•3	-1•7
44	-4•9	-2•9
45	-6•6	-2•6
46	-8•3	-2•0
47	-6•6	-2•1
48	-5•7	-2•8
49	-9•0	-3•7

Mean value ϕ_1 = -7•0 ± 1•2 mins./arc.

Mean value α = -2•5 ± 0•5 mins./arc.

Ratio $\alpha:\phi_1$ = 0.36

B. Muzzle Counterweight (Wt. 17 lb. 14 ozs.)

Round No.	ϕ_1 Mins./arc	α Mins./arc
33	-11•2	-1•8
34	-12•3	-1•2
35	-12•3	-1•4
36	-14•5	-1•6
39	-11•7	-2•2
50	-9•9	-2•4
51	-11•3	-2•3
52	-12•0	-2•6

Mean value ϕ_1 = -11•9 ± 0•9 mins./arc.

Mean value α = -1•9 ± 0•4 mins./arc.

Ratio $\alpha:\phi_1$ = 0•16.

Table 5

Jump (ϕ_1), Angular Displacement (α) and Linear Velocity Component (β)

A. Muzzle Brake

Round No.	ϕ_1 Mins./arc	α Mins./arc	β Mins./arc
67	-8·9	-2·6	0
68	-	-2·3	0
69	-10·1	-2·1	0
70	-	-1·9	0
71	-4·8	-2·3	0
72	-9·3	-2·3	+0·5
73	-8·8	-2·1	0
74	-6·2	-2·8	0
75	-6·2	-2·1	0

Mean value ϕ_1 = -7·9 min. ± 1·7 mins. (7 rds.). (Results unreliable due to near proximity to trajectory of auxiliary equipment.)

Mean value α = -2·3 ± 0·2 mins. (9 rds.).

Mean value β = 0·06 ± 0·06 mins. (9 rds.).

B. Counterweight

Round No.	ϕ_1 Mins./arc	α Mins./arc	β Mins./arc
76	-	-2·4	0
77	-	-2·3	0

Table 6

Angular Breech Displacement at Ejection (λ)

Round No.	λ Mins./arc	Mean λ Mins./arc
78	+14·8	
79	+13·4	+13·8 ± 0·7
80	+13·1	

PART 3

THE MEASUREMENT OF YAW IN THE IMMEDIATE POST-EJECTION ZONE AND THE ESTIMATION OF THE AERODYNAMIC AND MOMENTUM COMPONENTS OF JUMP DUE TO BLAST

(COMPILED FROM REPORTS B.R.140 AND B.R.146)

ABSTRACT

Conclusions as to the cause of gun jump are deduced from measurements of muzzle movements up to ejection and shot movements up to 10 feet beyond ejection. These are that the jump is dependent upon the yawing movement inside the barrel and the angular movement of the muzzle at ejection, and is considerably increased in the immediate post ejection period, possibly by (1) a radial flow component when the barrel is non-axial with the trajectory immediately after ejection and (2) the emergence of a yawing projectile from the muzzle gas cloud. The method of measurement of yaw is described.

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1. INTRODUCTION

In an earlier report[10] results are given showing that the vertical mean jump of a Q.F. 6 pr. (-7 min.) increases by -5 min. (to -12 min.) when the muzzle brake is replaced by a counterweight, while at the instant of ejection the measured angular displacement of the muzzle in the vertical plane containing the barrel axis remains sensibly the same (-2 min.) for both muzzle fitments. The measured linear velocity component of jump being negligible, it is concluded that the increase in jump is due to the increased mass of propellant gases flowing past the shot in the post ejection period when the gun is without the muzzle brake. Now it has been shown theoretically[8] on the assumption of negligible effect due to damping and all cross forces except lift, that the jump of a projectile fired from a gun barrel is dependent upon the yaw, the rate of change of yaw and the lateral linear momentum imparted to the projectile at the instant of ejection.

Thus:-

$$j = (K_L/K_m)\,(iAN\,\delta_o - B\,\dot{\delta}_o)/mdu + j_{Lm} \qquad \text{(i)}$$

where j is the aerodynamic jump (change in direction of the mean trajectory).

j_v = vertical component of jump.

δ_o is the vector yaw at the instant of ejection.

$\dot{\delta}_o$ is the vector yawing (rate of change of yaw).

K_L is the aerodynamic lift coefficient.

K_m is the aerodynamic moment coefficient.

K_L/K_m may be taken as unity.

i is $\sqrt{-1}$; the significance of i in the formula is a 90° rotation, in the same sense as N; i.e. a right handed rotation for most guns, and for those of the present investigation.

A is the axial moment of inertia of the shot.

B is the traverse moment of inertia of the shot.

N is the rate of spin in radians per sec.

m is the mass of the projectile.

d is the calibre.

u is the velocity of the shot.

j_{Lm} is the jump due to linear momentum.

An experimental analysis of jump making use of spark range data[8] shows that the deduced initial yaw is considerably greater than that determined from bore clearance data, the discrepancy being attributed to the flow of gas past the shot in the intermediate ballistic zone.

If only circumferential yawing is possible in the barrel then

$$\left.\begin{aligned} \delta_o &= \varepsilon \\ \dot{\delta}_o &= i\dot{\phi}\varepsilon \end{aligned}\right\} \quad \text{where } \varepsilon \text{ is a vector; } \dot{\phi} \text{ is rate of spin.}$$

If the yawing is at spin frequency $\dot{\phi} = N$ and the formula for jump reduces to

$$j = -i\,\frac{K_L}{K_m}\,\frac{AN}{mdu}\left[\left(\frac{B}{A}\right) - 1\right]\varepsilon \qquad \text{(Kent's Formula)} \qquad \text{(ii)}$$

In order to understand more fully the development of jump and the reasons for its dispersion it was decided to attempt an experimental study of yaw of the projectile from the instant of shot start until as far as was found practicable into the post ejection zone.

2. MIRROR ON NOSE OF SHOT METHOD FOR THE MEASUREMENT OF YAW (Fig. 36)

The equipment developed for the measurement of the vertical component of yaw uses a simple optical lever, the moving element being a plane mirror attached rigidly to the nose of the projectile with its reflecting surface accurately normal to the shot axis; the reflected beam is deviated directly into a recording drum camera fitted with a wide aperture receiving lens (7"). The recording and beam projection equipment are placed some 10 feet to the side of the trajectory and any convenient distance (6-20 feet) forward of the gun muzzle; they are adequately protected from blast. The incident and reflected beams are reflected through approximately 90° by a thin glass mirror mounted directly in the trajectory. This mirror is of course destroyed by the projectile; trials have shown that penetration of the mirror does not cause measurable deviation of the projectile. (The mean jump of the modified projectile fired through the mirror differed from the mean jump with the standard projectile by less than $\frac{1}{2}$ min.).

The shot mirrors used were mostly aluminized selected plate of about 1 in. in diameter attached with "Araldite" cement to an accurately ground surface on the nose of the shot; some shot was prepared by polishing the ground surface to a mirror finish. Errors of alignment of 1-4 mins. were accepted as satisfactory, corrections being made for this error using the theoretical space time curve and the known value of rifling twist for the particular gun. Where proof shot was used (17 pr.) it was possible to use mirrors of 2 ins. diameter; this reduced the risk of the record being interrupted by obstruction of the reflected light beam in the barrel.

The change in refractive index ahead of the projectile in the barrel is estimated at less than 0.1%, while in the flash region outside the barrel it should not exceed a few per cent. (See Appendix 1.) The error of measurement due to this cause however is thought to be negligible as the incident and reflected beams remain almost coincident and only linear displacement of the image could occur upon traversing a plane boundary separating layers of different refractive indices. The error of measurement of yaw then would appear to be almost entirely one of record measurement and up to the instant of ejection is estimated at about $\frac{1}{2}$ min. arc. An alignment error of a few minutes of arc is permissible and may be compensated by assuming symmetry of movement in the bore.

3. EXPERIMENTAL DETAILS OF SIGHTING AND LOADING

The gun was aligned onto the target by muzzle bore sight before erection of the trajectory mirror and the elevation was checked by means of a $\frac{1}{8}$ min. clinometer. The shot was then lightly hand rammed, a note being made of the direction of mirror error, and was adjusted by light blows until the reflected light beam was coincident with the bore axis (and the incident beam). A shortened case was then loaded behind the shot and the gun made ready, final adjustment of elevation being made with the aid of the clinometer and of line by the gun telescope sighted on an auxiliary target.

Angular movements of the muzzle in the vertical plane were simultaneously recorded on some rounds using the previously described technique.[1a, 1b]

4. CONCLUSIONS FROM TRIALS WITH Q.F. 6 PR. USING MODIFIED A.P.C.B.C. PROJECTILE (Typical Records - Figs. 37 and 38)

1. The yaw of the projectile when in the barrel is much in excess of the measured bore clearance angle (2 mins.), a value of 25 minutes being recorded in a new barrel. (The recovered shot had a depth of engraving which corresponded to the 25 minutes value.)

2. The precessional movement of the projectile in the barrel after about one foot of travel is approximately that of the spin frequency of the projectile.
3. Muzzle movements at the instant of ejection (-2 mins.) are negligible compared with maximum yaw.
4. The direction of the vector yaw is predominantly within 10° of the vertical at ejection, i.e. the measured vertical component of yaw is a maximum near ejection. (See Part 1 Table 1.)
5. There would appear to be a correlation between the maximum in the barrel and the vertical jump on the target. The relationship may be expressed as

$$j_V = -0{\cdot}25\varepsilon - 7{\cdot}2 \text{ mins} \quad \text{(iii)}$$

with standard deviations of 0·18 and 1·18 in the coefficient of ε and the constant term respectively. This cannot be explained by formula (ii) (which for the 6 pr. gives $j = -i \times 0{\cdot}15\varepsilon$ (iv)) as here a 90° rotation is involved (Fig. 39).
6. When the barrel is fitted with the counterweight attachment there would appear to be a relationship between the vertical jump as recorded on a target at 200 yards and the vertical component of yawing at the instant of ejection (Fig. 40). The results given are for a series of 11 rounds; they cover a range of jump from -6·5 to -9·1 minutes and are as follows:-

$$j_V = -5{\cdot}3 \times 10^{-5}\ \dot{\delta}_o - 7{\cdot}2 \text{ mins.} \quad \text{(v)}$$

with standard deviations in the coefficient of $\dot{\delta}_o$ and the constant terms of 0·02 and 0·46 respectively.

The formula (i) for the jump of this gun gives:-

$$j = i \times 0{\cdot}029\ \delta_o - 4{\cdot}12 \times 10^{-5}\ \dot{\delta}_o + j_{Lm} \quad \text{(vi)}$$

($A = 0{\cdot}029$ $B = 0{\cdot}184$ lb. ft.^{2} $N = 3{,}430$ rad./sec.
$M = 6{\cdot}95$ lb. $D = 0{\cdot}183$ ft. $U = 2{,}800$ ft./sec.)

The term in δ_o may be neglected for the small angles of horizontal yaw component deduced, whence, on comparing (v) with (vi) we came to the conclusion that the jump due to linear momentum j_{Lm} of formula (i) is approximately -7·2 mins. Now the linear momentum imparted to the projectile by the barrel in the vertical plane is known to be negligible,[10] while the mean angular muzzle movement in the vertical plane is -2·3 mins. The jump component which must be attributed to the effect of the blast zone is thus about -5 mins., a value in agreement with that deduced from the difference of recorded mean jump with and without the muzzle brake (see Introduction).
7. It is possible that the difference in mean jump sometimes observed for different trail lodgements (see Part 1, para. 6.6) may be due to differences in angular movements of the barrel immediately after ejection, causing differences in the lateral flow components past the projectile or angle of impact of shot with shockwave.
8. No sudden changes to the yaw occur at ejection or after ejection up to some 10 feet from the muzzle, the maximum yaw for these zones being about 25 mins.
9. At 10-20 feet a rapid change in yaw occurs up to a maximum of 6°. This zone has been investigated by A.R.E.[9] using an X-ray flash method. Part or nearly all of this increase in yaw may result from an impulse received on emergence from the gas cloud.

5. CONCLUSIONS FROM TRIALS WITH 17 PR. PROOF TANK MOUNTING - PROOF SHOT (Typical records are shown in Figs. 41-43.)
1. With the concentric tank mounting angular muzzle movements are very much reduced and at ejection are zero. The mean point of impact on the target is also zero and the maximum recorded jump 1·6 mins.

2. The maximum yaw in the barrel is now reduced to some 10 mins., while that to be expected from bore clearance data is 40 mins. This improved centering over that in the 6 pr. is presumably due to the twin driving bands of the 17 pr. projectile.

3. The precessional frequency acquired by the projectile in the barrel, after an initial disturbance at about 1,000 c/s, is approximately that of the spin frequency.

4. The orientation of the vector yaw at ejection would appear to be random.

5. Neither the vertical component of yaw at ejection, the maximum yaw in the barrel, or the rate of change of the vertical component of yaw show any correlation with the vertical component of jump.

6. GENERAL CONCLUSIONS

1. Jump would appear to be dependent upon the amplitude of the yawing in the barrel and in particular to the rate of change of yaw at ejection.

2. Angular muzzle movements are relatively unimportant up to the instant of ejection, but rapid changes immediately after ejection might well be responsible for large components of jump.

3. An impulsive increase of yaw (and presumably of jump) can occur in the region of emergence of the projectile from the propellant gases.

APPENDIX 1

ERROR DUE TO REFRACTIVE INDEX CHANGES

The increase of refractive index corresponding to the increase in air density in the shock front ahead of the projectile when travelling in the barrel at about 3,000 ft./sec. is about 0·1%. Outside the barrel the state of affairs is little changed until the propellant gases have enveloped the projectile when the shock front of the advancing propellant gases will maintain the density change. Propellant gases CO, CO_2, H_2, N_2 and H_2O have a mean refractive index of 1·00029, close to that of air, 1·00027 (both at 15°C.). The possible higher temperature of these gases resulting from re-inflammation will cause a small reduction in refractive index of about 0·02% per 1,000° rise.

It will be seen therefore that any error caused by refractive index changes will be small. As, however, the measurement is one of angular movement it is unlikely that any error will be caused from this effect, the incident beam of light being nearly coincident with the emergent beam (the maximum difference which can be recorded is about 30 mins./arc); no angular change can be caused by the passage of the beam through layers of gas of different refractive indices if the entry and exit occur at the same plane surface.

The pressure (p_1) in the shock front ahead of a projectile when moving in the barrel is given by:-

$$\frac{p_1}{p_o} = 1 + \frac{(\gamma + 1)V^2}{4\,RT_o} + \frac{V}{(RT_o)^2}\left[\gamma + \frac{(\gamma + 1)^2V^2}{16\,RT_o}\right]^{\frac{1}{2}} \quad \text{(i)}$$

where p_o is the atmospheric pressure T_o is the atmospheric temperature (288°K).

$$RT_o \doteq \frac{1}{\gamma_o}(\text{vel. sound})^2 = \frac{(1120)^2}{1.41} \text{ (ft./sec.)}^2$$

γ = 1.38 for heated air.

V = shot velocity $\doteq$ 3,000 ft./sec.; whence p_1 = 14·1 atmospheres.

The density (ρ) of air in the shockwave" is given by:-

$$\frac{\rho_1}{\rho_o} = \frac{(\gamma + 1)p_1 + (\gamma - 1)p_o}{(\gamma + 1)p_o + (\gamma - 1)p_1} \quad \text{(ii)}$$

whence $\rho_1 = 4.4\,\rho_o$.

Now the refractive index (n) of a gas is related to density as follows:-

$$\frac{(n_1 - 1)}{(n_o - 1)} = \frac{\rho_1}{\rho_o} \quad \text{(iii)}$$

At 15°C. $(n_o - 1)$ for air is 0·000276

$\therefore (n_1 - 1) = 0.000276 \times 4.4 = 0.0012$

giving a percentage change in refractive index of 0·09%.

Outside the barrel the density (ρ_1) in the shock front is given by:-

$$\frac{\rho_1}{\rho_o} = \frac{(\gamma + 1)V^2}{(\gamma - 1)V^2 + 2\gamma\,RT_o}$$

For γ = 1·38 V = 3,000 ft. sec. $\rho_1 = 3.7\rho_o$

or a percentage refractive index change of +0·07%.

The variation of refractive index with temperature for air at constant pressure is given by:-

$$\frac{(n_o - 1)}{(n_t - 1)} = 1 + \alpha t \qquad \text{(iv)}$$

where $\alpha = \cdot0037$ for $\lambda = 0\cdot65\mu$.

Assuming a similar co-efficient (α) for the propellant gases an increase in temperature of 1,000°C. will result in a reduction of 0·02 per cent in the refractive index.

FIGURE 1. SYSTEM FOR ANGULAR MEASUREMENTS.

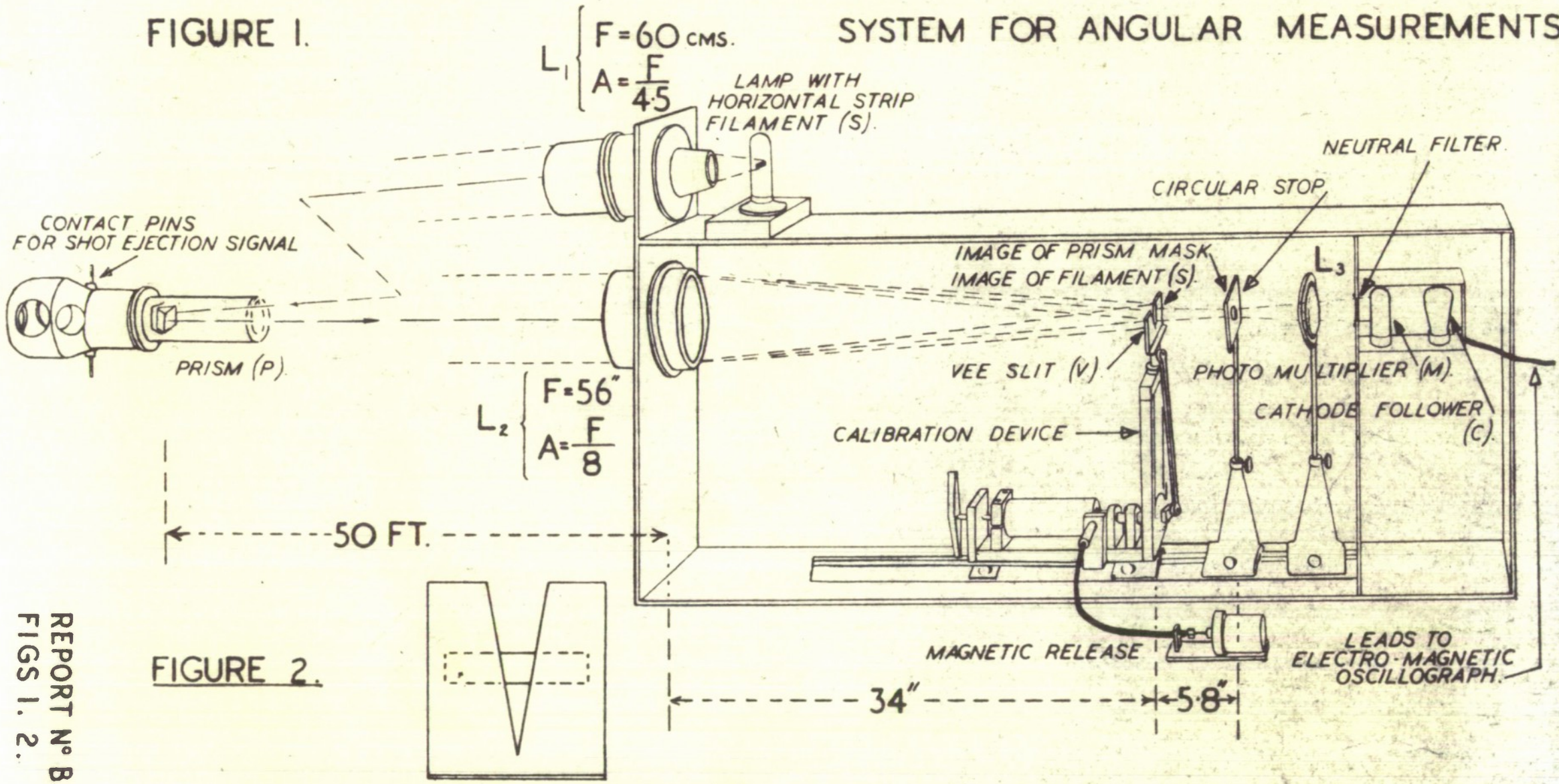


FIGURE 2.

IMAGE OF STRIP FILAMENT (S) CUT OFF BY VEE SLIT.

REPORT Nº B.R.147
FIGS 1. 2.

FIG. 3 Muzzle prism mounting.

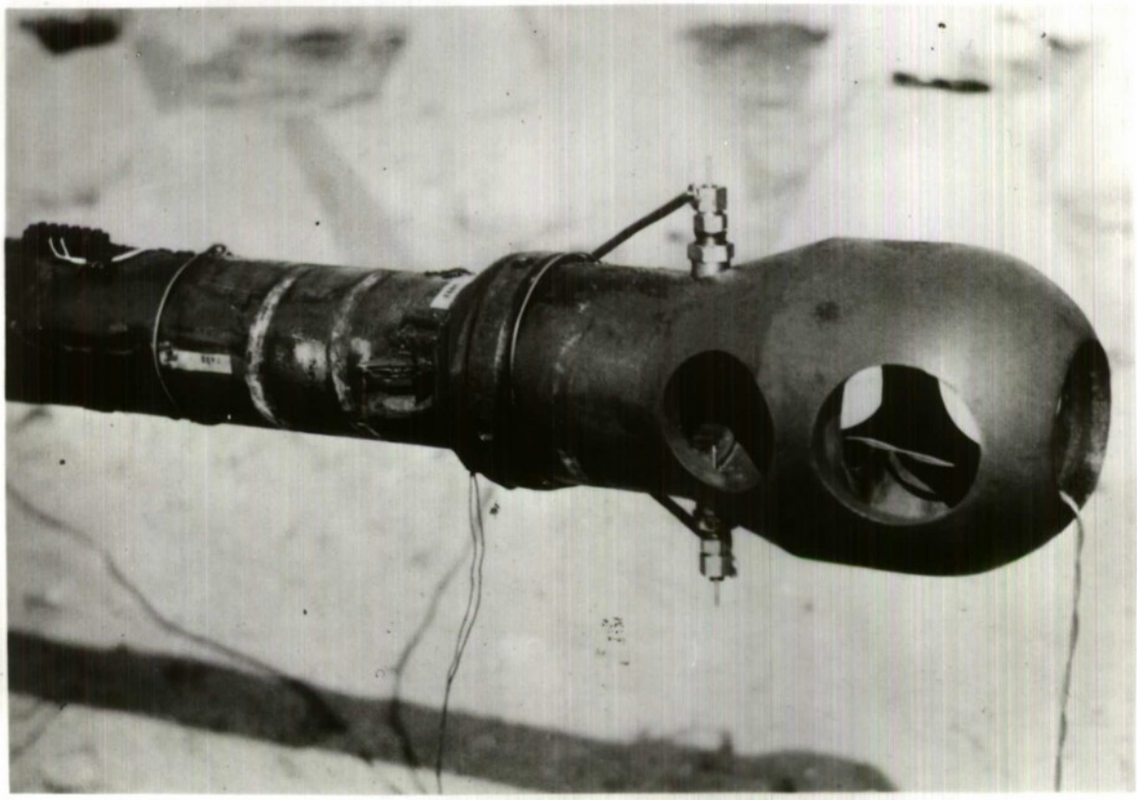


FIG. 4 Ejection signal device.

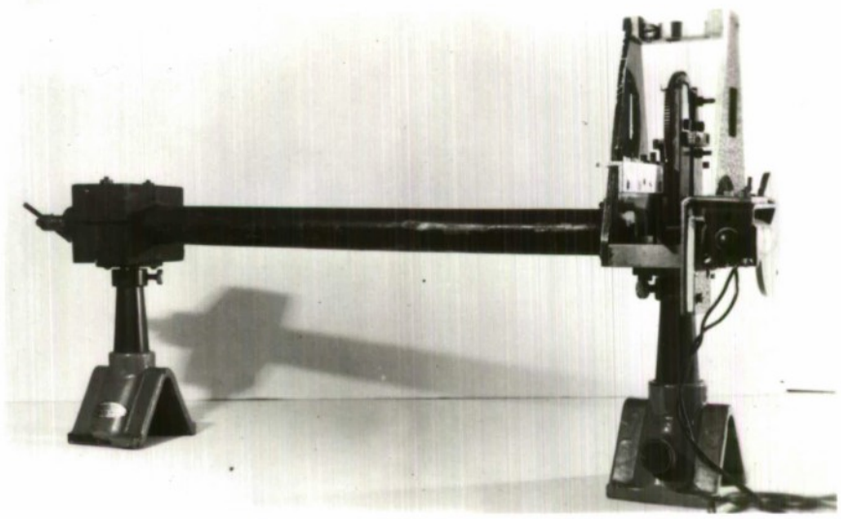


FIG. 5 Step calibration device for angular movements.

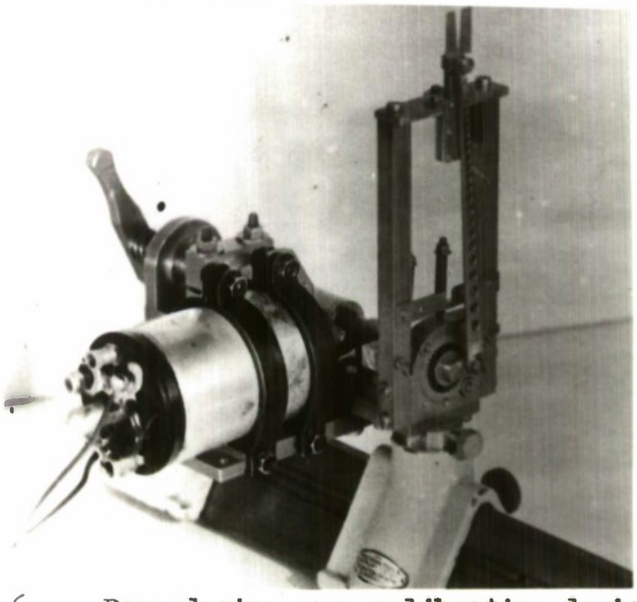


FIG. 6 Damped sine wave calibration device for angular movements.

FIGURE 7. SYSTEM FOR LINEAR MOVEMENTS.

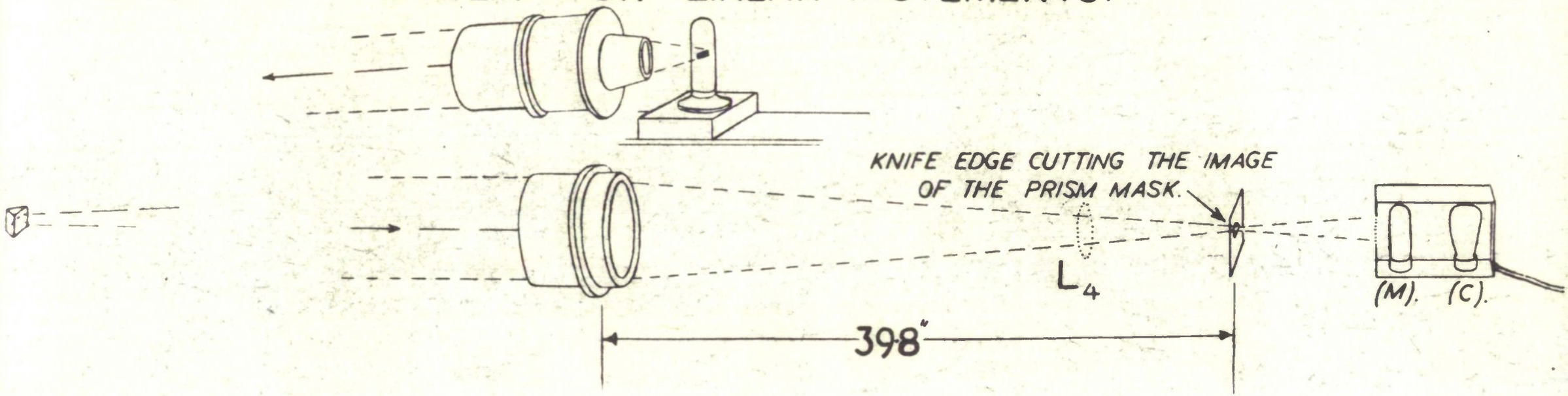
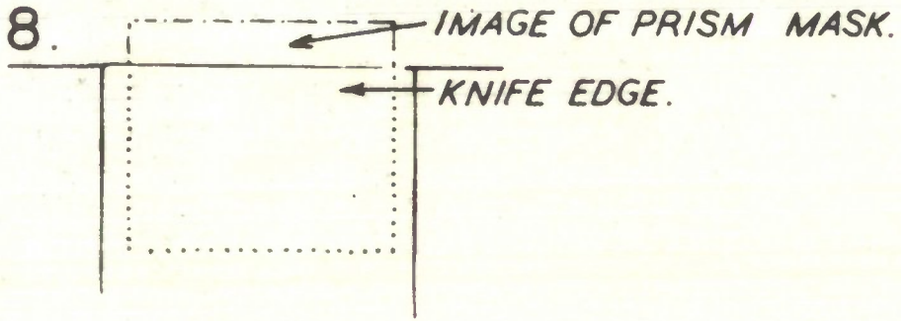


FIGURE 8.



REPORT Nº B.R.147
FIGURE 7. 8.

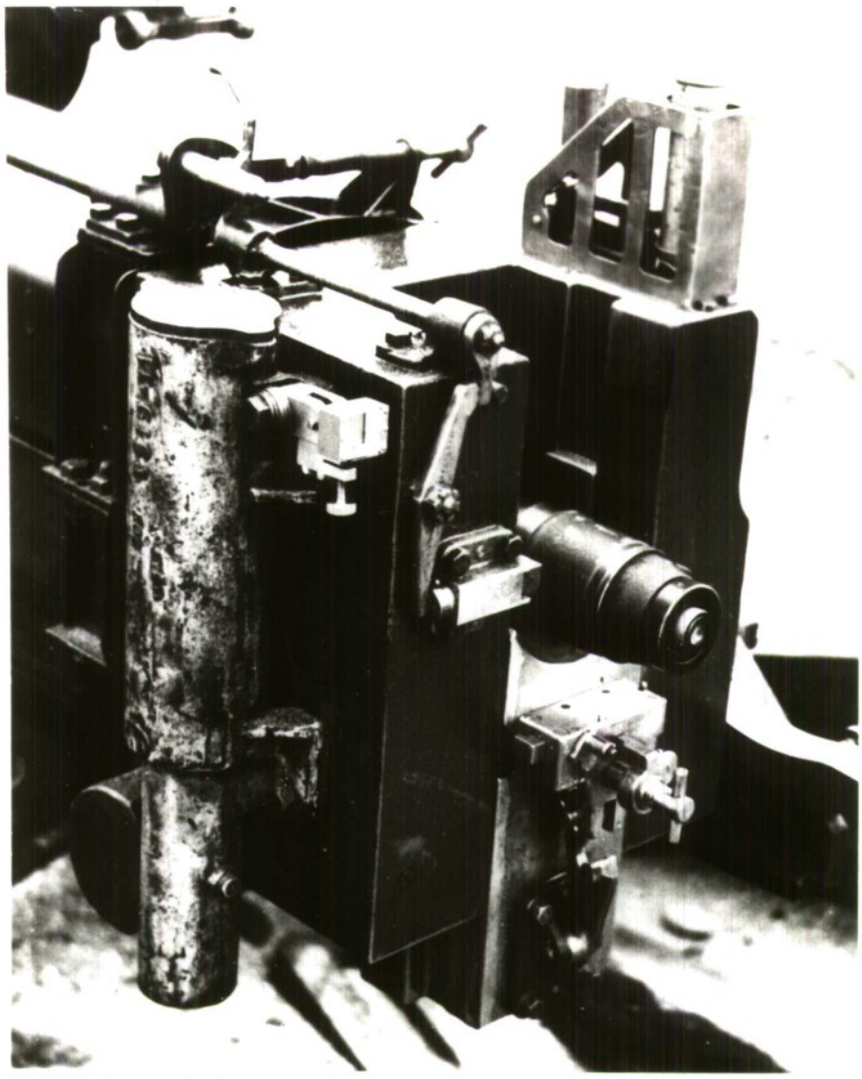


FIG. 9 Breech Prism and muzzle bore sight telescope.

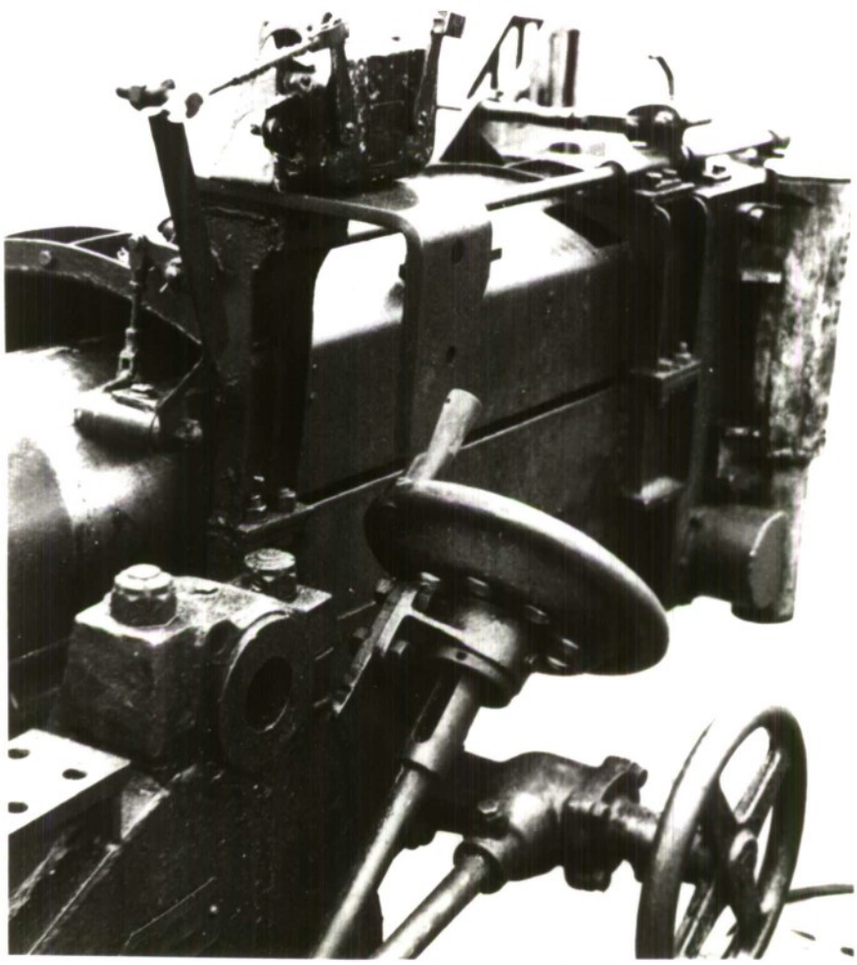


FIG. 10 "Bomb release" switch mounted for electrical firing of gun.

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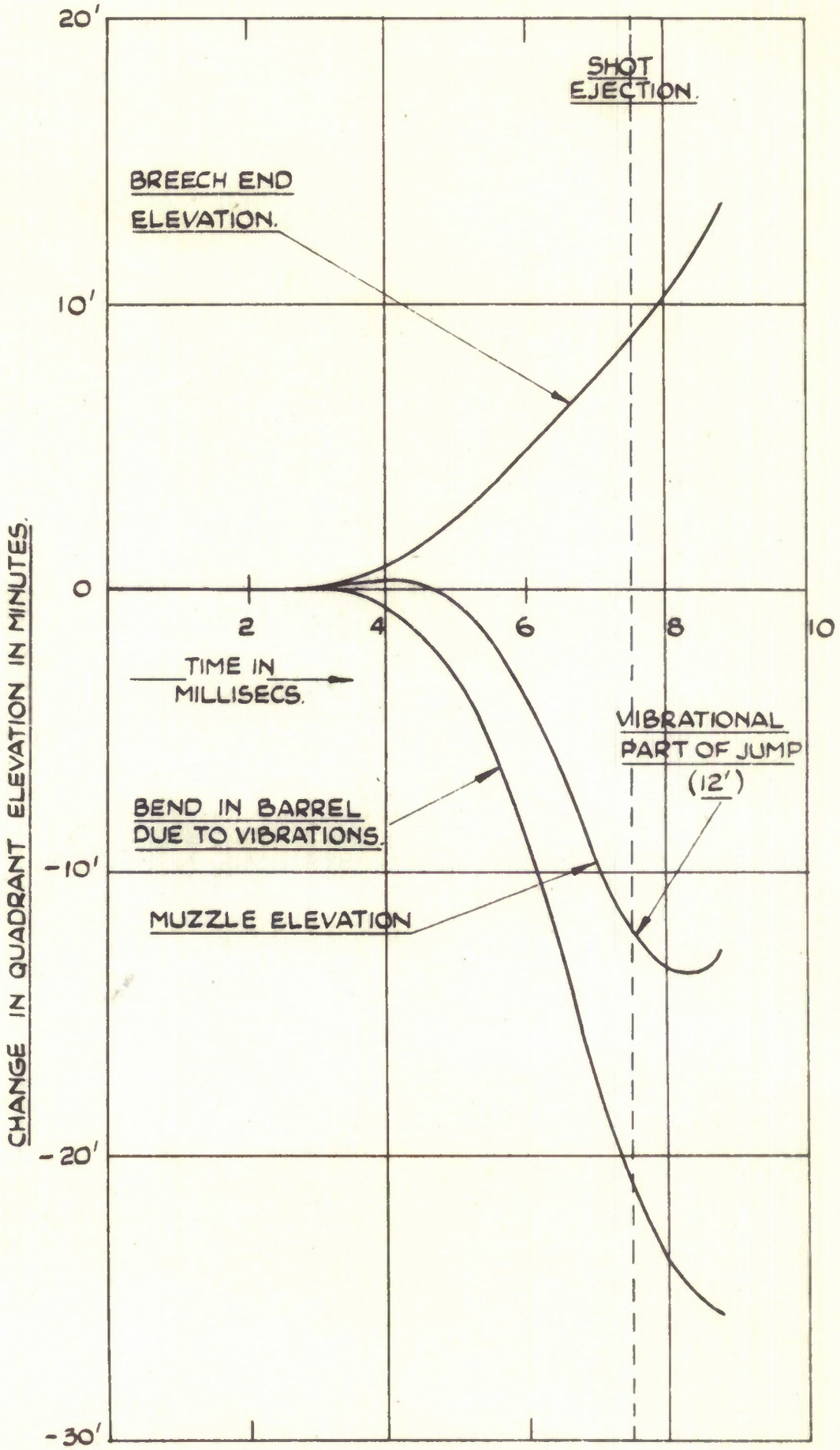

CALCULATED ANGULAR MOTION OF THE 6 PR GUN COMPONENTS DURING SHOT TRAVEL.

REPORT N° B.R. 147

FIGHTING VEHICLES RESEARCH AND DEVELOPMENT ESTABLISHMENT.

FIG. N° 11

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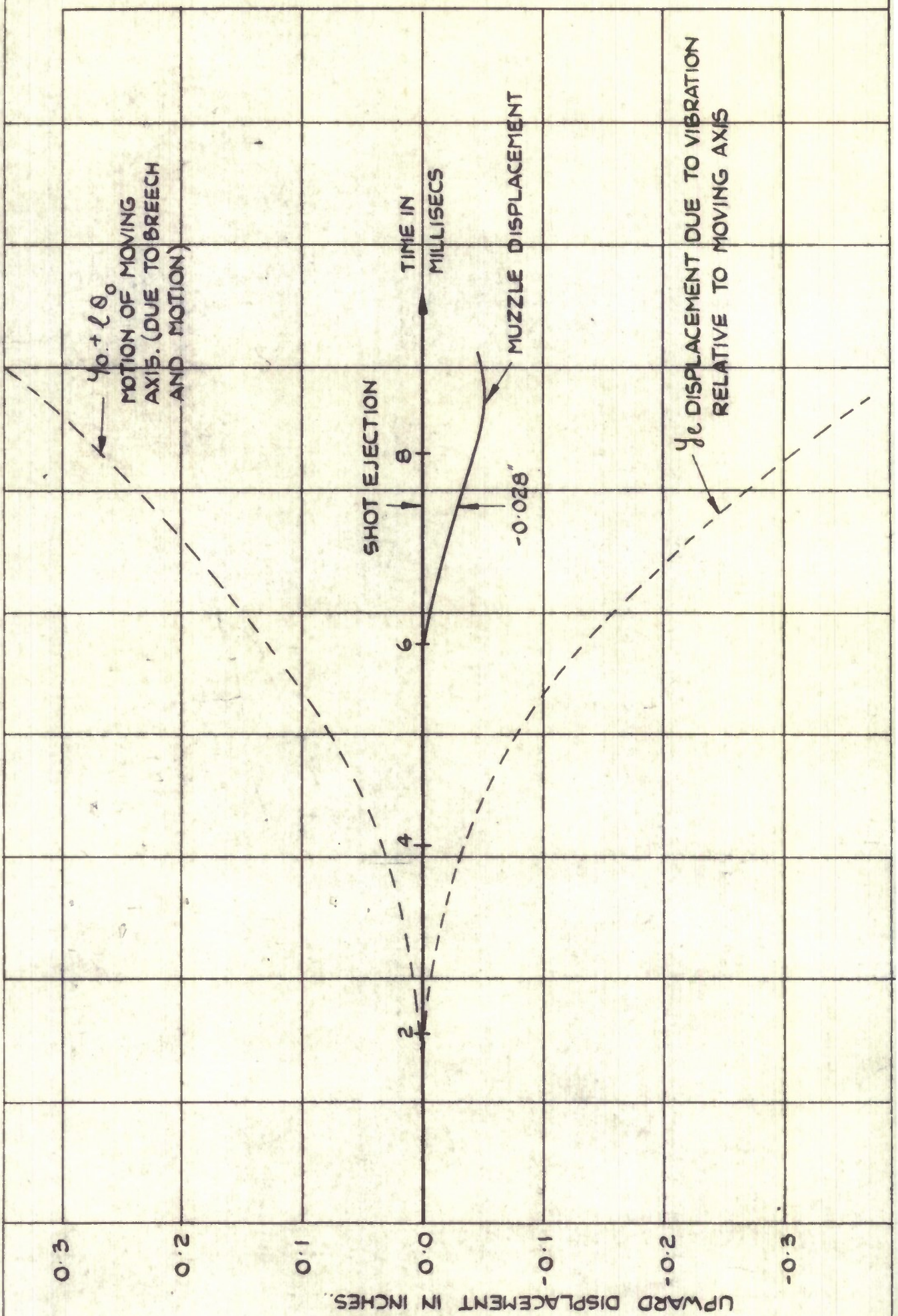
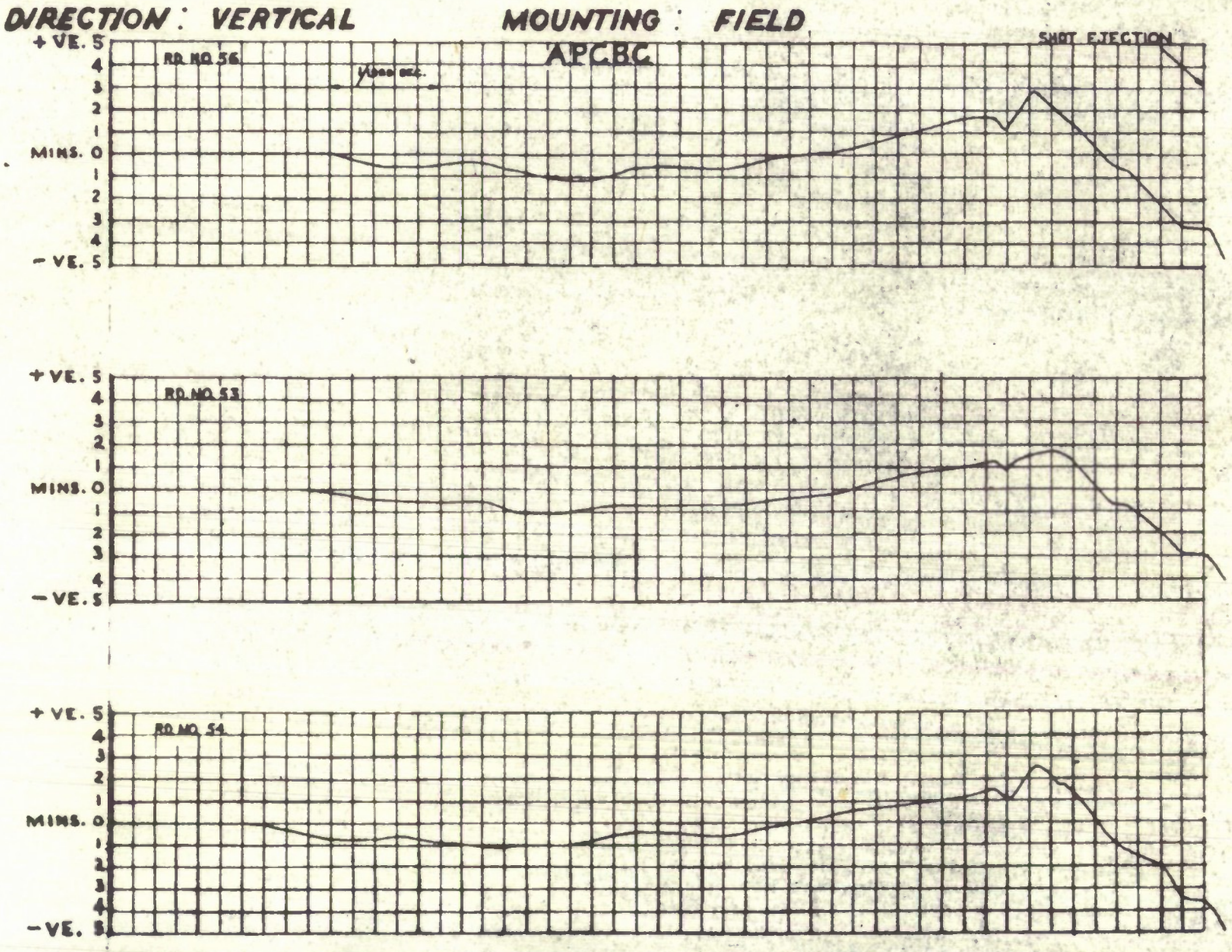


CALCULATED LATERAL MUZZLE DEFLECTION DURING SHOT TRAVEL (6 PR)	REPORT N° B.R.147
FIGHTING VEHICLES RESEARCH AND DEVELOPMENT ESTABLISHMENT.	FIG. N° 12

ANGULAR MOVEMENT OF 17 PR. MUZZLE WITH BRAKE.

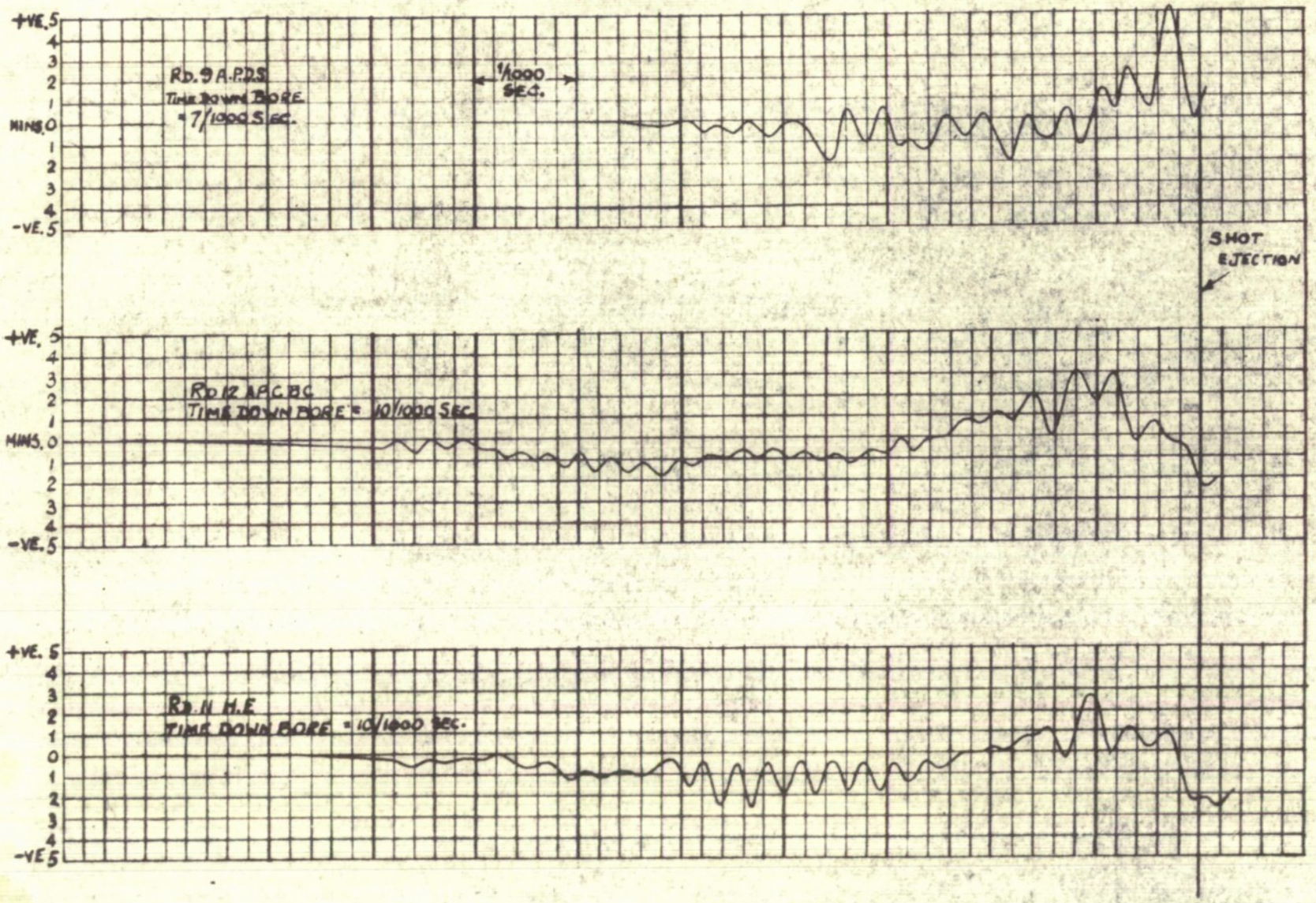


REPORT Nº B R 147
FIGURE 13.

VERTICAL ANGULAR MOVEMENT OF 17PR. MUZZLE WITH BRAKE

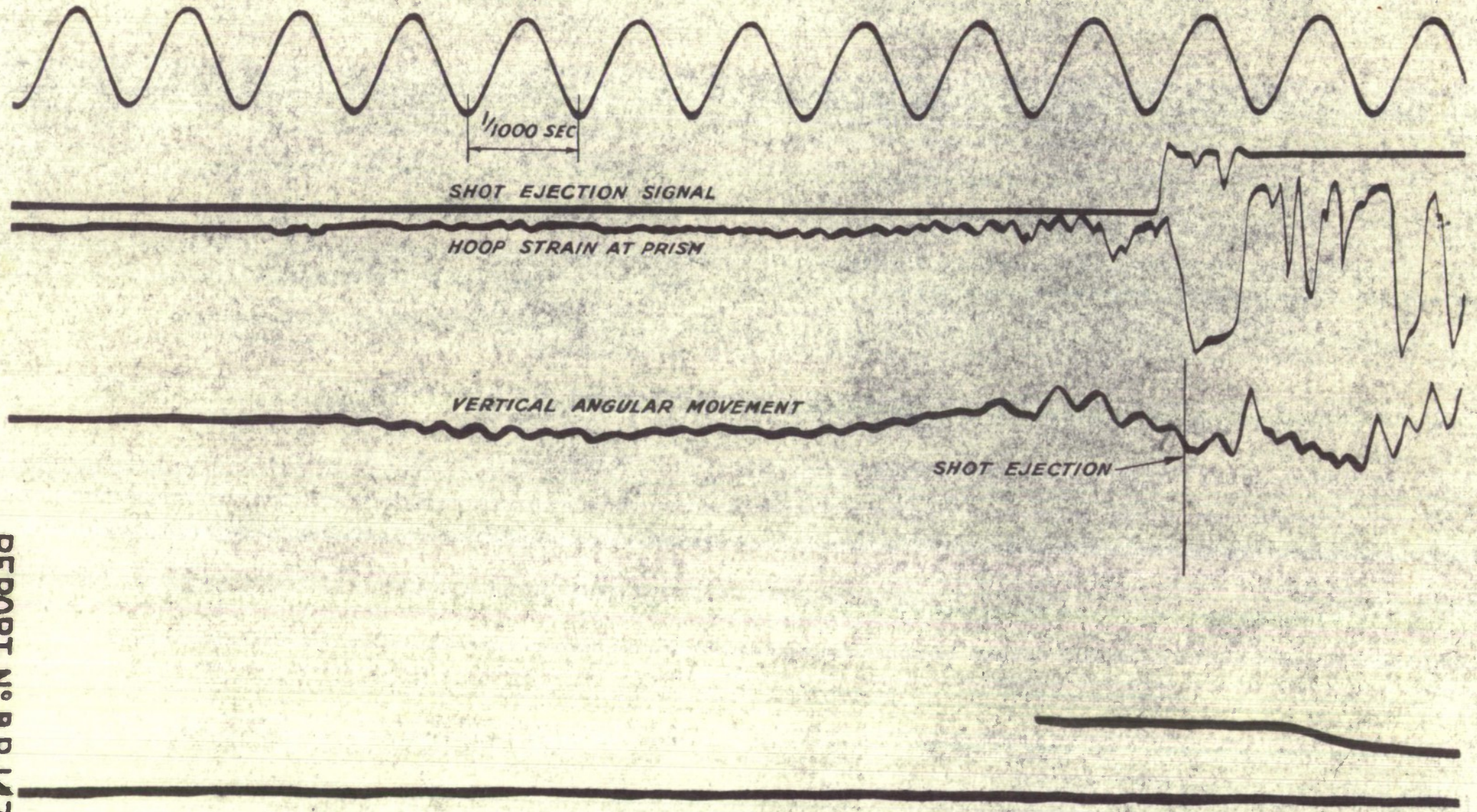
MOUNTING : FIELD

PRISM AT 12 O'CLOCK.



REPORT Nº BR 147
FIGURE 14.

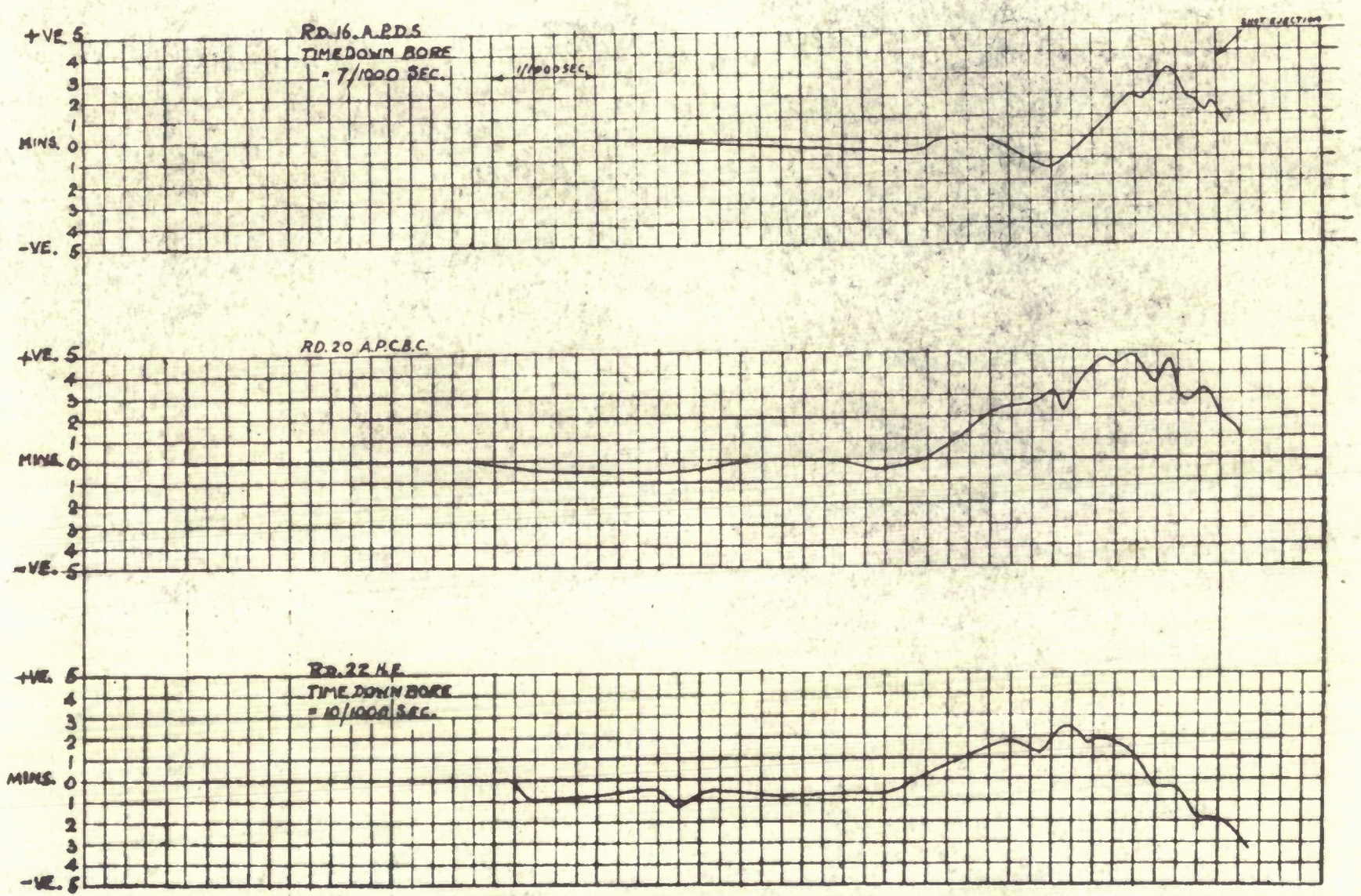
RD. 13 A.P.C.B.C. PRISM AT 3 O/CLOCK.



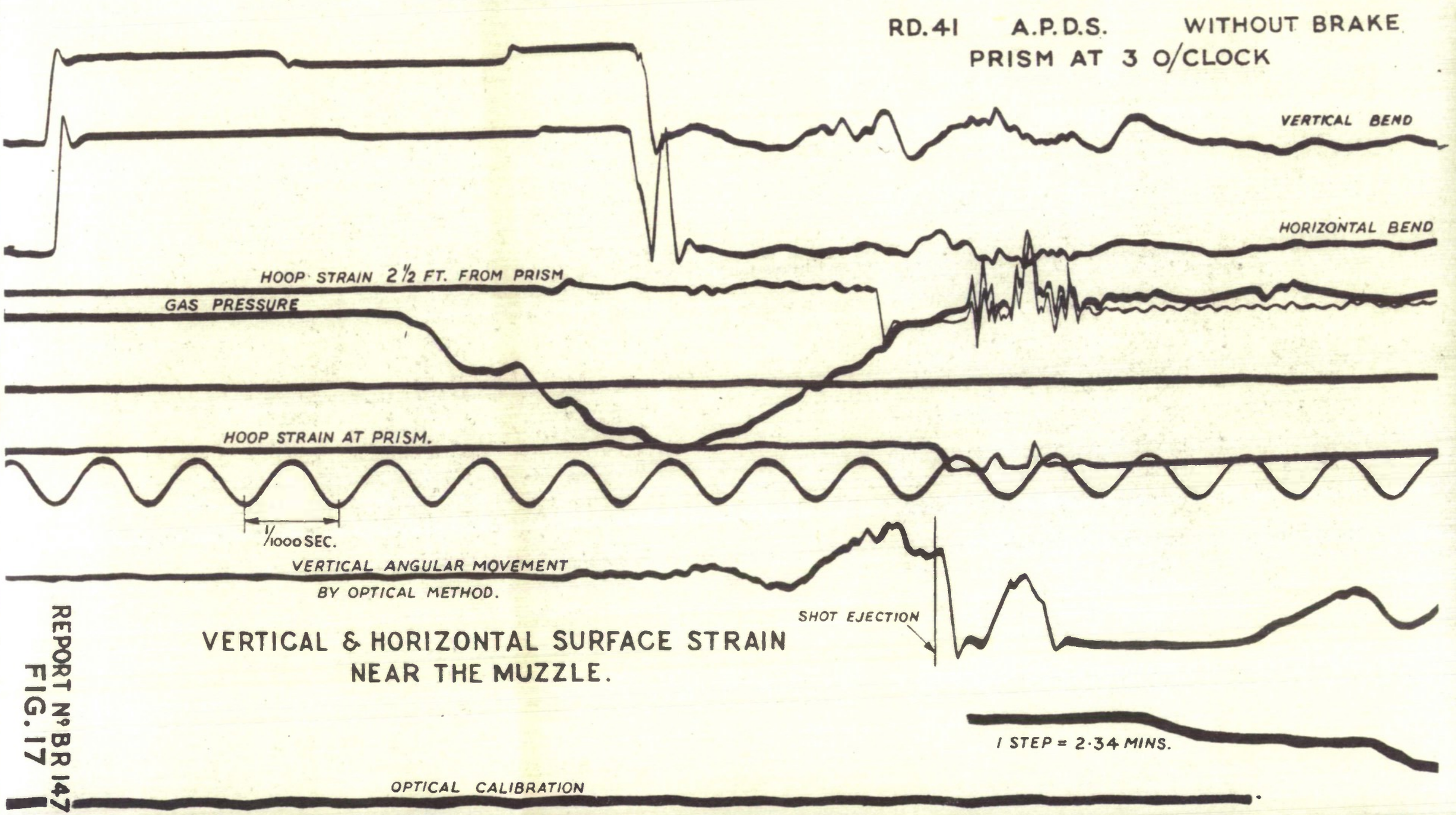
REPORT Nº BR 147
FIG. 15.

VERTICAL ANGULAR MOVEMENT OF 17PR. MUZZLE WITH BRAKE

MOUNTING: FIELD.
PRISM AT 3 O'CLOCK



REPORT No. B R 147
FIGURE 16.



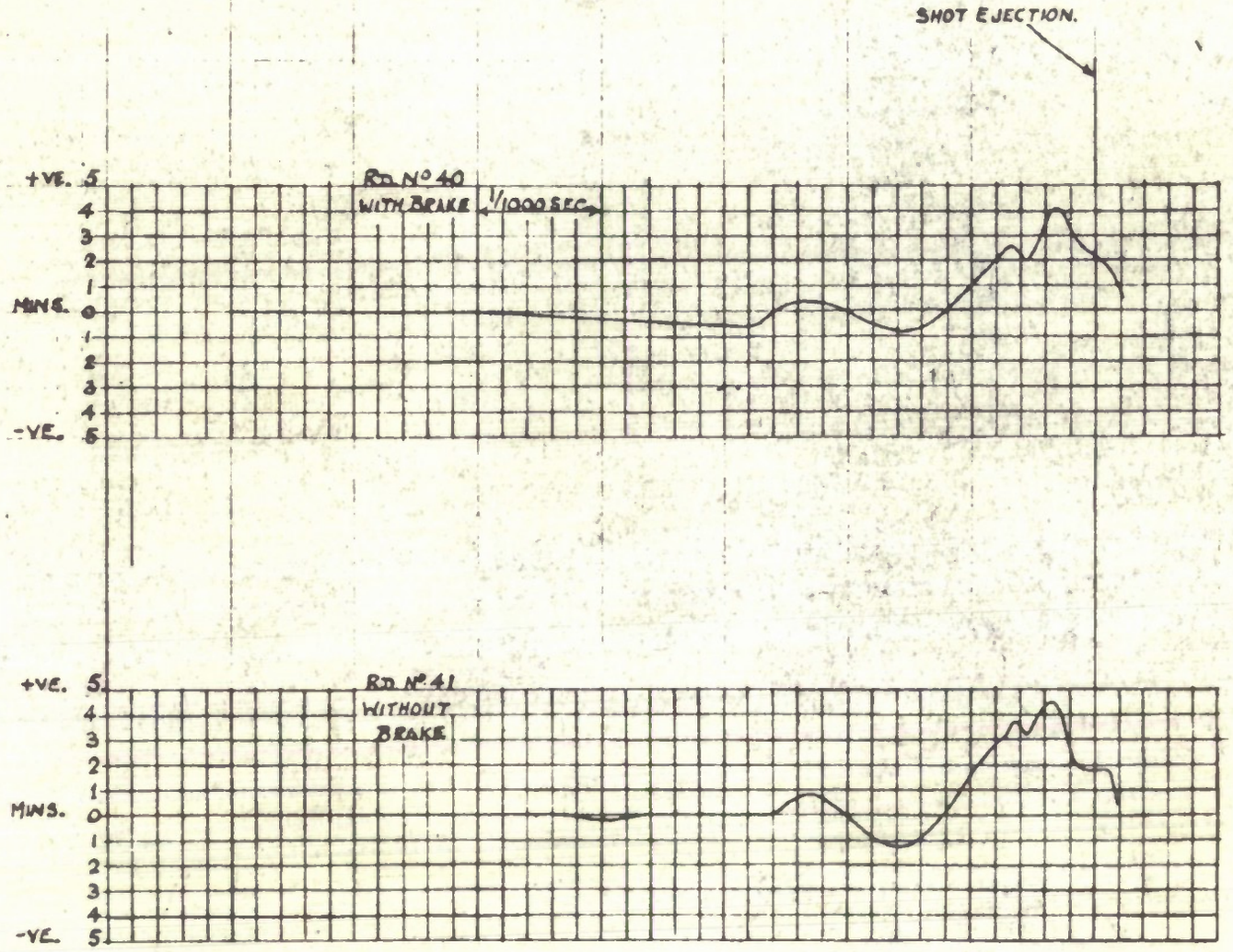
VERTICAL & HORIZONTAL SURFACE STRAIN
NEAR THE MUZZLE.

REPORT Nº BR 147
FIG. 17

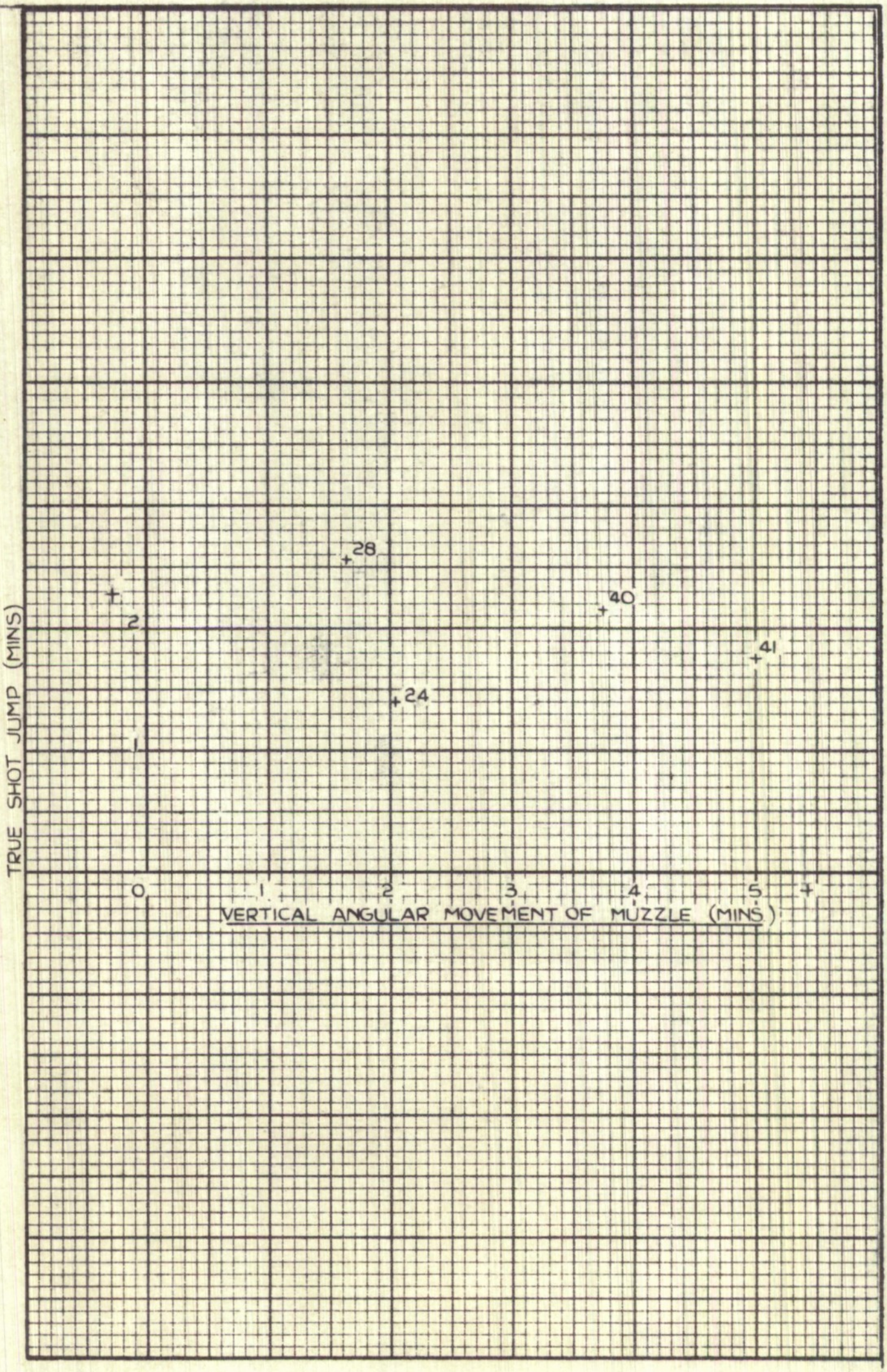
VERTICAL ANGULAR MOVEMENT OF 17 PR. MUZZLE

MOUNTING: FIELD

A.P.D.S.



REPORT No BR 147
FIGURE 18.



JUMP / ANGULAR MOVEMENT 17 PR. A.P.D.S. FIELD MOUNTING. CHARGE : 6 LBS 10 OZS. N.H. 033.	REPORT Nº B.R. 147.
FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.	FIG. Nº 19.

JUMP / ANGULAR MOVEMENT 17 PR A.P.C.B.C. FIELD MOUNTING CHARGE: 8 LBS 2 OZS N.H. 055.	REPORT Nº BR. 147.
FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.	FIG. Nº 20

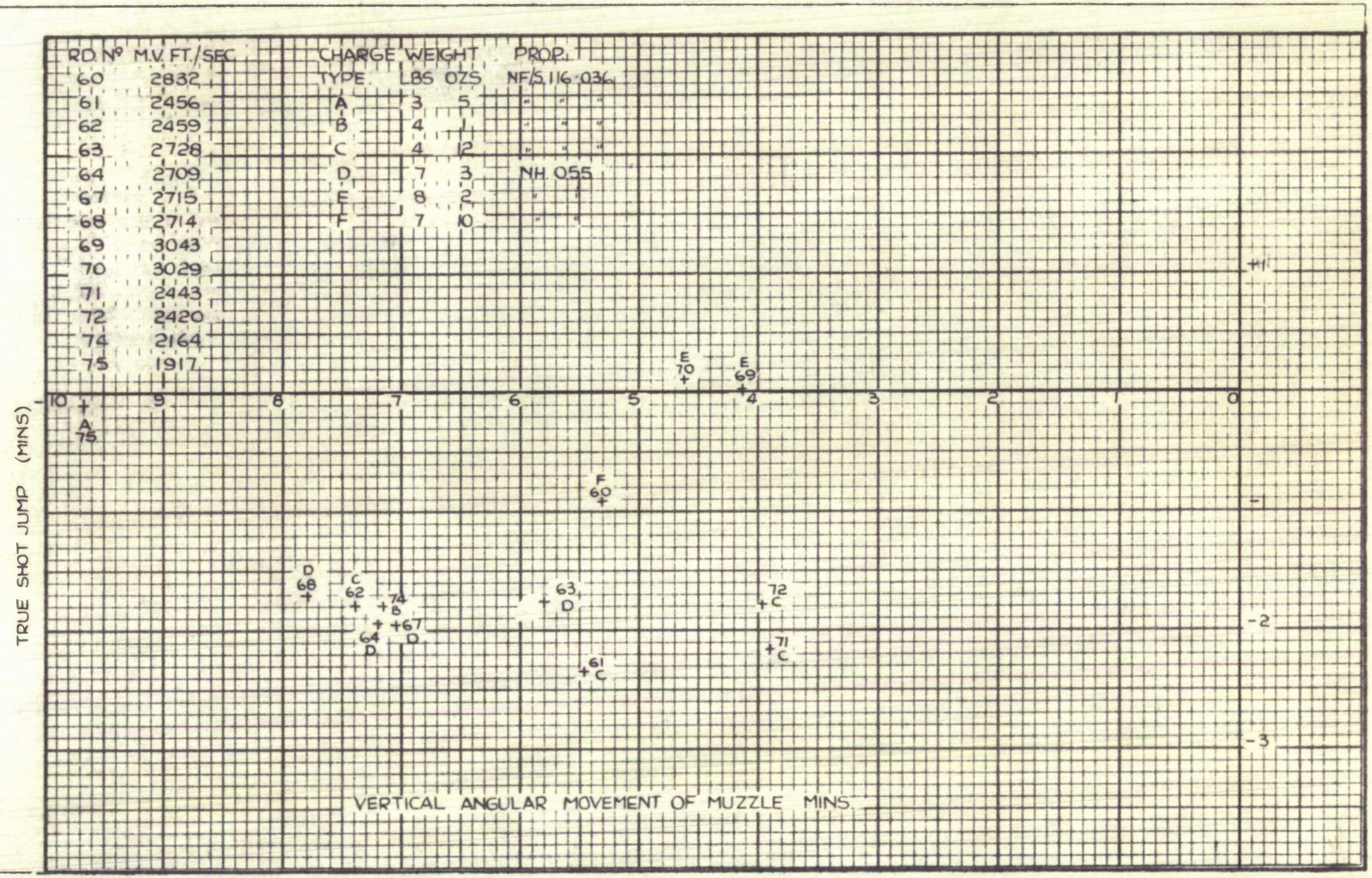
JUMP/ ANGULAR MOVEMENT 17 PR A.P.C.B.C. SHOT FIELD MOUNTING CHARGE N.H. 055 8 LBS 2 OZS	REPORT Nº B.P. 147.
FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.	FIG. Nº 21.

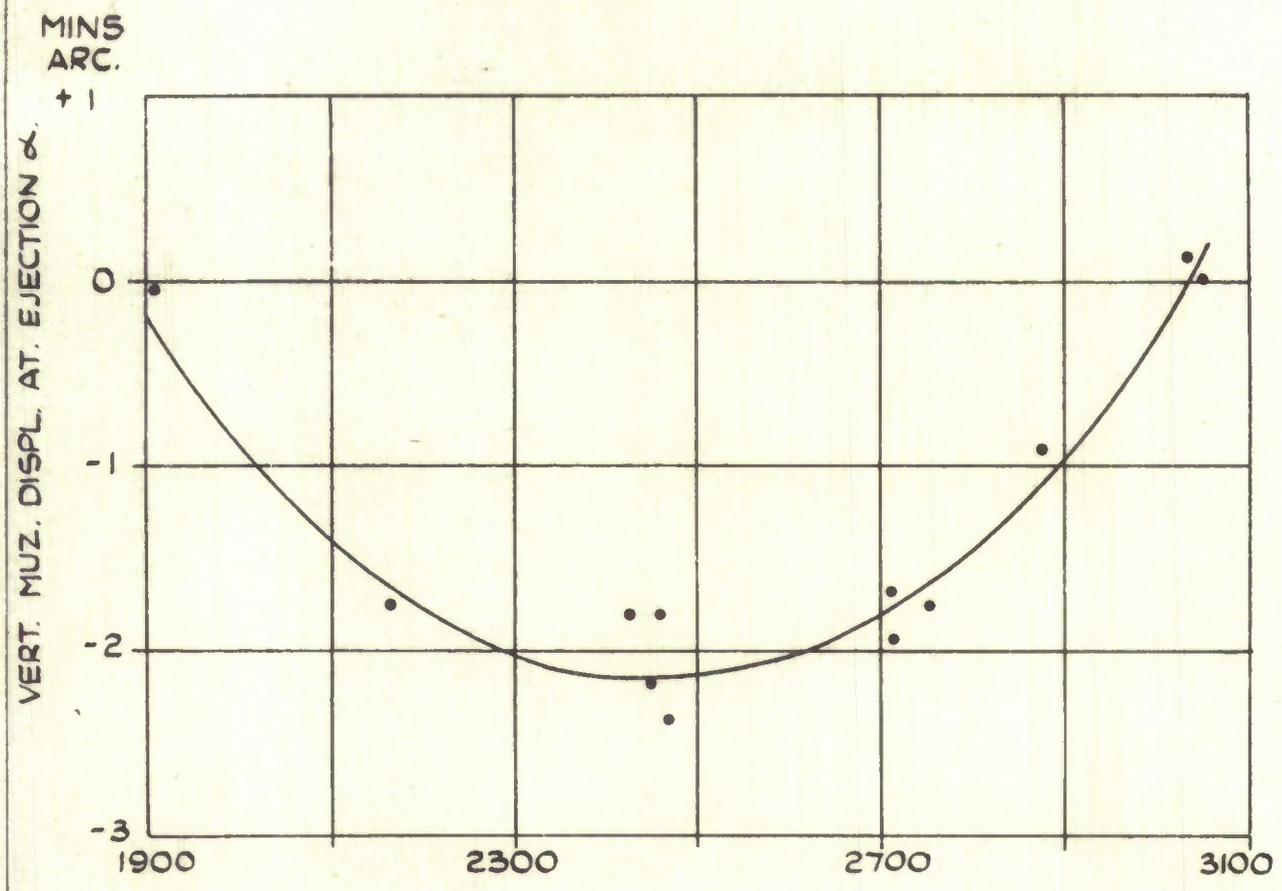
JUMP/ANGULAR MOVEMENT 17 PR APC B.C.
FIELD MOUNTING

REPORT No
B.R. 147

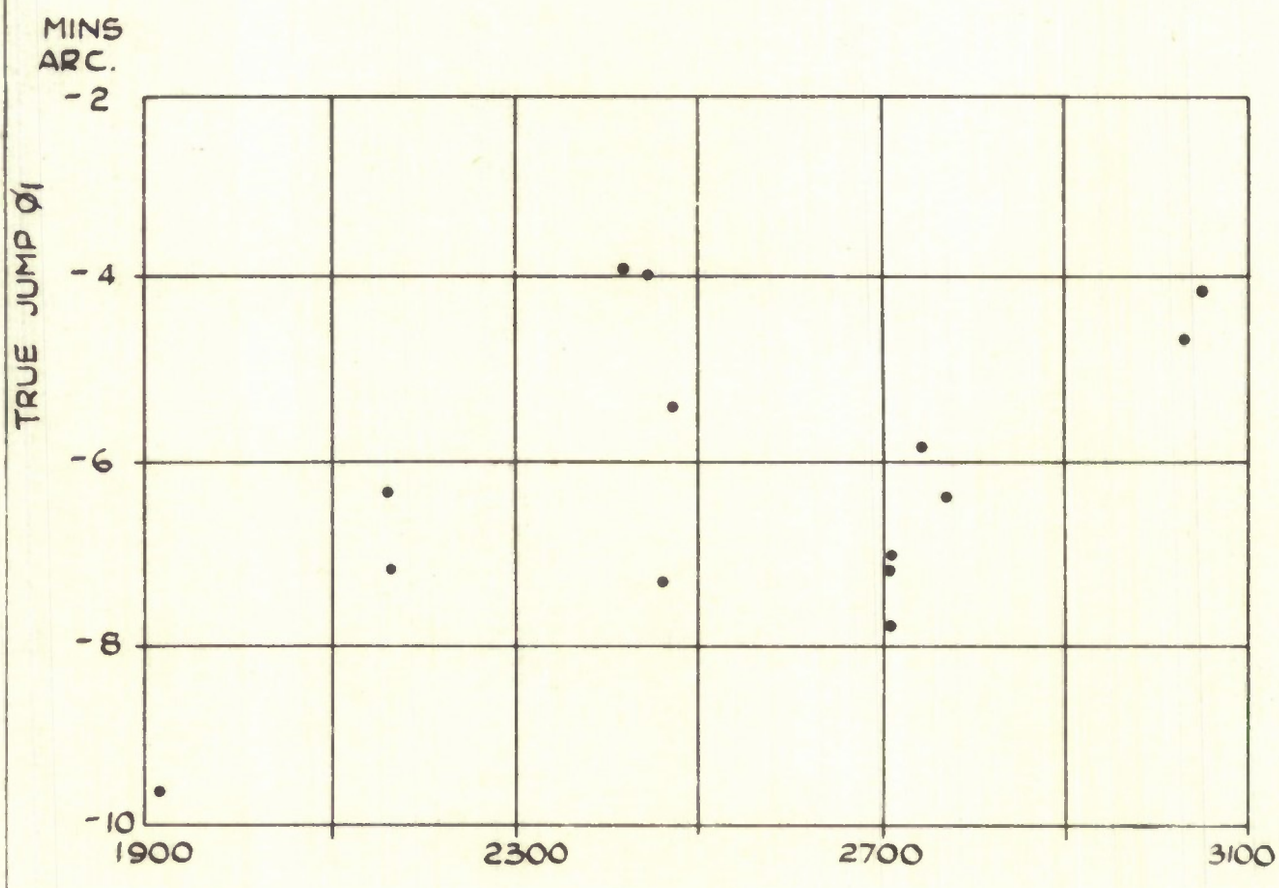
FIG. No. 22.

FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.



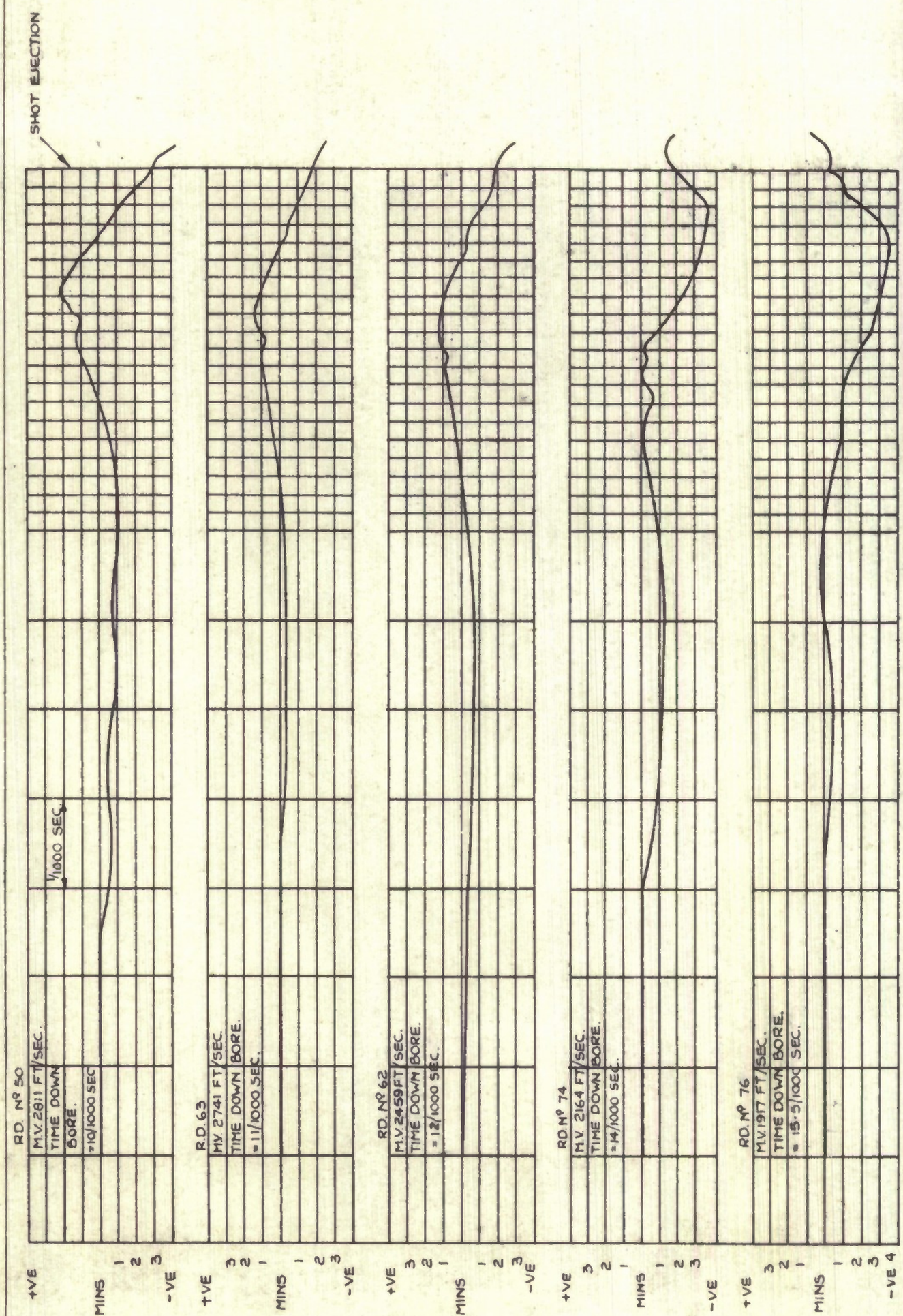


(a)



(b)

	REPORT N° BR. 147
FIGHTING VEHICLES RESEARCH AND DEVELOPMENT ESTABLISHMENT.	FIG. N° 23

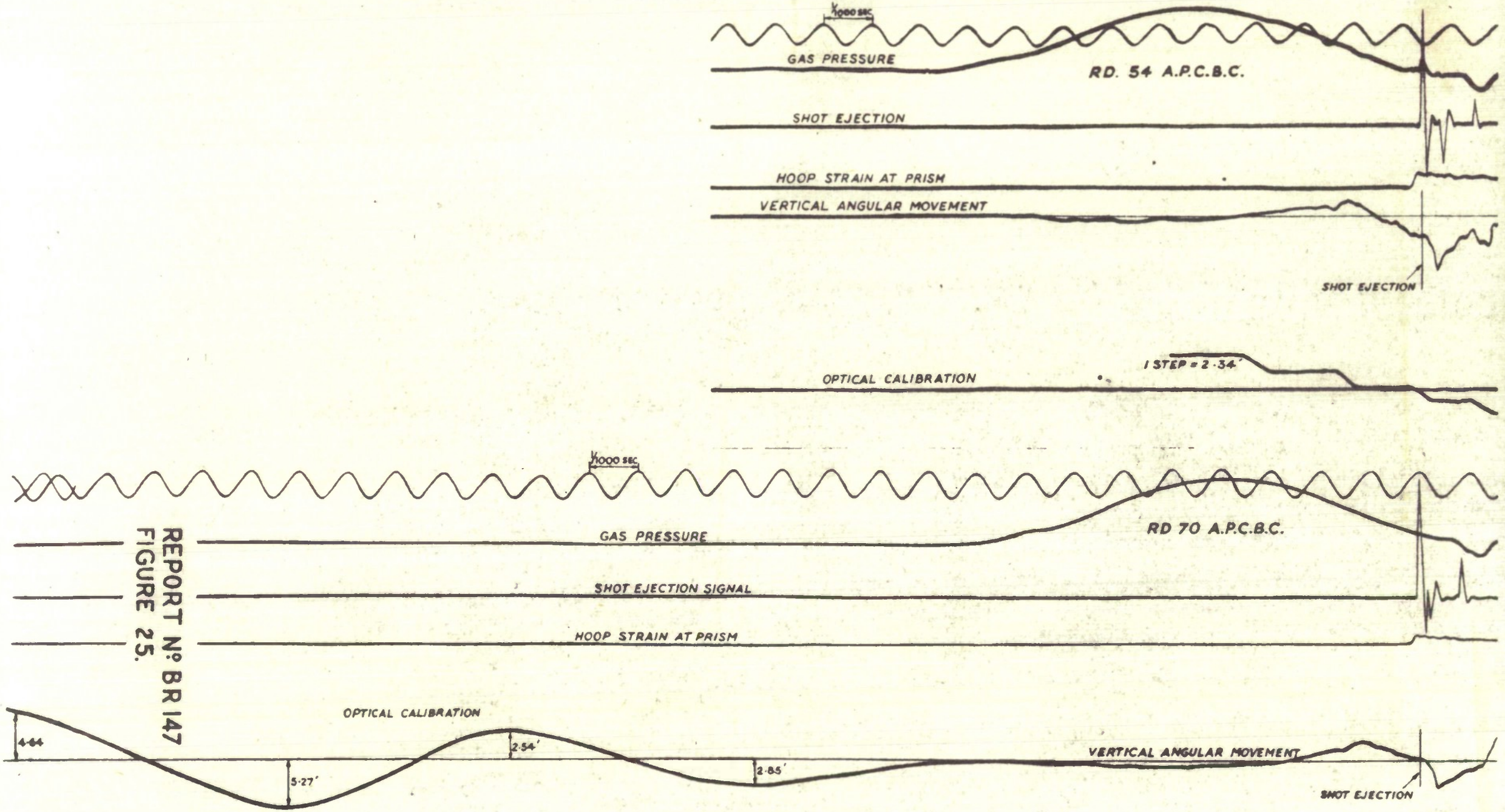


VERTICAL ANGULAR MOVEMENT OF 17 PR MUZZLE WITH BRAKE. FIELD MOUNTING A.P.C.B.C.

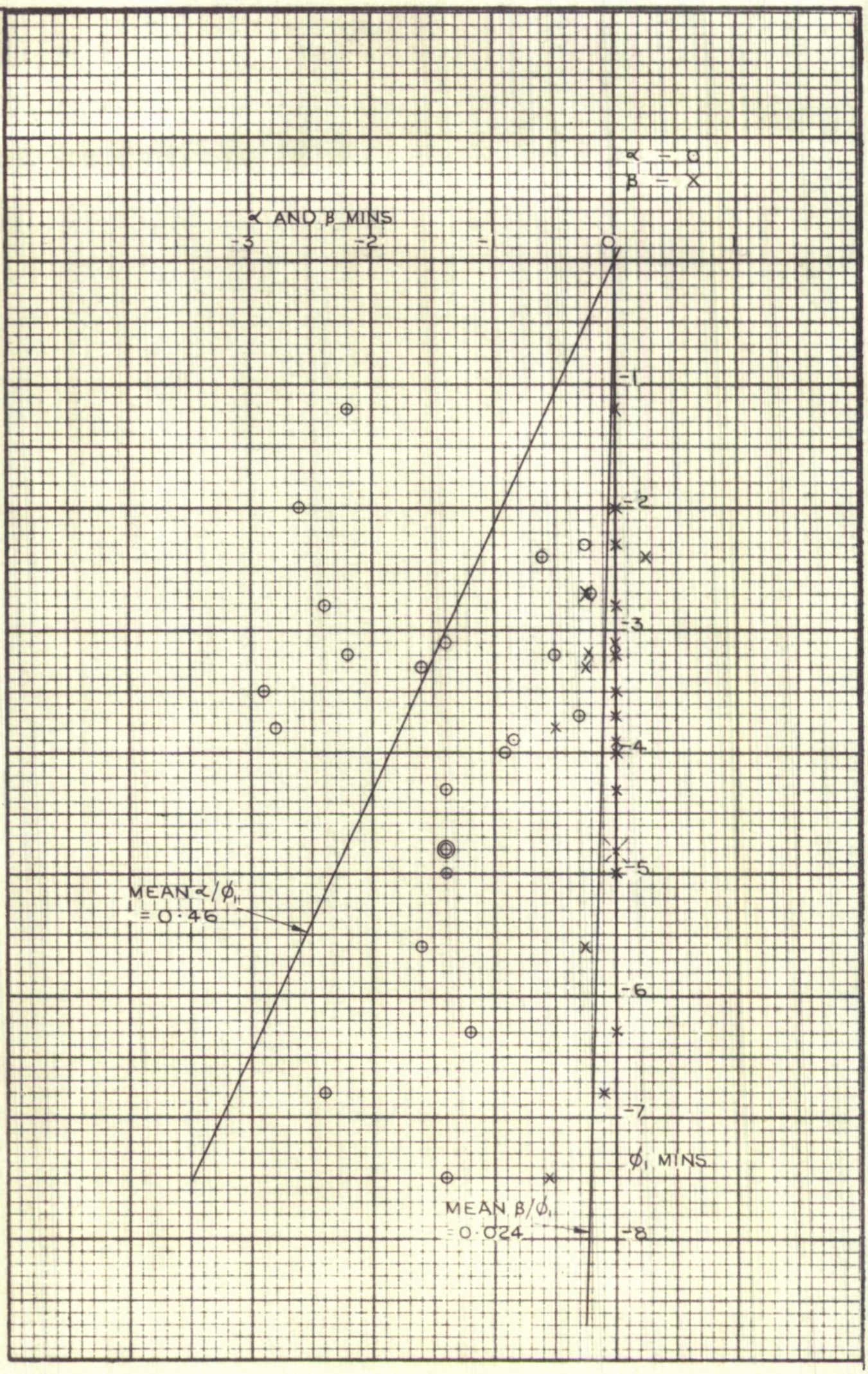
REPORT Nº B.R. 147.

FIGHTING VEHICLES RESEARCH AND DEVELOPMENT ESTABLISHMENT.

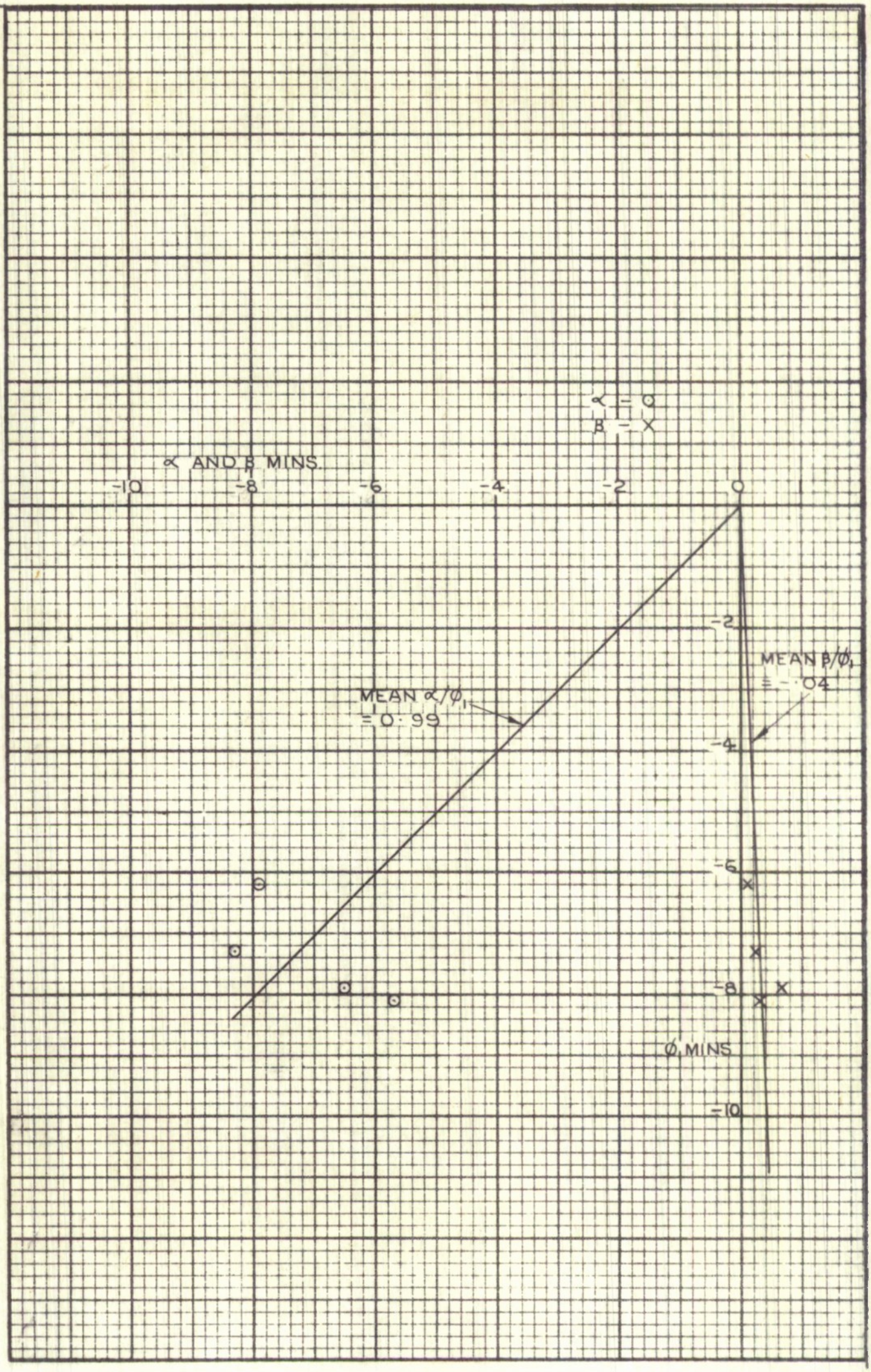
FIG. Nº 24.



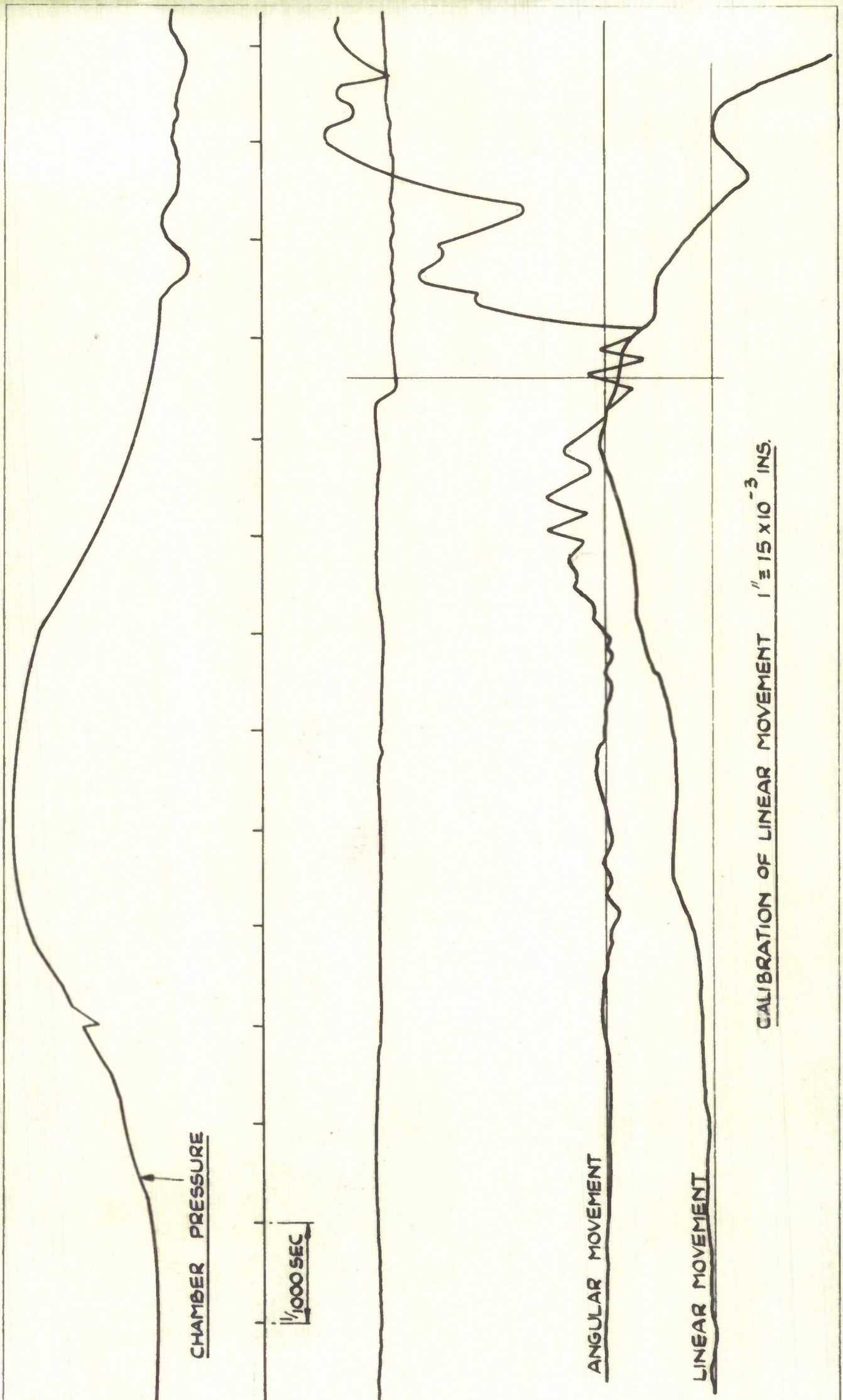
REPORT Nº BR 147
FIGURE 25.



RELATIONSHIPS α/ϕ_1 AND β/ϕ_1 (CHARGE F)	REPORT Nº B.R. 147
FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT	FIG Nº 26



RELATIONSHIPS α/ϕ_1 AND β/ϕ_1 (CHARGE A).	REPORT Nº B.R. 147
FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.	FIG. Nº 27

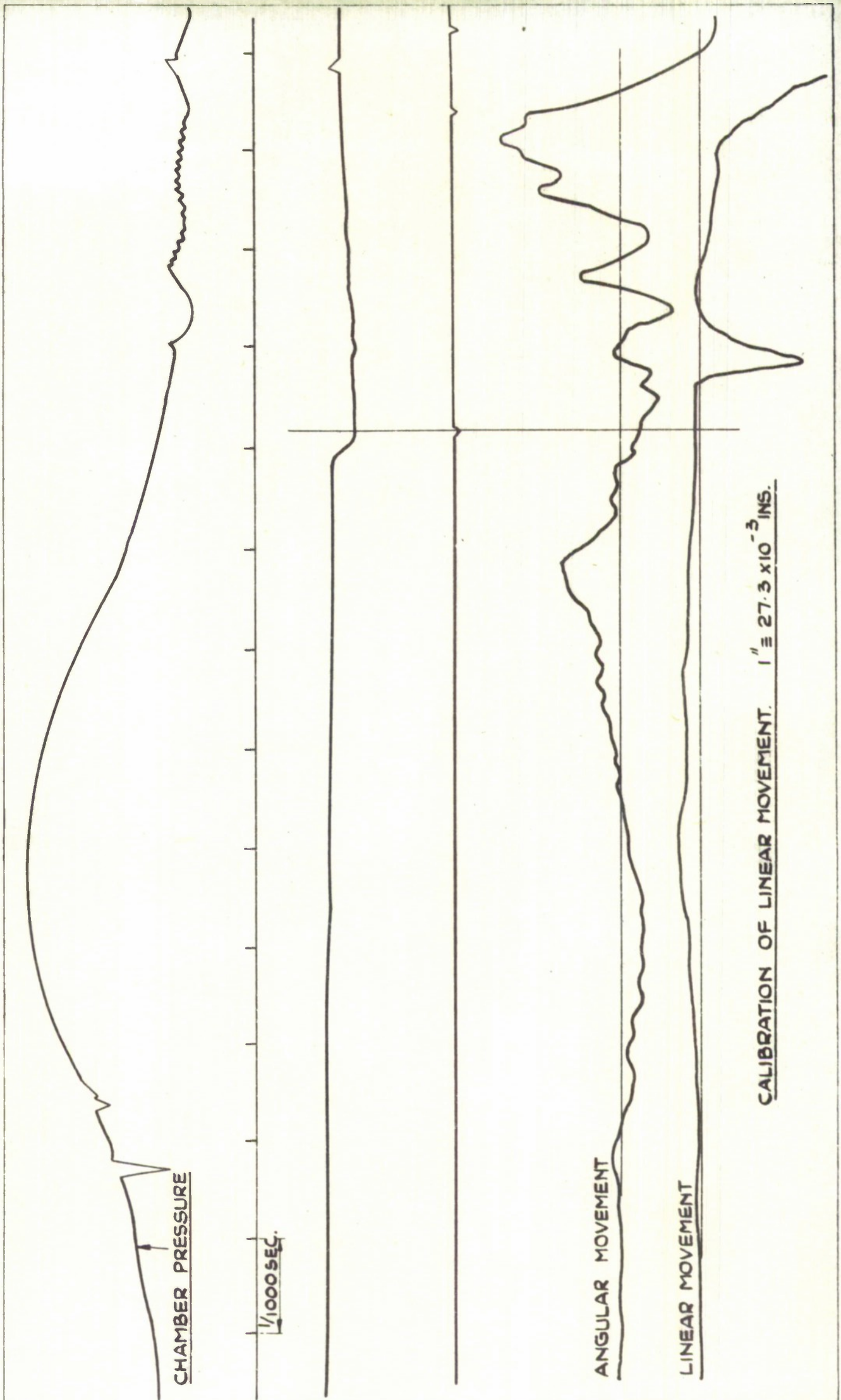


TYPICAL RECORD.

REPORT N° BR 147

FIGHTING VEHICLES RESEARCH AND DEVELOPMENT ESTABLISHMENT.

FIG. N° 28

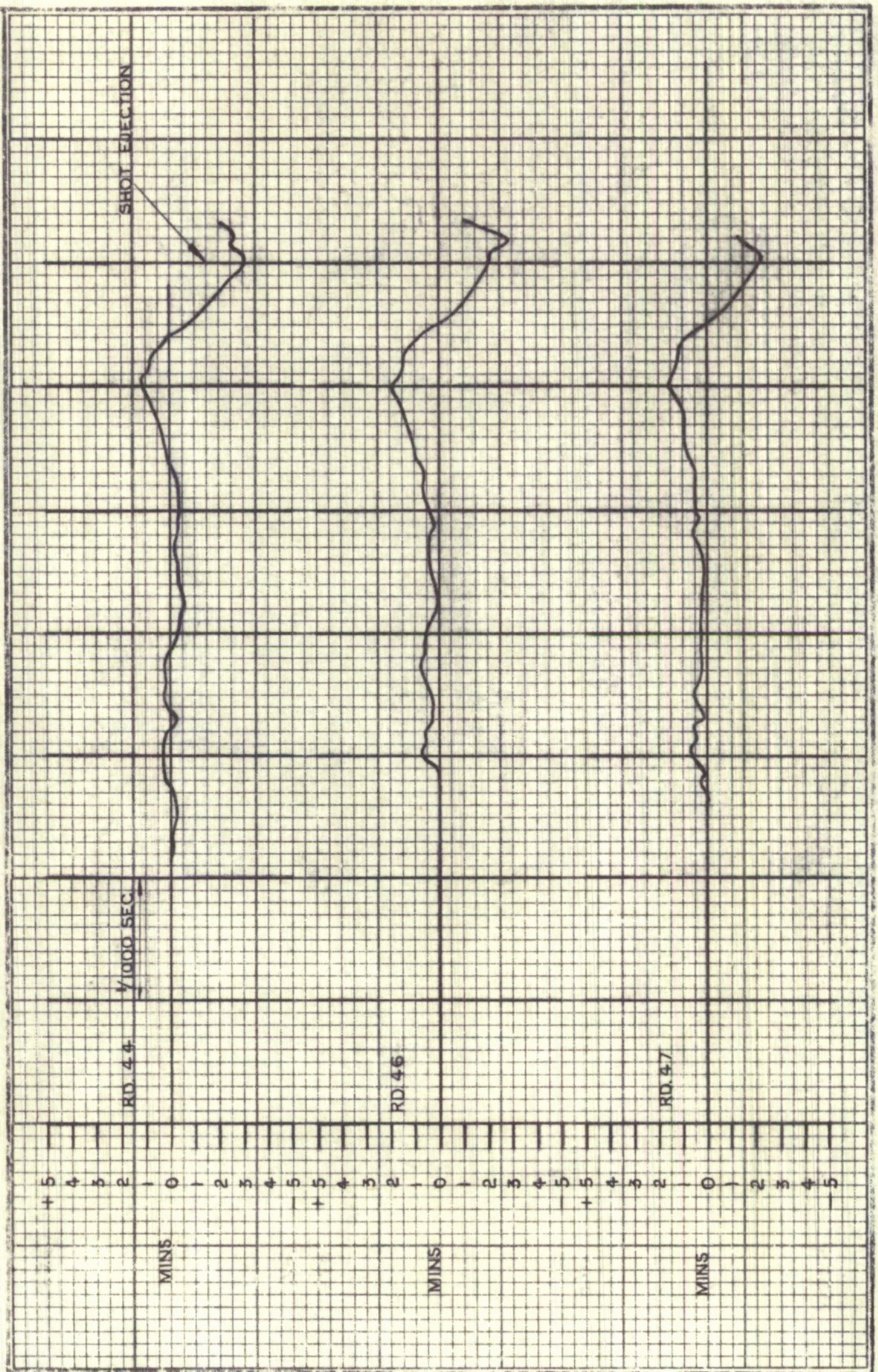


TYPICAL RECORD.

REPORT N° BR 147

FIGHTING VEHICLES RESEARCH AND DEVELOPMENT ESTABLISHMENT.

FIG. N° 29.

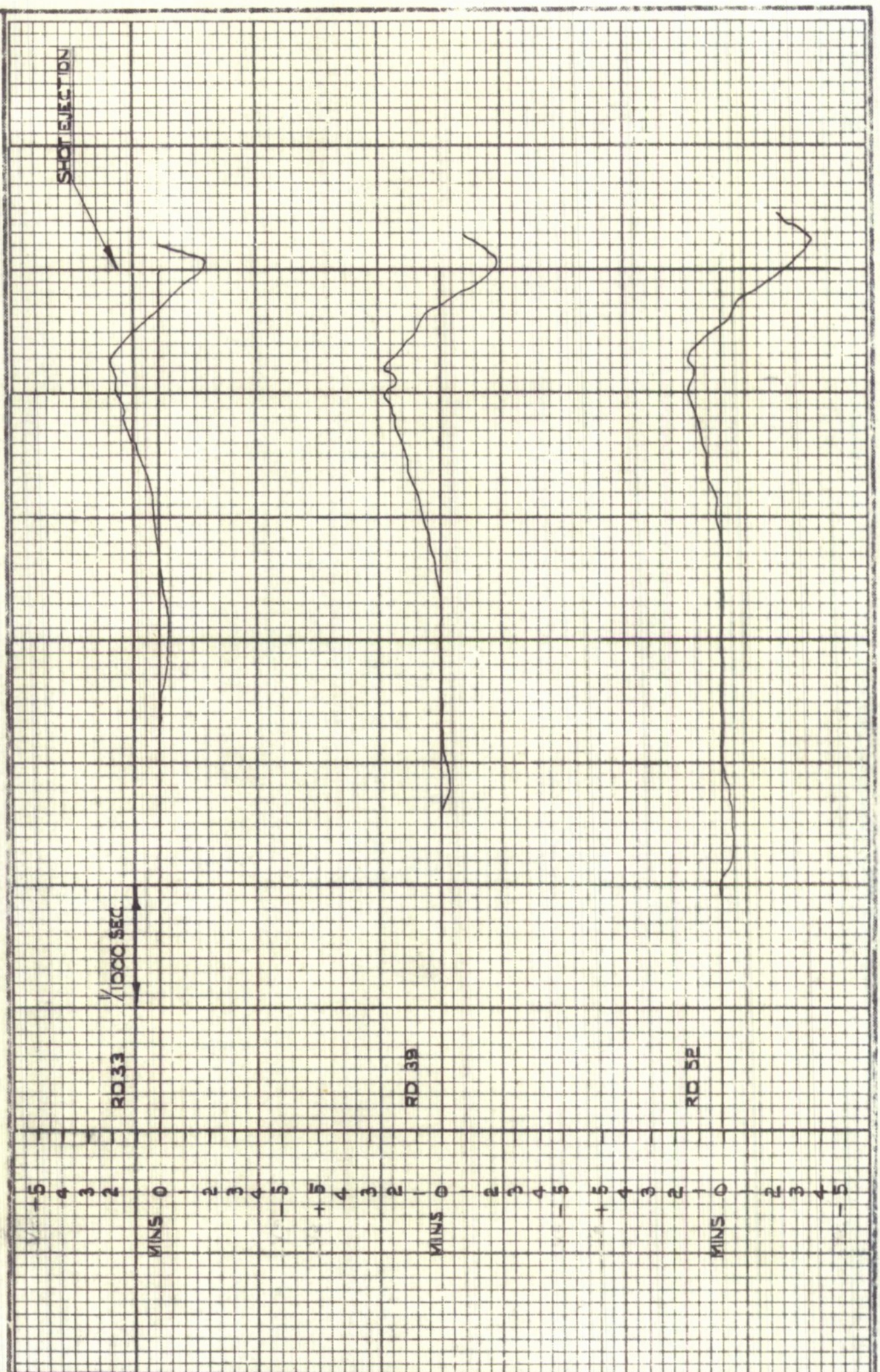


VERTICAL ANGULAR MOVEMENT OF MUZZLE
6 PR. 7 CWT. Mk 4. FIELD MTG. WITH MUZZLE BRAKE
A P. C.B.C.

REPORT Nº B R 147.

FIGHTING VEHICLES RESEARCH & DEVELOPMENT EST.

FIG Nº 30

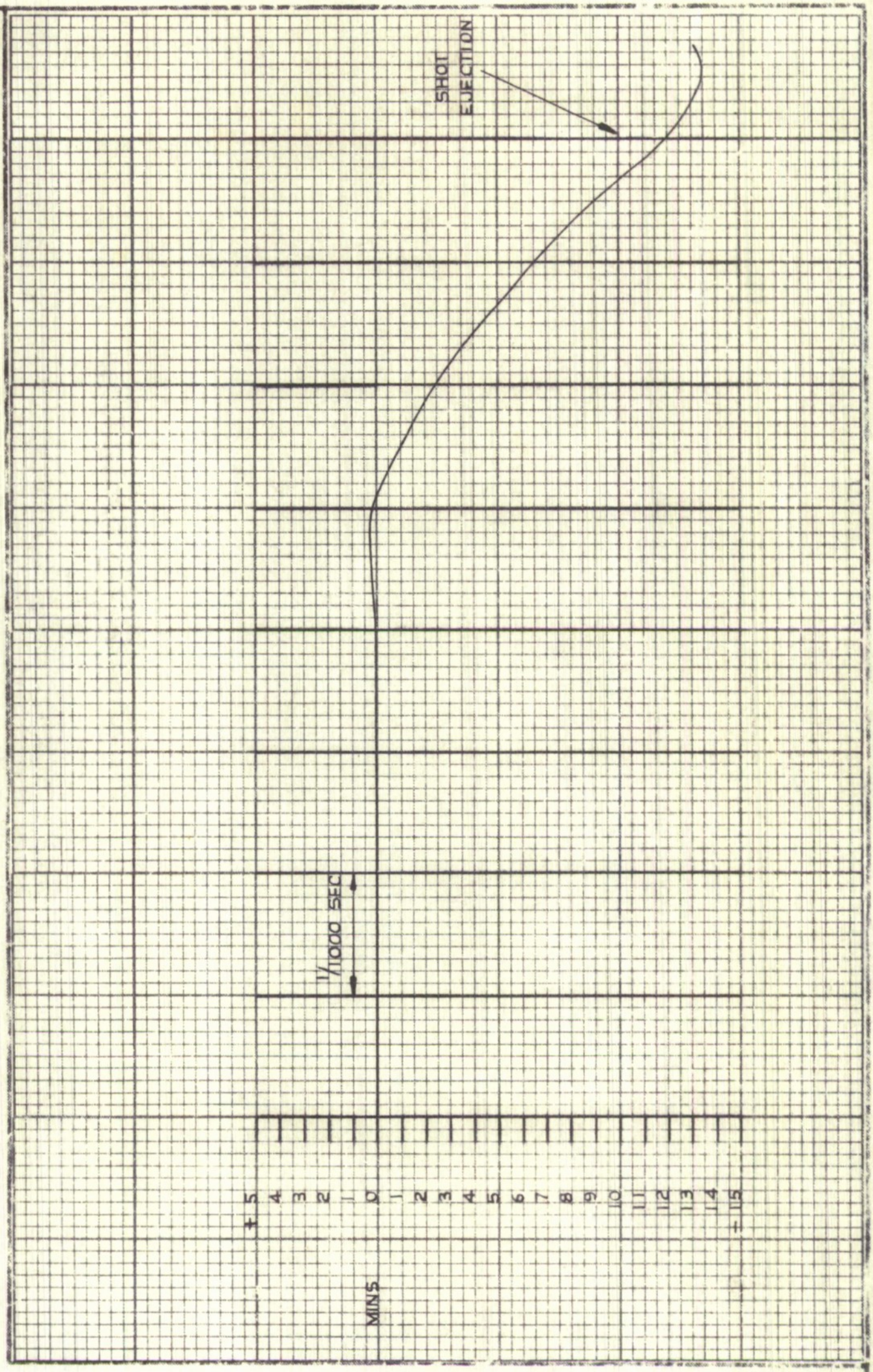


VERTICAL ANGULAR MOVEMENT OF MUZZLE.
6 PR. 7 CWT. MK. 4 FIELD MTG. WITH COUNTER WEIGHT
A.P.C.B.C.

REPORT Nº BR.147

FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTB.

FIG Nº 31.

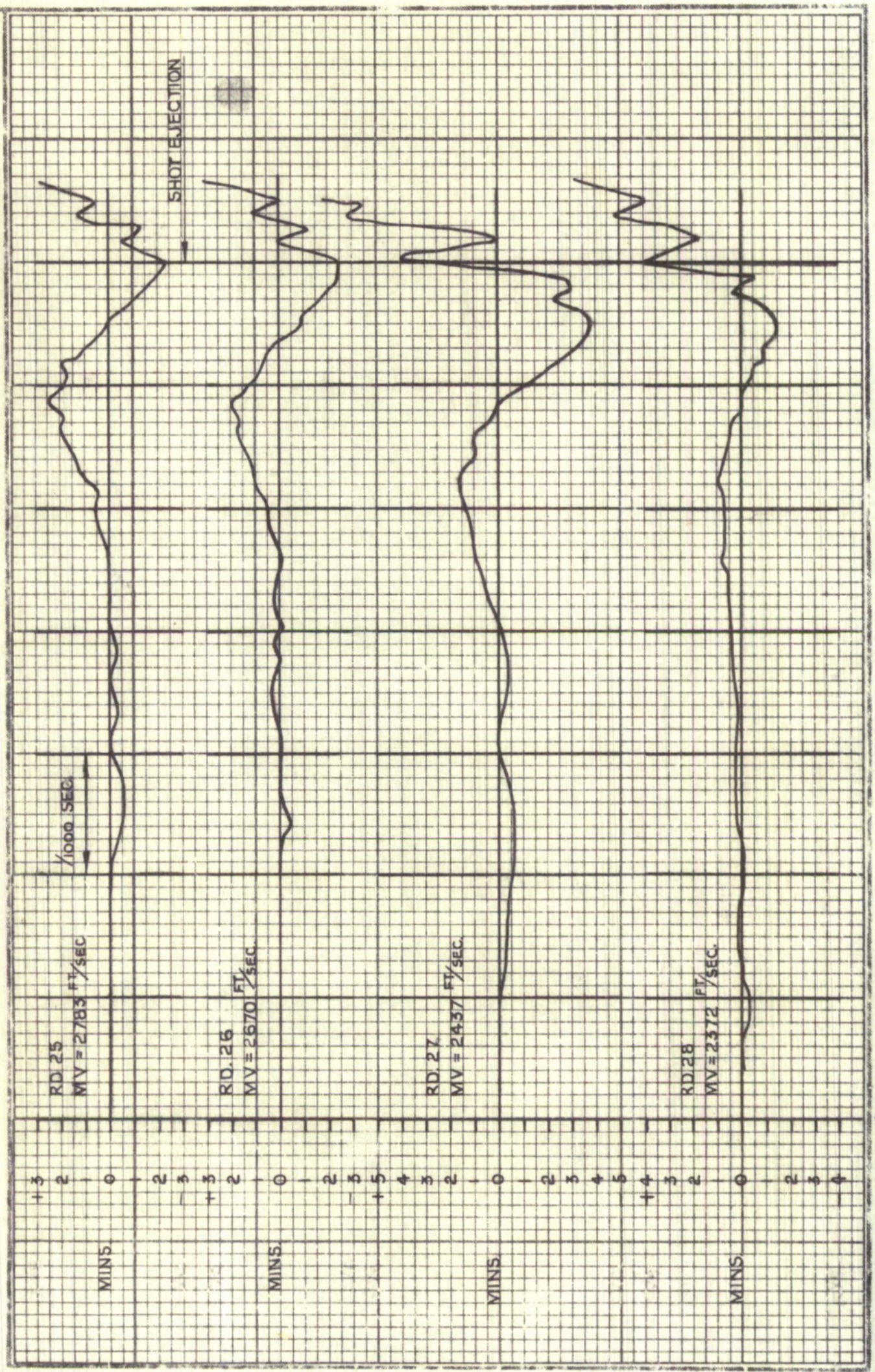


VERTICAL ANGULAR MOVEMENT OF MUZZLE
6 PR 7CWT Mk 4 FIELD MTG.
FROM A.R.D THEORETICAL RESEARCH REPORT Nº 9/45

REPORT Nº. B.R.147.

FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTB

FIG Nº. 32

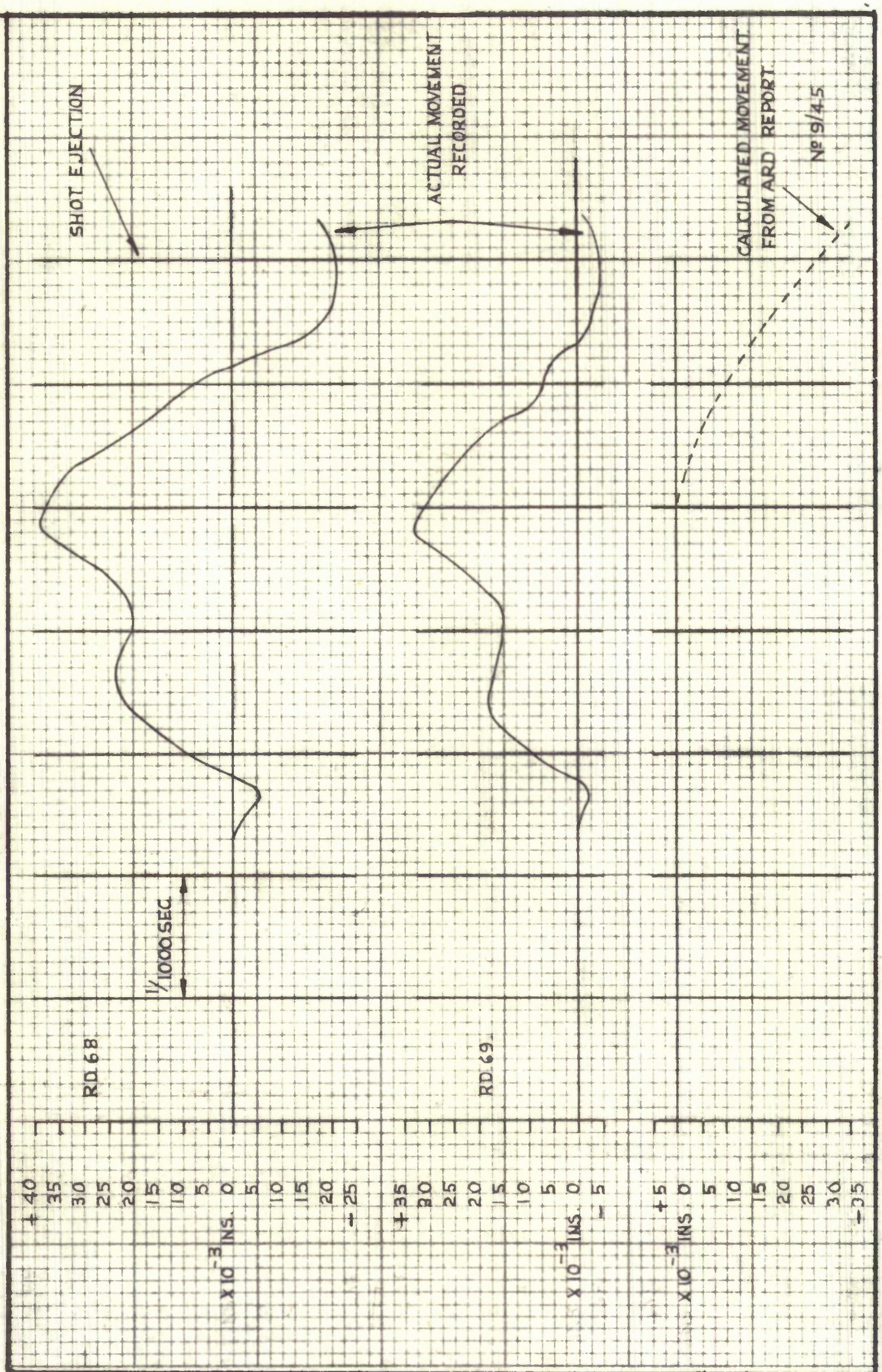


VERTICAL ANGULAR MOVEMENT OF MUZZLE
6 PR. 7 CWT. MK. 4 FIELD MTG. WITH MUZZLE BRAKE.
A.P.C. B.C. REDUCED CHARGES.

REPORT Nº B.R. 147

FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTB

FIG Nº 33



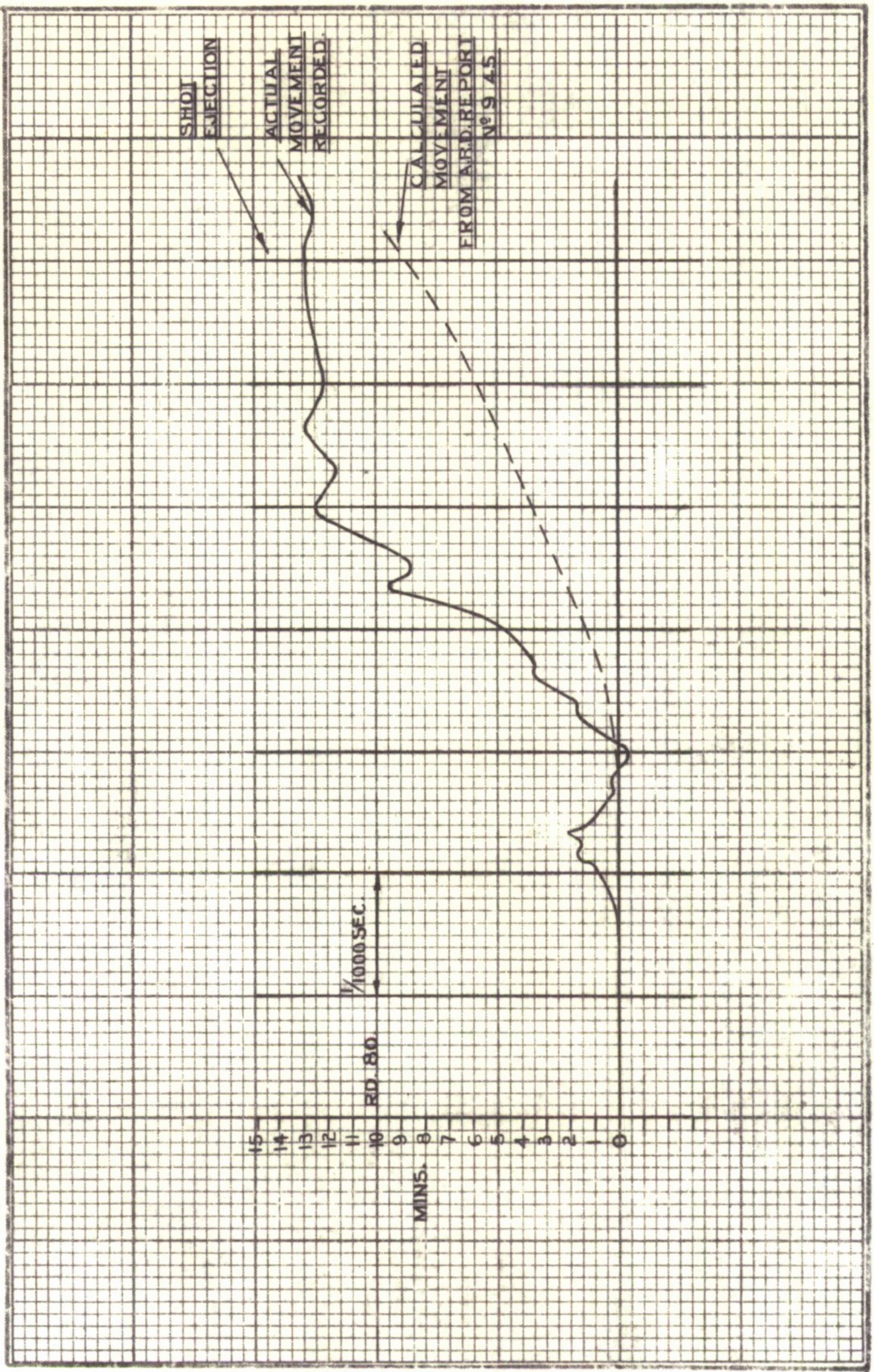
A.P.C.B.C

VERTICAL LINEAR MOVEMENT OF MUZZLE
6 PR. 7CWT. Mᴷ 4 FIELD MOUNTING WITH MUZZLE BRAKE
COMPARED WITH CALCULATED MOVEMENT A.R.D. REPORT Nº 9/45

REPORT No. B.R.147

FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTᴮ

FIG Nº 34



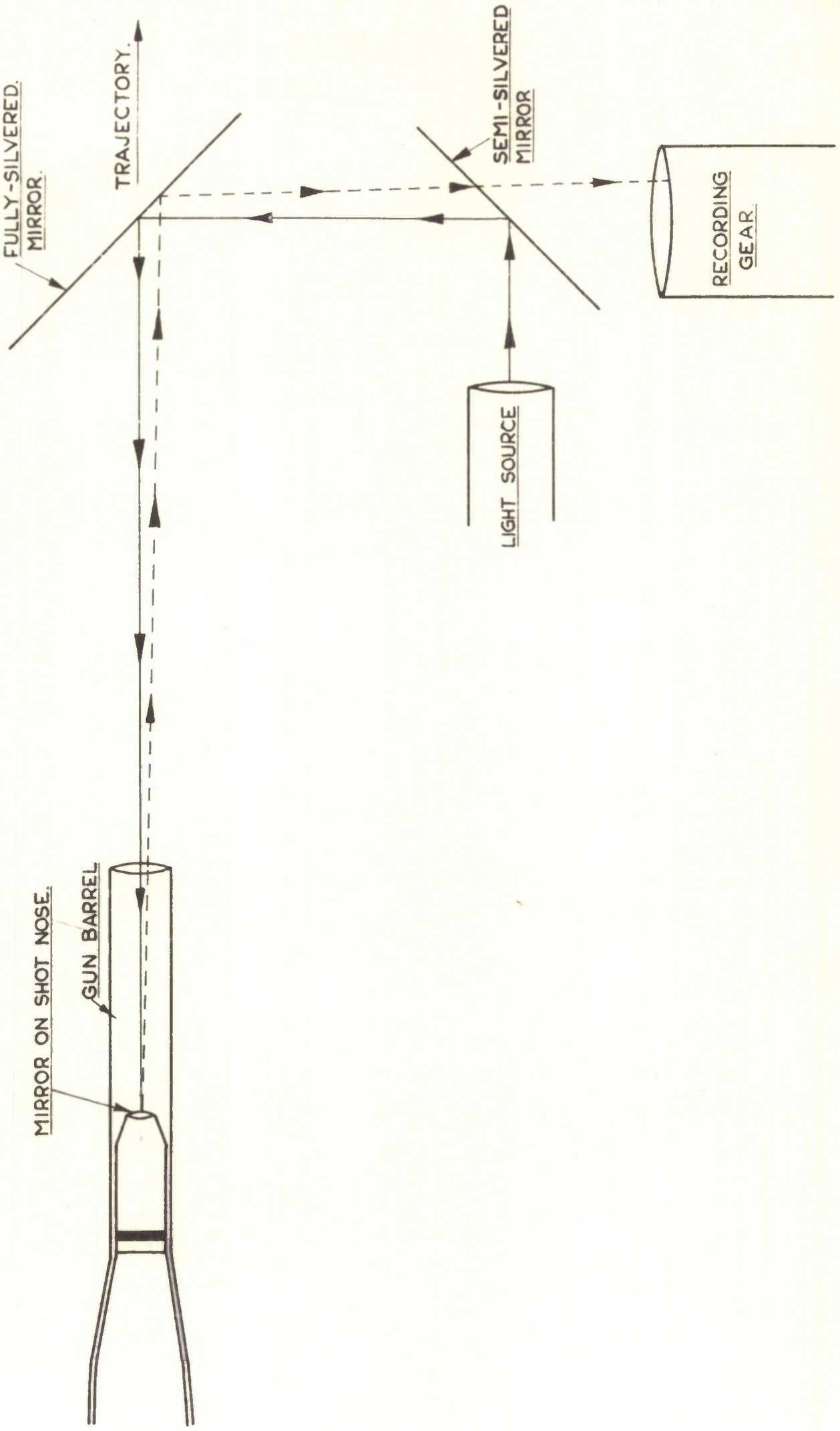
A.P.C.B.C.

VERTICAL ANGULAR MOVEMENT OF BREECH. 6PR.7CWT. MK.4 FIELD MOUNTING WITH COUNTER WEIGHT COMPARED WITH CALCULATED MOVEMENT. A.R.D. REPORT Nº 9/45

REPORT Nº B.R.147

FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTB.

FIG Nº 35

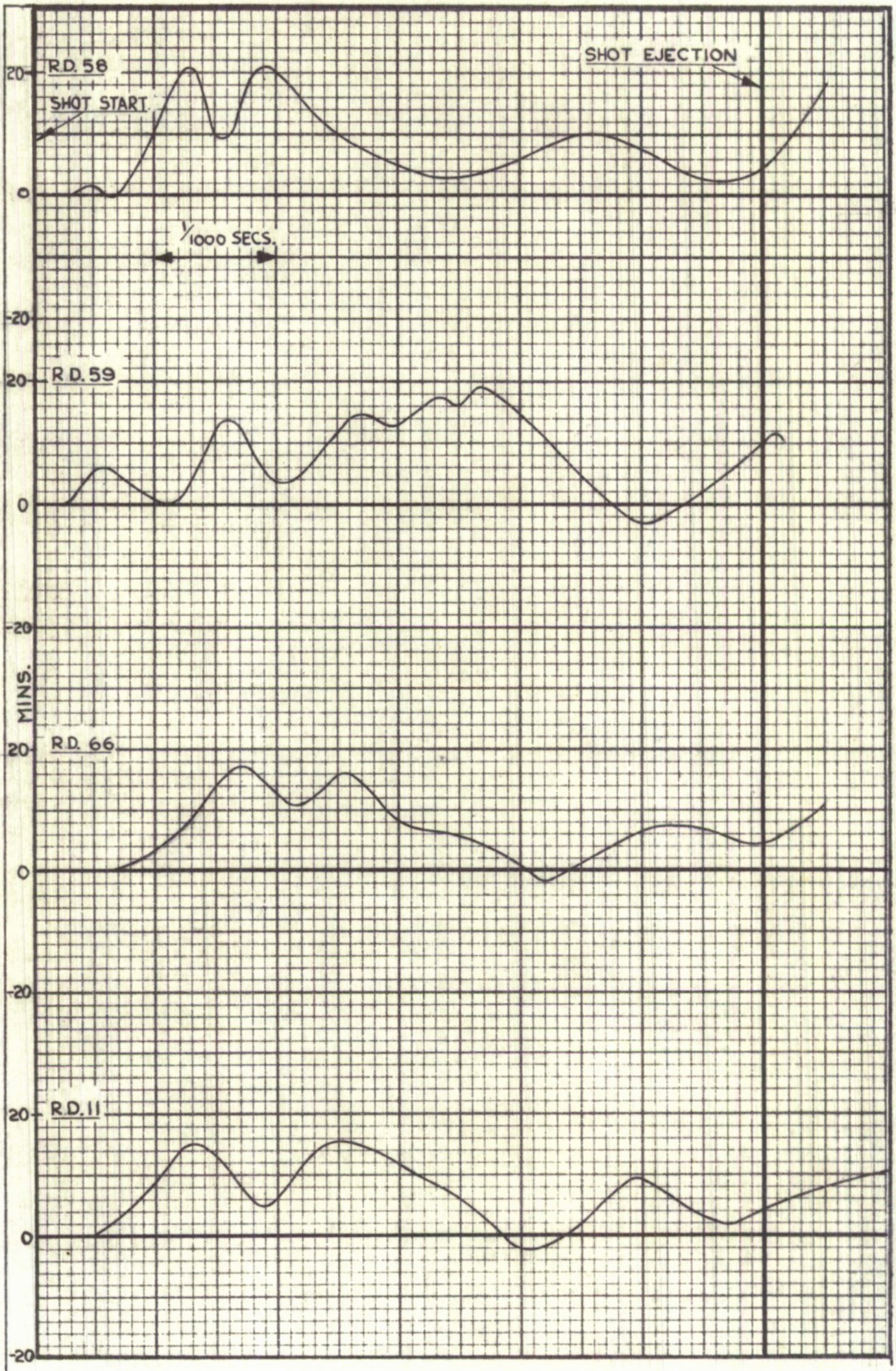


SYSTEM FOR RECORDING YAW IN THE BORE.

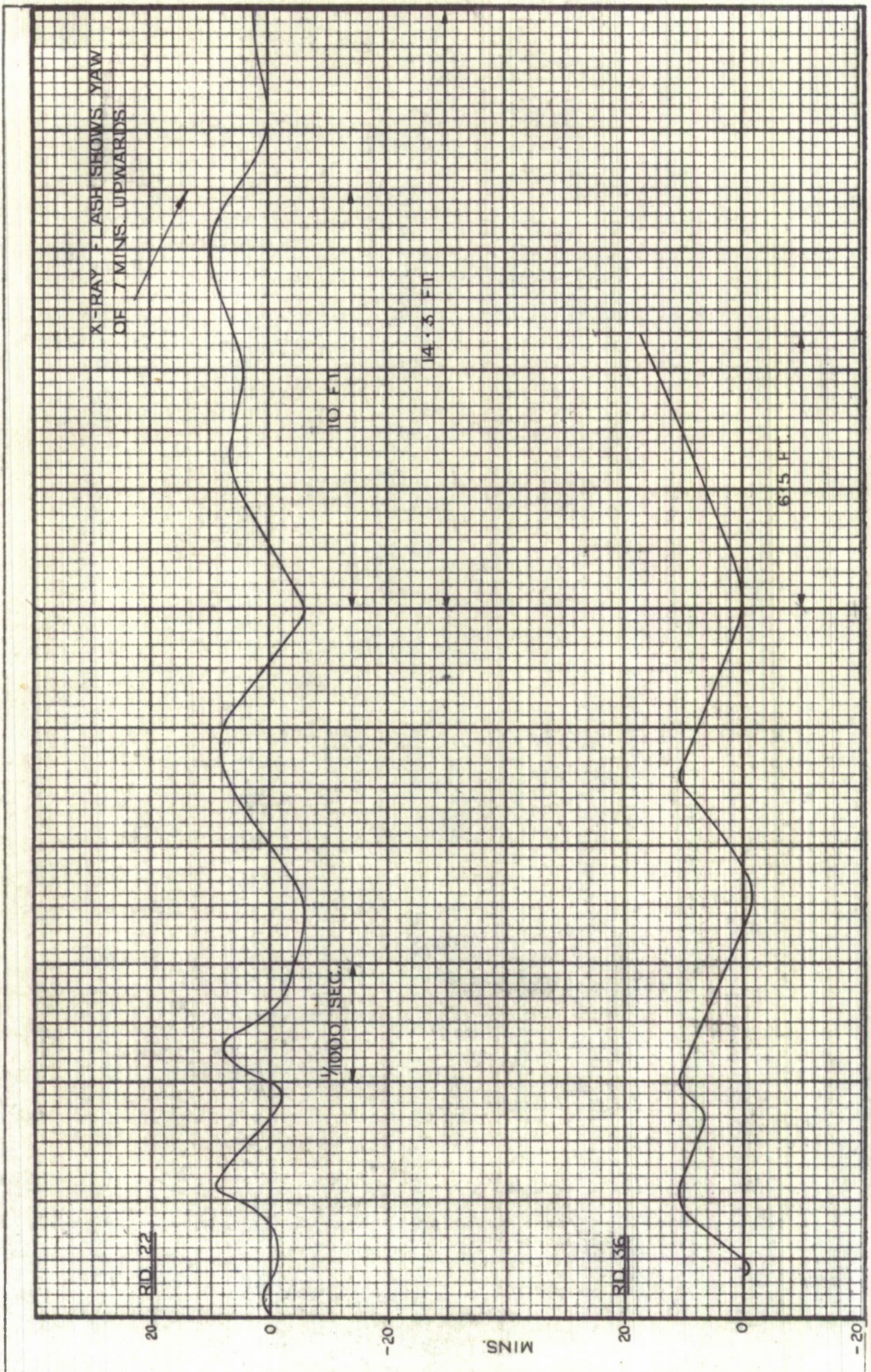
REPORT N° B.R. 147

FIGHTING VEHICLES RESEARCH AND DEVELOPMENT ESTABLISHMENT.

FIG N 36

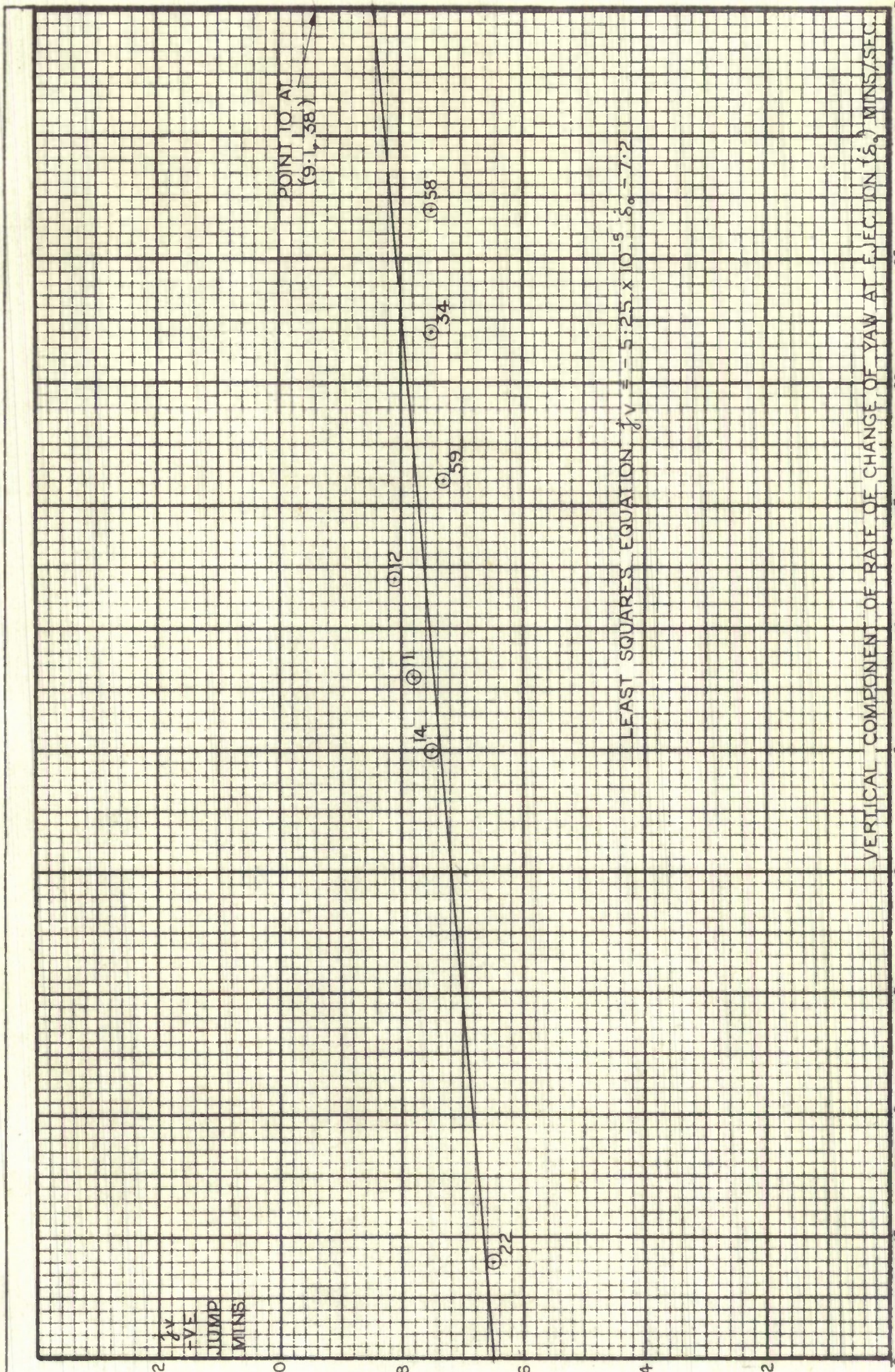


VERTICAL COMPONENT OF YAW IN THE BORE – TYPICAL RECORDS. 6. PR. FITTED WITH COUNTER WEIGHT	REPORT Nº B.R. 147
FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.	FIG. Nº 37



VERTICAL COMPONENT OF YAW IN THE BORE 6 PR. FITTED WITH COUNTER WEIGHT.	REPORT Nº B. R. 147
FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.	FIG. Nº 38

VERTICAL JUMP v AMPLITUDE OF VERTICAL COMPONENT OF YAW NEAR EJECTION – 6 PR.	REPORT Nº B.R. 147
FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.	FIG. Nº 39



VERTICAL JUMP v VERTICAL COMPONENT OF RATE OF CHANGE OF YAW AT EJECTION; 6 PR. MUZZLE FITTED WITH COUNTERWEIGHT.

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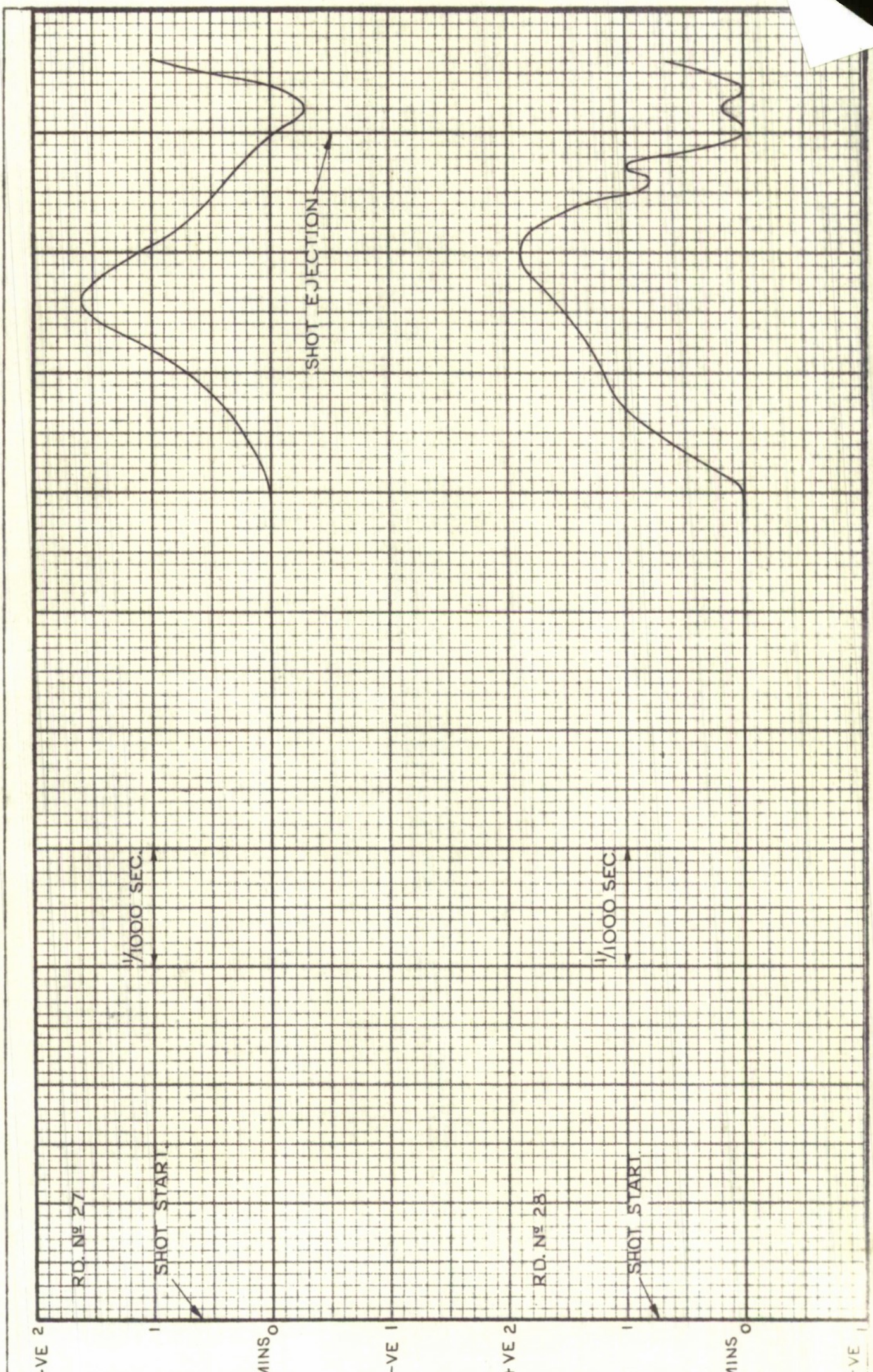
FIG. Nº 40

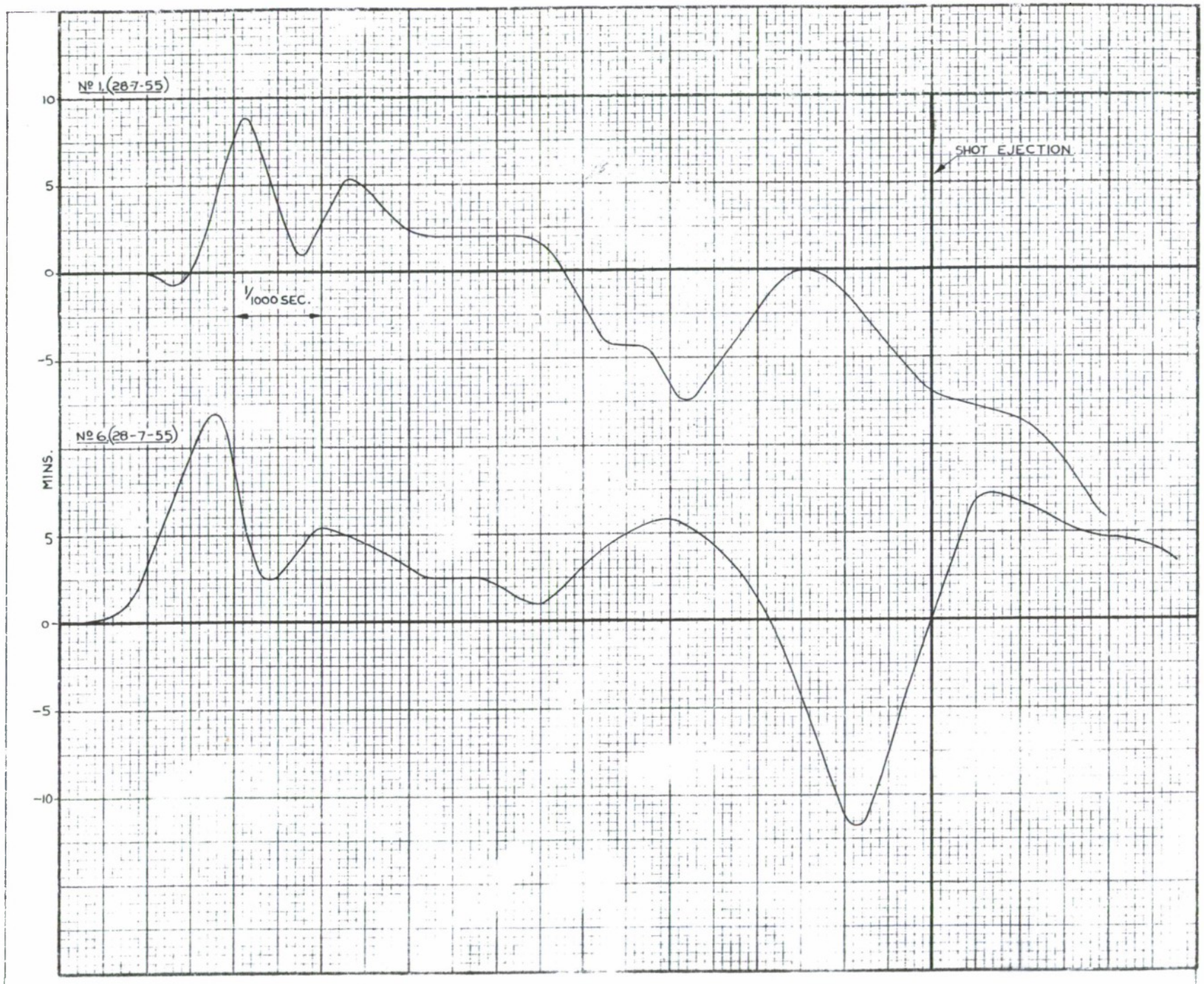


VERTICAL ANGULAR MOVEMENT OF MUZZLE
17 PR. TANK MTG.

REPORT Nº
B.R. 147

FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.

FIG. Nº 41



VERTICAL COMPONENT OF YAW IN THE BORE 17 PR. TANK MTG FITTED WITH MUZZLE BRAKE.

FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.

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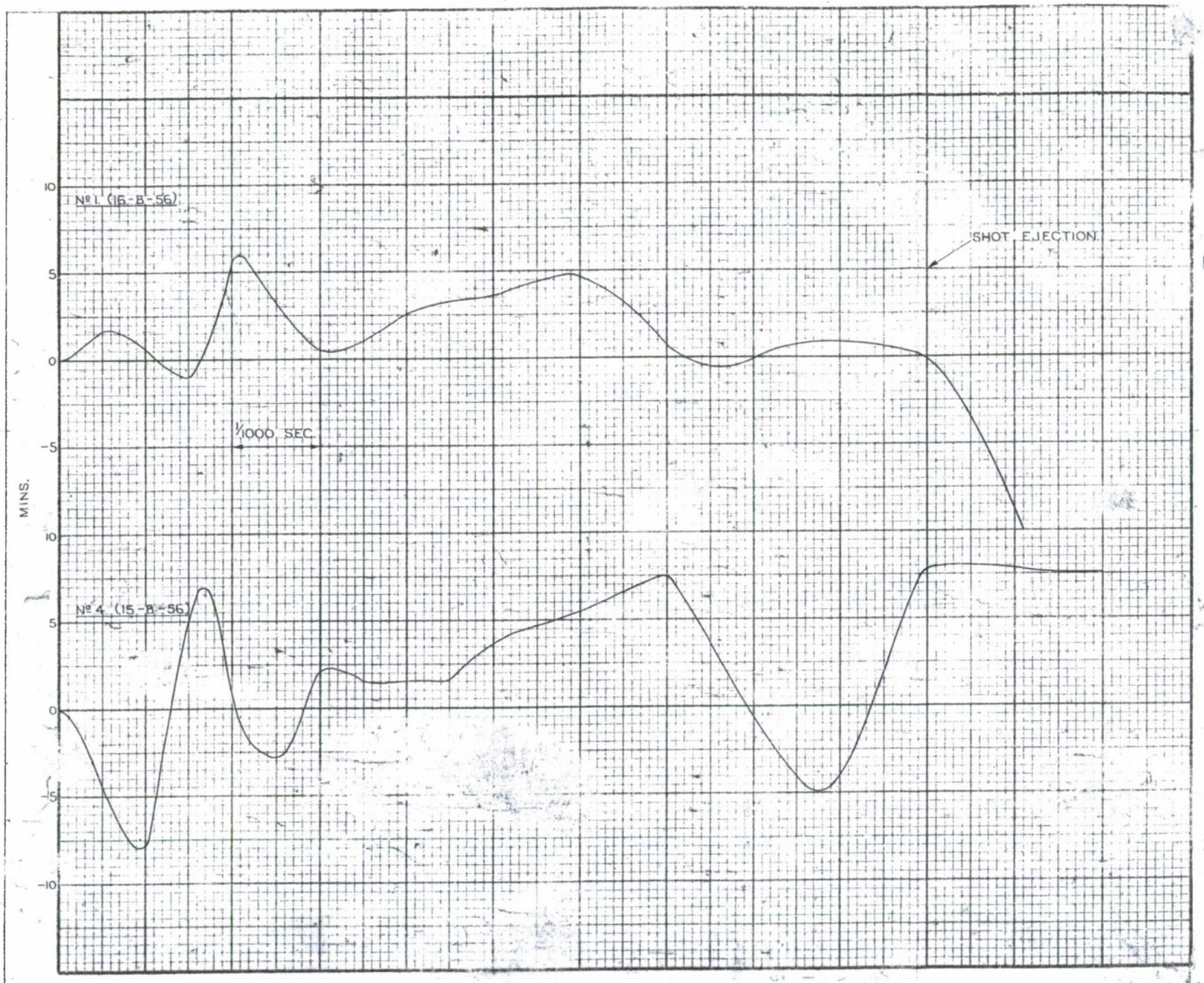
FIG. Nº 42



HORIZONTAL COMPONENT OF YAW IN THE BORE – 17 PR. TANK MTG. FITTED WITH MUZZLE BRAKE

FIGHTING VEHICLES RESEARCH & DEVELOPMENT ESTABLISHMENT.

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FIG. N° 43

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U.S.A.

AD#:
Date of Search: 15 February 2007

Record Summary:

Title: Fundamental causes of gun jump and dispersion of jump
Covering dates 01/01/1959 - 31/12/1959
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (Department) Report BR 147
Note with photographs
Held by The National Archives, Kew

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