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July 23, 1935. J. B. HENDERSON ET AL **2,009,264**

PREDICTOR MECHANISM

Filed Dec. 5, 1930 3 Sheets-Sheet 1

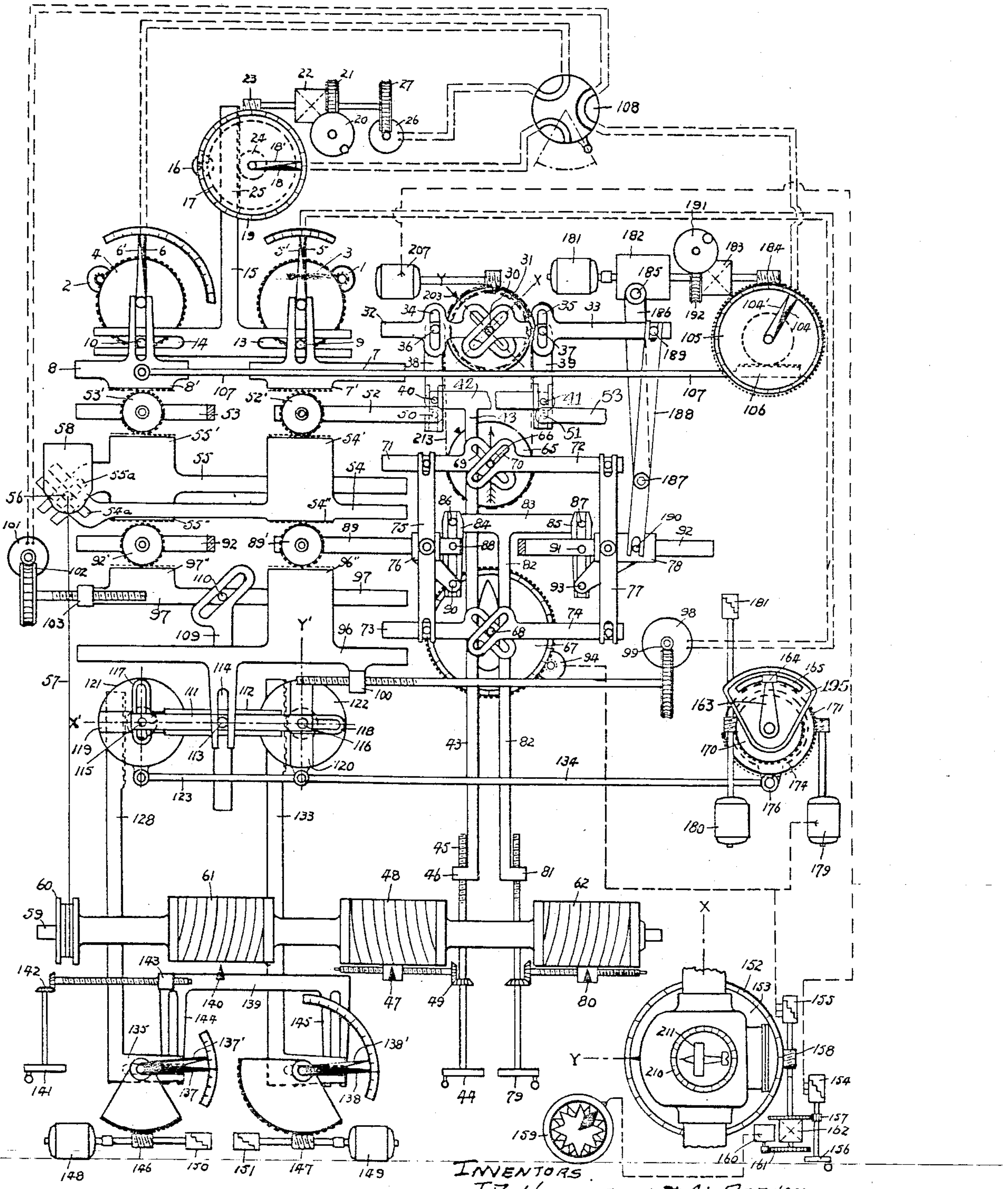

FIG. 1.

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PREDICTOR MECHANISM

Filed Dec. 5, 1930 3 Sheets-Sheet 2

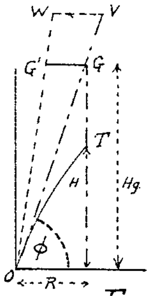

FIG. 2.

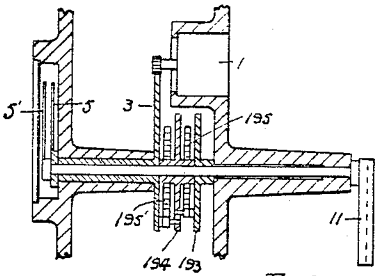

FIG. 3.

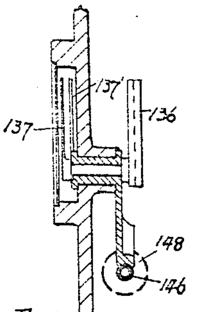

FIG. 4.

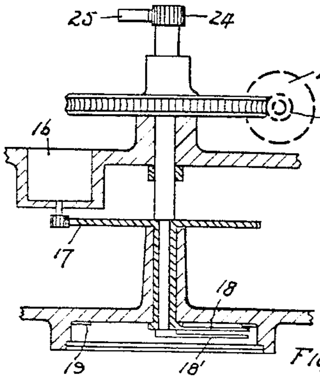

FIG. 5.

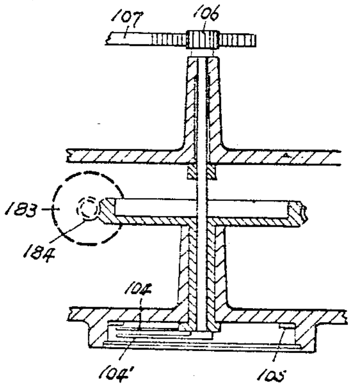

FIG. 6.

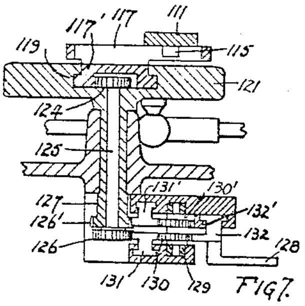

FIG. 7.

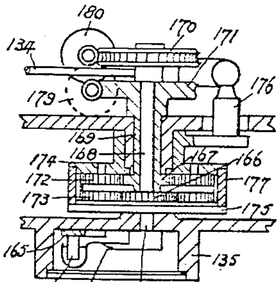

FIG. 8.

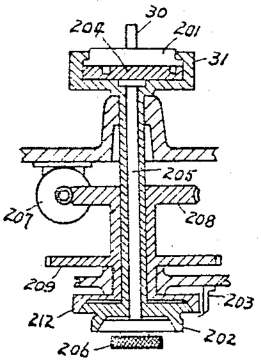

FIG. 9.

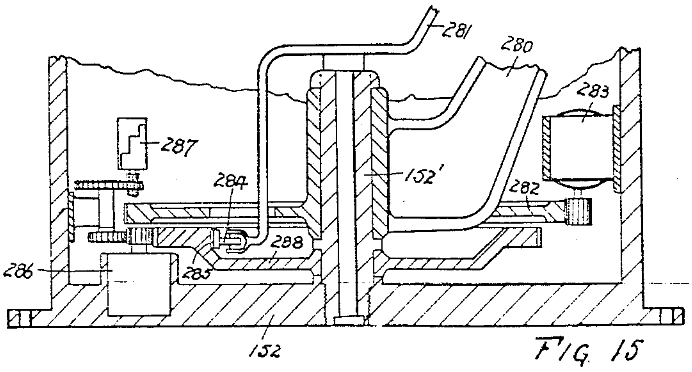

FIG. 15

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PREDICTOR MECHANISM

Filed Dec. 5, 1930 3 Sheets-Sheet 3

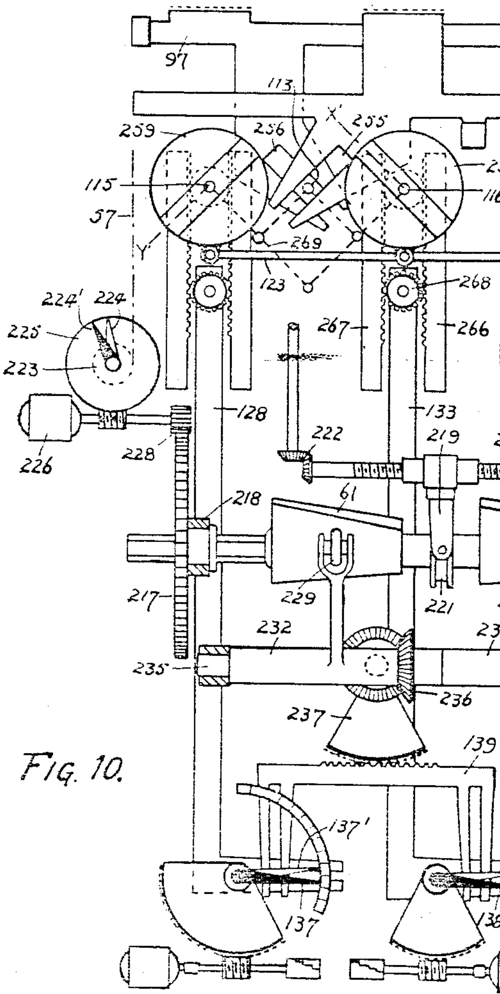

FIG. 10.

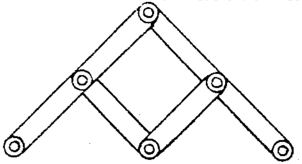

FIG. 13

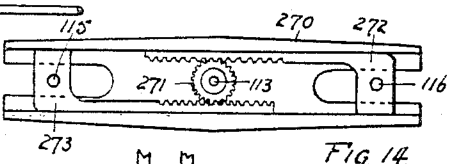

FIG. 14.

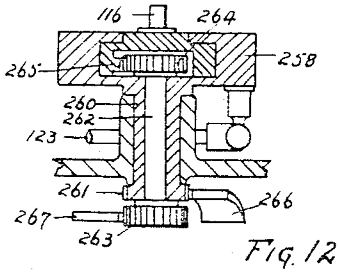

FIG. 12.

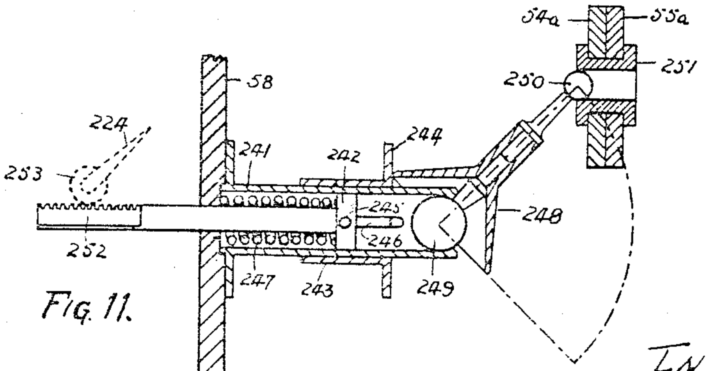

FIG. 11.

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Patented July 23, 1935 2,009,264

UNITED STATES PATENT OFFICE

2,009,264

PREDICTOR MECHANISM

James Blacklock Henderson and Arthur Leonard
Perham, London, England

Application December 5, 1930, Serial No. 500,402
In Great Britain December 31, 1929

28 Claims. (Cl. 235—61.5)

Our invention relates to improvements in apparatus for, and methods of, controlling guns and more particularly to improvements in mechanisms of the type known as predictors for determining the angular displacements to be applied to a gun to enable it to be accurately laid on a target. The invention is therefore particularly applicable to anti-aircraft gunnery, but is also applicable to other types of gunnery.

The invention forms one part of a complete system of gun control comprising a sighting unit, a predictor and a conversion unit which we have generally described in our co-pending U. S. Patent application Serial No. 428,177, issued as Patent No. 1,979,155, wherein we particularly described and claimed the patentable features of the sighting and conversion units. The present invention relates to the same system but more particularly to the predictor portion of it.

Although our invention is applicable to any type of ordnance, we shall describe it in relation to anti-aircraft gunnery as it is particularly adapted and designed to solve the complex problems arising in that branch of gunnery both on ships and on land. It will be necessary, however, before explaining the invention in detail, to recapitulate briefly the complete system of which it forms a part and which we have already described in general, and in detail as regards its other portions, in co-pending application Serial No. 428,177, in order better to explain the part played in the system by the predictor.

Stated briefly, our new method of solving the problems of determining the required direction of anti-aircraft guns is as follows. We first of all obtain a record of the present position of the target in relation to the observer, and with this record we combine data of the target traverse during the time of flight of the shell and so obtain a record of the future or predicted target position which the shell is required to hit. We determine the droop of the trajectory and the deflection of the trajectory due to wind, and we set off these deflections to determine the position which the gun axis is required to occupy. We then materialize this direction in the settings of a member which we call the "ideal gun", and therefrom we derive the actual settings which must be applied to a real gun in order to point it in the same direction as the ideal gun.

In order to record directions in space relatively to the observer, such as the present line of sight to the target, we employ a system of three coordinate axes, OX, OY and OZ, of which OX and OY are horizontal and mutually perpendicular and OZ is vertical, the origin O being at the observer. We record the direction of any vector relatively to this coordinate system by means of two planes pivoted on the axes OX and OY, which we shall call the X and Y planes respectively, which we tilt round their respective axes until they intersect along the required vector. The angular rotations of the X and Y planes from the vertical, or, as we shall call them, the X and Y angles, give a record of the direction of the vector. The azimuth of the axes OX and OY is arbitrarily placed at the convenience of the sight operators who can train them round OZ, but, more especially on board ships, they may be controlled by compass with reference to the cardinal or other points convenient to the observer.

We provide mechanism for levelling two trunnions representing the axes OX and OY to eliminate the effects of tilt of the pedestal on which they are carried or of the ship or platform on which the pedestal is mounted, and we also arrange that this levelling mechanism does not alter the azimuth of the axes, i. e. if the pedestal tilts, the azimuth of the axes OX and OY will be the same after the tilt correction is applied as it was before the tilt occurred. We also arrange that so long as the tilt of the training axis of the pedestal remains constant, as on a land mounting, the tilt correction holds good for any angle of training of the pedestal, while on ships where the tilt is constantly varying we vary the tilt correction continuously by a gyroscopic control.

The levelled trunnions representing the OX and OY axes are mounted in the sighting unit and associated with them we employ a gimballed member, or "sight arm", to represent the direction of the line of sight, this sight arm being controlled by two members tilting round the OX and OY trunnions to represent the tilting X and Y planes. The sighting mechanism is so arranged that in sighting on the target the operators point the sight arm straight at the target and in so doing transmit to the predictor the X and Y angles measured by the tilting movements of the X and Y plane members round their OX and OY trunnions.

To determine the position of the target we require to know, in addition to the X and Y angles, either the range or the height of the target, these being obtained from the range-finder or height-finder respectively. When the target is at low elevations we prefer to use range as the datum, and at medium and high elevations target height is more convenient. Our predictor is arranged to accept either height or range, but for purposes of preliminary explanation of the system we shall consider the case where height is used with the target at a considerable angular elevation.

In the predictor we receive the X and Y angles of the line of sight by transmission from the sighting unit, and from these, together with the height setting *H*, we derive the *y* and *x* coordinates respectively of the present target position, i. e. the coordinates of that position projected on to the horizontal plane XOY, *x* being *H*.tan Y and $y=H.\tan X$. Target speed and course in relation to the air are set on a dial, as determined either by observation or by estimate, and by the setting of this dial a crank pin is moved on a disc to a radius representing the speed, and in phase representing the direction relatively to OY, of the target's movement relatively to the air. This vector is then resolved into *x* and *y* components, and each of these is applied to a separate slide through a variable-lever multiplying mechanism whose fulcrum is displaced proportionally to the time of flight of the shell, this quantity being derived from a drum scale in the predictor, to produce movements of the slides proportional to the *x* and *y* components of target air-traverse during the time of flight. These components are then combined with the coordinates of present target position to give *x* and *y* coordinates of the future or predicted target position in relation to the air, and these coordinates are combined to set out a vector representing the component horizontal range of the future target position and its azimuth relatively to OX and OY.

The coordinates of future target position could be combined with target height H to determine that position or to obtain the corresponding X and Y angles, but for purposes of gun settings we are not so much concerned with the future position of the target as with the direction of the gun axis required to hit the target in that position, and in determining this direction we must allow for droop of the trajectory and for the effect of wind.

In the absence of wind, and neglecting drift, the gun axis produced intersects the vertical through the future position of the target. The point of intersection is higher than the target and may be termed for convenience the "gun axis position", and its height, which we shall call "gun height", denoting it by the hymbol H*g* to distinguish it from target height H, is given by the expression $Hg=R.\tan\phi$ in which R is the horizontal component range of the future target position and ϕ is the quadrant elevation of the gun. Knowing R and H, H*g* can be plotted on a drum scale of curves as a function of R, the curves being labelled in terms of different values of H and the drum being mechanically rotated through an angle proportional to R by the vector setting of R above referred to. To determine the direction of the ideal gun axis, therefore, we use such a scale to give the value of H*g* appropriate to the occasion and so make full allowance for the droop of the trajectory.

In the case of wind allowance, to avoid the usual allowances for the effect of wind on both shell and target, we proceed on the principle that once the shell has left the gun it becomes part of a conservative system of shell, air and target, moving together with the velocity of the wind. For that reason we set out, as already stated, the target course and speed vector on the predictor in terms of movement of the target relatively to the air and not relatively to the earth, and no allowance has then to be made for the down-wind deflection of shell and target. The only effect of wind with which we are then left to deal is an effect produced on the shell and not on the target, namely the gyroscopic deflection of the trajectory immediately the shell leaves the muzzle of the gun, this being in an up-wind direction relatively to the air and along the direction of relative velocity between shell and air. To allow in the predictor for this deflection of the trajectory, we determine the horizontal *x* and *y* components of the horizontal traverse subtended at height H*g* by the angle between the axis of the gun and the direction of relative velocity of shell and air at the muzzle of the gun. For this lateral traverse we find a convenient expression $Hg.\text{cosec}\,\phi.W/V$, the derivation of which we shall explain later, in which W is the velocity of the wind and V the muzzle velocity of the shell. To obtain the *x* and *y* components of this quantity we set out a wind vector representing the direction and velocity of the wind relatively to OY and resolve it into *x* and *y* components, combining each of these with a variable lever mechanism whose fulcrum we adjust proportionally to $Hg.\text{cosec}\,\phi/V$ by means of a third drum scale bearing curves of this quantity labelled in terms of H and rotated proportionally to R. Since $Hg=R.\tan\phi$ and V is a constant each curve on the drum can be arranged to give an appropriate range of values of $Hg.\text{cosec}\,\phi/V$ for different values of R at a given value of H, separate drums being provided for different values of V. Where the gun is itself in motion, as on a ship, we treat its linear motion as an additional component of relative wind. Ship's speed and course relatively to OY are set out as a vector and resolved into *x* and *y* components, and these are combined with the *x* and *y* components of true wind to produce corresponding components of relative wind before being combined with the $Hg.\text{cosec}\,\phi/V$ lever mechanism.

By the mechanism so far described we have obtained movements of slides proportional to the *x* and *y* components or coordinates of (*a*) present target position, (*b*) target traverse relatively to the air, and (*c*) horizontal deflection of the gun axis position to allow for wind. By means of a simple arrangement of differential slides we add together all the *x* coordinates and components and, separately, all the *y* coordinates and components, giving resultant *x* and *y* coordinates of the deflected gun axis position. These we could combine with height H*g* to give the direction of the gun axis as two X and Y angles, but since the gun axis position may be deflected considerably from the present target position, and since the original OX and OY axes were located in azimuth to suit the convenience of the sight operators, these axes may not be convenient axes of reference for the deflected gun. We therefore find it more convenient to introduce a second set of coordinate axes O'X', O'Y' and O'Z' to suit the gun, O'Z' being vertical and O'X' and O'Y' horizontal and mutually perpendicular, O'X' and O'Y' being normally coincident with OX and OY but displaceable in azimuth relatively to them according to the circumstances of the moment as determined by the predictor, but being in all cases convenient axes of reference for the gun. We then employ a mechanism similar to that used in the sight, to control a gun axis member in the conversion unit, called the "ideal

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gun", so that it will point at the gun axis position determined by the predictor, its movements being related to two trunnions O'X' and O'Y' whose azimuth is determined solely by the predictor. To control the movements of the ideal gun we have to determine in the predictor not only the azimuth of the axes O'Y' and O'X' but the Y' and X' angles of planes pivoted on these axes and rotated from the vertical so as to intersect along the direction of the gun axis position. For this purpose we apply the vector setting obtained for the horizontal range and azimuth of the gun axis position relatively to OX and OY to two other vectors or crank pins sliding at right angles to each other on two discs which can rotate equally on their centres. The displacements of the two crank pins then give respectively the x' and y' coordinates of the gun axis position relatively to the axes O'X' and O'Y' disposed in azimuth relatively to OX and OY at any angle through which the discs may have been forced to swing on their centres. The rotation of the discs is transmitted to the ideal gun as a training displacement, and the displacements of the crank pins we utilize in the predictor to ascertain the required X' and Y' angles which must be applied to the pivoted elements controlling the ideal gun. The crank pins are connected to a mechanism which produces linear displacements of two slides proportional to the movements of the crank pins on their respective discs, i. e. proportional to the x' and y' coordinates of the gun axis position. These movements we combine with the motion of a slide at right angles to them which we move through a distance proportional to Hg obtained from the second drum scale mentioned above, rotating through an angle proportional to R and bearing curves of Hg labelled in terms of H. Each pair of slides applies a radial setting to a crank pin which moves a pointer through an angle whose tangent, in one case, is x'/Hg, and in the other case y'/Hg, i. e. the Y' and X' angles respectively. Follower pointers transmit these angles to the conversion unit where they are applied to the controlling elements of the ideal gun.

A "dummy gun" in the conversion unit, which is a small-scale replica of an actual gun and its mounting, is arranged concentrically with the ideal gun, that is their gimbal centres are both at O', and we cause the dummy gun to maintain its axis collinear with or parallel to the axis of the ideal gun by follower mechanisms of suitable type. Where the actual and dummy guns are gimballed or have more than two pivot axes, we constrain one of these axes to the corresponding gimbal axis of the ideal gun so as to ensure that any given position of the ideal gun will produce only one possible position of the dummy gun pivotage. The displacements of the dummy gun and its pivotage are obviously the settings which must be applied to the actual gun in order to point it at the gun axis position, and we therefore transmit these displacements to the receiver pointers at the guns.

The foregoing is a general description of the system of gun control which we have invented and serves to explain our general method of prediction and the part which the predictor occupies in the system. In co-pending patent application Serial No. 428,177 we have described and illustrated in detail the sighting and conversion units, and we shall now describe and illustrate the predictor which forms the particular subject matter of the present invention.

Fig. 1 shows a diagrammatic representation of the predictor mechanism, developed to show all the several parts as far as possible in one drawing. All the parts are shown in operative relationship to each other so that the action of the mechanism can be followed more easily than in a complete structural design. To explain the system as adapted for use on board ships we have also included in the lower right hand corner a diagrammatical small-scale representation in plan of the director sight described in co-pending application Serial No. 428,177 and of a gyro compass.

Fig. 2 is a diagram showing the derivation of the quantities Hg and Hg.cosec $\phi.W/V$.

Fig. 3 is a section on the axis of the "target" pointers **5** or **6** of Fig. 1.

Fig. 4 is a section on the axis of the "gun" pointers **137** or **138** of Fig. 1.

Fig. 5 is a section on the axis of the "target height" dial **19** of Fig. 1.

Fig. 6 is a section on the axis of the "range" dial **105** of Fig. 1.

Fig. 7 is a section on the axis of the crank discs **121** or **122** of Fig. 1.

Fig. 8 is a section on the axis of the training dial **135** of Fig. 1.

Fig. 9 is a section on the axis of the "target speed and course" dial **31** of Fig. 1, the "wind velocity and direction" dial **65** being similar.

Fig. 10 is a diagram illustrating alternative methods of obtaining the quantities Hg, Hg.cosec ϕ/V and time of flight from automatic cams instead of hand-operated drums. The drawing also shows an alternative method of obtaining the x' and y' coordinates of gun axis position.

Fig. 11 shows a mechanism to eliminate the flexible cord **57** of Fig. 1 for rotating the drum scales.

Fig. 12 is a section on the axis of the crank disc **258** or **259** of Fig. 10.

Fig. 13 shows a pantagraph, and

Fig. 14 shows a mechanical arrangement of slides which we may use in the Fig. 10 arrangement instead of the pantagraph shown in Fig. 13.

Fig. 15 shows a part of the conversion unit to illustrate a method of controlling the training of the ideal gun from the predictor.

Before referring to Fig. 1 in detail it should be explained that to simplify the drawings the framework and the guides in which the various slides **7**, **8**, **32**, **33** &c. travel have all been omitted. It has to be understood, however, that all slides shown are carried in fixed guides which permit only of lengthwise motion of the slides, except in the case of slide **111** which slides lengthwise in a movable guide so that the slide **111** can move both lengthwise and parallel to itself.

Referring now to Fig. 1, the Y and X angles are transmitted respectively from the sight pedestal **153**, as explained in co-pending patent application Serial No. 428,177, to two repeat motors **1** and **2** which drive the toothed wheels **3** and **4** carrying the black pointers **5** and **6**. The white follower pointers **5'** and **6'** are power-driven in a manner which will be described later so as to follow the pointers **5** and **6** respectively by means of vertical slots in the slides **7** and **8** which engage with crank pins **9** and **10**, sliding respectively in slotted cranks **11** and **12** (**11** is shown in Fig. 3), fixed to the spindles of the white pointers **5'** and **6'** and collinear with these pointers the power being applied indirectly, as will hereinafter appear to the slides **7** and **8**. These sliding crank pins also engage in horizontal slots 13 and 14 in the target height slide 15 which is set in accordance with the indications of target height transmitted to the repeater motor 16, this motor driving a gear wheel 17 which carries the black pointer 18 and moves the pointer over a height scale 19. A section of this dial is shown in Fig. 5. The white pointer 18′ is made to follow the black pointer 18 by the hand wheel 20 through the worm gear 21, differential gear 22 and worm 23, while the height slide 15 is moved with the pointer 18′ through the pinion 24 engaging with the rack 25 on the slide 15.

If the distance of the crank pin 9 below the centre of pointer 5′ represents to scale the target height H and the pointer 5 is tilted through the angle Y, the motion of the slide 7 necessary to align the pointers is $x=H.\tan Y$, and similarly the motion of slide 8 in aligning pointers 6 and 6′ is $y=H.\tan X$. These movements of the slides are therefore proportional respectively to the x and y coordinates of the present target position relatively to the sight datum axes OX and OY.

The pointer 18′ may be driven alternatively by the motor 26 and worm gear 27 through the differential gear 22. The object of this method is associated with the direct control of the y slide 8 when using range instead of height at low elevations of the target, which will be described fully later.

Target air-speed and heading are set on a crank pin 30 on a crank disc 31, shown in detail in Fig. 9. The pin is mounted on the centre of a slide 201 which moves in diametral guides on the disc 31, and the phase of the pin, to represent the direction of the target air-course relatively to OY, is set by rotating the disc by means of the milled head 202 relatively to the fixed index 203. A second pin mounted eccentrically on the under-side of the slide 201 engages in a spiral cam slot in the circular plate 204 fixed to one end of a spindle 205, and the radial setting of the pin to represent the air-speed of the target is produced by rotating the milled head 203 and cam plate 204 relatively to the knob 202 and disc 31, a scale of speeds being engraved on the knob 206 to read against an index on knob 202. The disc 31 can be rotated (without altering the relative position of crank pin 30) by a repeat motor 207 controlled by a transmitter 154 at the director, the motor driving a worm wheel 208 and chain wheel 209 which are frictionally connected to the knob 202 as shown in Fig. 9. The transmitter 154 transmits the azimuth of the axis OY, so that when target course has once been set on dial 31, the setting does not have to be altered for any change in the azimuth of OY because as the axis OY is trained round by the director training hand-wheel 156, the crank disc 31 is similarly rotated by the motor 207.

To facilitate the phase setting of dial 31 the director canopy may be fitted with a dial 210 marked in degrees, zero being on the bearing of the axis OY. Pivoted on the centre of this dial there is an index 211, shown as a model of an aeroplane, and on picking up a target the operator swings the index model round until it is parallel to the apparent heading of the target, not the apparent course. The bearing of the index 211 on scale 210 is then the correct phase setting for the dial 31. For purposes of lining up the disc, the knob 202 can be rotated relatively to disc 212, but otherwise there is no relative motion between these two parts which engage frictionally and are turned together by the motor 207.

The crank pin 30 engages with two 45° slots in the horizontal slides 32, 33, these slots representing in this part of the mechanism the directions of axes OY and OX. These slides are also provided with vertical slots 34 and 35 which engage with pins 36 and 37 at the ends of levers 38 and 39 pivoted on fulcrum pins 40 and 41 on the horizontal bar 42 which is fixed to a vertical slide 43. The slide 43 can be moved up and down by the handwheel 44 through the screw and nut 45—46. The handwheel 44 also moves a pointer 47 along the "time of flight" drum scale 48 through the bevel gears 49. The lower ends of levers 38 and 39 are slotted and engage with pins 50 and 51 fixed to horizontal slides 52 and 53, 53 being longer than 52 and its centre portion being shown cut away to disclose the latter. When the pointer 47 is set to zero on the drum 48, the pins 40 and 41 are coaxial respectively with pins 50 and 51 so that movement of the slides 32 and 33 produces no movement of slides 52 and 53, but if the pointer is set by the handwheel 44 away from zero to the curve corresponding to the observed target height, the slide 43 and levers 38 and 39 are raised by an amount proportional to the horizontal movement of the pointer 47, and movement of slides 32 and 33 will then produce movement of slides 52 and 53.

It has been explained that the crank pin 30 is set in radius and phase to represent the air-speed and heading of the target relatively to OX and OY, that the 45° slots in slides 32 and 33 represent respectively the directions of the axis OY and OX, and that the phase setting of the crank pin is automatically maintained correct in relation to OX and OY by the motor 207. It will therefore be seen that the setting of the crank pin 30 will produce in the slides 32 and 33 horizontal displacements which are proportional to the x and y coordinates of the setting of the crank pin, i. e. the x and y coordinates of the pin relatively to the disc, multiplied by $\sqrt{2}$. The curves on the drum are curves of time of flight for given target heights and given horizontal ranges, and, as will be seen later, the drum is rotated through an angle proportional to the horizontal range R of the future target position The movement of the pointer 47 and of the fulcra 40 and 41 is therefore proportional to the time of flight of the shell at the observed target height and the predicted horizontal range, so that the movements of slides 52 and 53, which are respectively the movements of slides 32 and 33 multiplied by movement of the fulcra 40 and 41, are respectively proportional to the x and y components of the target air-traverse during the time of flight of the shell.

Coordinates of future target position relatively to the air are obtained by adding together the motions of slides 7 and 52 to give an x coordinate, and 8 and 53 to give a y coordinate. This is done by differential slide mechanisms, the sums being imparted to slides 54 and 55 respectively. One differential slide mechanism consists of a pinion 52′ carried by the slide 52 and gearing with a rack 7′ on slide 7 and a rack 54′ on slide 54; the other comprises a pinion 53′ on slide 53 meshing with racks 8′ and 55′ on slides 8 and 55 respectively.

The movements of slides 54 and 55 therefore give respectively the x and y coordinates of future target position relatively to the air on which, in the absence of wind, the gun is to be laid. We combine these coordinates at right angles by means of the two 45° slots **54***a* and **55***a* in the slides **54** and **55**. These slots engage with a double slide block carrying a central pin **56**, and the movements imparted to the slides **54** and **55** cause this pin to move radially from a central position to a distance which represents on a reduced scale of

$$1:\sqrt{2}$$

the resultant of the movements of the slides, but since the latter movements are themselves produced by displacement of the slides **32** and **33** which are

$$\sqrt{2}$$

times the coordinate displacements of pin **30** on disc **31**, the displacement of the pin **56** gives the horizontal range of the future target position on the same scale as is used for the setting of the crank pin **30**.

We use this radial displacement of the pin **56** to rotate the three drum scales **61**, **48** and **62** which carry different families of curves used in the process of prediction, all of the curves being plotted on a base of horizontal range of future target position. For this purpose the pin **56** in its central position is exactly opposite a small hole in a fixed plate **58** and a cord **57** which is attached to the pin is passed through the hole and wound once or twice round a pulley **60** on the shaft **59** to which the three drums are attached. The cord is kept under slight tension by a spring (not shown) on the shaft **59** and as the pin **56** is displaced radially in any direction in proportion to the horizontal range of the future target position, the three drums are rotated proportionally.

Having now determined data for the future target position relatively to the air, we have next to ascertain the position of the gun axis to hit the target in that position. In this we must take into consideration two factors, namely the droop of the trajectory and the effect of wind.

The allowances which we make for these factors are derived by means illustrated diagrammatically in Fig. 2. In the absence of wind, and neglecting drift, if the gun is situated at O and laid with quadrant elevation ϕ so as to hit the target in its future position T at horizontal range R, then the gun axis produced cuts a vertical line through T at a point G, which is the "gun axis position" for the conditions stated and whose height Hg is given by the expression $Hg=R.\tan\phi$. In our conversion unit we do not wish to materialize the future position of the target T which the gun is required to hit, but the point G at which the gun axis has to be pointed in order to hit T. By taking Hg as the height of this position we therefore make full allowance for the droop of the trajectory.

When there is a wind, it has one effect that is common to both shell and target, both of them being deflected down-wind. By setting the "target course and speed" dial to target heading and air-speed we make it possible to neglect this effect entirely because if the gun is laid so as to hit the target in the future position which it will occupy in still air, it will still hit the target when there is a wind (except for a deflection which we shall consider immediately) because the wind will affect both target and shell equally. The deflection which we have just mentioned as an exception is one which we must take into account as it is due to an effect which wind produces on the shell alone. After the shell leaves the gun it becomes part of a conservative system of shell, air and target moving together with the velocity of the wind, but at its moment of entry into this system the shell, having an initial velocity along the axis of the gun, has its axis inclined to the direction of the air resistance, in consequence of which it precesses quickly in spiral fashion round the line of relative velocity between shell and air and quickly settles on that line. This initial deflection may be due to true wind or to movement of the gun, as on a ship, or to both, that is to say, it is due to relative wind between the air and gun. This angular deflection of the trajectory is in an up-wind direction relatively to the air and we must take it into account in fixing the final gun axis position.

As we have been dealing throughout with positions and linear movements in the horizontal plane, what we have now to determine is the horizontal intercept subtended at height Hg by this angular deflection of the trajectory, and we then move the gun axis position in the opposite direction by an equal amount. In Fig. 2, if there is a wind, let OV be measured along OG to represent on any scale the muzzle velocity V of the shell, and let VW be drawn horizontally to represent on the same scale the velocity of the relative wind W, then draw GG′ parallel to VW to meet OW in G′. Then if the gun is laid along OG′ the shell will be deflected very quickly along OV, the direction of relative velocity of shell and air and will hit the target at T, as required. The required displacement of the gun axis position from G is therefore GG′, which is

$$\frac{WV\times OG}{OV}$$

or $Hg.\operatorname{cosec}\phi.W/V$. This expression is not strictly correct because we measured the length V along OG while the initial velocity of the shell in wind is actually along OW, but since the velocity of the shell is very large compared with that of the strongest wind, the formula is both convenient and sufficiently accurate for the purpose. As the deflection of the trajectory is upwind, we have to deflect the gun axis position downwind by an equal amount, i. e. by an amount equal to $Hg.\operatorname{cosec}\phi.W/V$. for purposes of land gunnery W is true wind, but on board ship W is relative wind so that ship's course and speed must be included as a component. We could set relative wind on a dial similar to dial **31**, but the setting would have to be continually altered with every change of the ship's course, because on a ship the angular change of relative wind is not equal to the change of course. In order to obviate this necessity for resetting we employ two dials, one for true wind and one for ship's speed and course, the first being automatically compensated for changes in the azimuth of OY and the latter for changes in the ship's course relatively to OY, so that neither dial requires to be reset for a change of course or a change in the azimuth of OY.

Fig. 1 shows the method which we employ to combine true wind and ship's course and speed to give relative wind. The true wind crank disc **65** carries a crank pin **66** which is set in radius to wind velocity and in phase to wind direction relatively to OY, the mechanism being similar to that of the target speed and course dial **31** shown in Fig. 9, except that the motor **207** and wormwheel **208** are omitted, and instead the chain wheel **209** is coupled by a chain **213** to the corresponding chain wheel of dial **31**. Ship's speed and course are similarly set on a dial 67 carrying a crank pin 68, the mechanism of which is also similar to that of Fig. 9 except that it has no chain wheel and the motor 94 by which it is automatically rotated at every yaw or change of course is controlled by the transmitter 155 at the director which transmits the bearing of the ship relatively to OY. The wind setting of crank pin 66 is resolved along OX and OY by the 45° slots 69 and 70 in the slides 71 and 72, which are thus displaced in proportion to the x and y components of true wind. Similarly the crank pin 68 engages in 45° slots in slides 73 and 74 and displaces these slides in proportion respectively to the x and y components of ship's speed. In this connection it must be noticed that although we call this setting a setting of ship's speed and course, since it is actually a component of relative wind the crank pin must be actually set to the speed and course of the air relatively to the ship, i. e. if the ship's course is actually in the direction relatively to OY which we have shown by the plan of a ship on dial 67, the crank pin must be moved towards the stern of this model ship. In the case of the true wind crank pin 66, on the other hand, the setting must be made in the direction in which the wind is blowing, that is towards the tip of the arrow on the dial, the arrow being set relatively to the fixed index in the direction in which the wind is blowing relatively to OY.

The two x components of relative wind given by slides 71 and 73 are combined by a lever 75 and applied to a slide 76 on which the lever is pivoted at its centre, and the y components given by slides 72 and 74 are similarly combined by a lever 77 and applied to a slide 78. The movements of slides 76 and 78 are therefore the x and y components of relative wind on half the scale by which the slides 71, 72, 73 and 74 are displaced, or

$$\sqrt{2}/2$$

times the scale of movement of the crank pins 66 and 68. To obtain the x and y components of the deflection of the gun axis position we have now to multiply these components by $Hg.\text{cosec}\,\phi/V$. This quantity we obtain from the drum scale 62 which bears a family of curves of $Hg.\text{cosec}\,\phi/V$ for different values of H, separate interchangeable drums being provided for different values of V. By means of a handwheel 79 an operator keeps a pointer 80 aligned with the appropriate curve of H on the drum as it rotates through R, and by so doing he causes a screw and nut gear 81 to move a vertical slide 82 which carries a cross-bar 83, whose arms carry two swinging levers 84 and 85 pivoted respectively on pins 86 and 87 on the cross-bar 83. A slot in lever 84 engages pins 88 on the slide 89, and 90 on slide 76, while a similar slot in lever 85 engages pins 91 on slide 92 and 93 on slide 78. When pointer 80 is set at zero on the drum 62 the fulcrum pins 86 and 87 are in line with pins 88 and 91, but as the pointer is moved along the drum to its appropriate curve the fulcra 86 and 87 are raised proportionately, i. e. in proportion to $Hg.\text{cosec}\,\phi/V$. The resultant movements of slides 89 and 92 are therefore proportional respectively to the x and y components of $Hg.\text{cosec}\,\phi.W/V$, or of the required horizontal displacement of the gun axis position to allow for relative wind.

In the case of position artillery on land where relative wind is true wind, the dial 67 and levers 75 and 77 will be unnecessary and the slides 89 and 92 can then be controlled by the direct cooperation of slides 71 and 72 with the vertical movement of the cross-bar 83 and levers 84, 85.

In the absence of wind the gun axis position is vertically over the future target position and has the same horizontal coordinates. To obtain coordinates of the deflected gun axis position we have therefore merely to add the components of wind deflection to the coordinates already obtained for the future target position. That is to say, we have to add together the displacements of slides 54 and 89 to give the x coordinate of the final gun axis position, and of slides 55 and 92 to give the y coordinate. For this purpose racks 54'' and 96'' on slides 54 and 96 mesh with a pinion 89' on slide 89, and similar racks 55'' and 97'' on slides 55 and 97 mesh with a pinion 92' on slide 92. The slides 96 and 97 then give respectively the x and y coordinates of the final gun axis position at which the gun has to be pointed.

The continuous operation of the mechanism so far described is effected by moving the slides 96 and 97 so as to keep the pointers 5' and 6' continuously in line with the X and Y angle receiver pointers 5 and 6 despite the movements introduced by the slides 52, 53, 89 and 92 and despite the movements of the pointers 5 and 6 themselves. This may be done by hand, but we prefer to use power automatically controlled by relative displacements between the pointers. The slide 96 is displaced by a motor 98, worm gear 99 and screw gear 100, this motor being controlled by contacts between the pointers 5 and 5'. The slide 97 is similarly moved by a motor 101 through worm gear 102 and screw gear 103, the motors being controlled alternatively by contacts between the pointers 6 and 6' or by other contacts between the pointers 104 and 104' on the range dial 105, the pointer 104' being driven by a rack and pinion gear 106 operated by the slide 8 through the connecting rod 107. The current to motor 101 is switched over from one set of pointers to the other by the switch 108. We shall explain later the reason for this alternative control of slide 97.

Having thus obtained on slides 96 and 97 the x and y coordinates of gun axis position, we combine them at right angles to obtain a vector representing the horizontal component range of that position. We turn the motion of slide 97 through 90° on to the vertical slide 109 by a 45° slot on the slide 109 engaging with a pin 110 on slide 97. The horizontal motion of slide 96 and the vertical motion of slide 109 are then imparted jointly to a slide 111 which slides in a guide 112 fixed to the slide 109 and having a pin 113 engaging with a slot 114 on slide 96. The slide 111 also carries two other pins 115 and 116 which engage respectively in the slots 117 and 118 in two Oldham couplings sliding at right angles to each other in diametral slots 119 and 120 cut in the faces of two similar discs 121 and 122. The movement of the pin 113, being compounded of the x and y component motions of slides 96 and 109, is proportional to the horizontal range of the gun axis position, and as the pins 115 and 116 move parallel to it from zero positions on the centres of the discs 121 and 122, the latter pins will be displaced on their respective discs in proportion to the horizontal range of the gun axis position. The slots 117 and 118 of the Oldham couplings are at right angles respectively to the slots 119 and 120 and the latter are also kept at right angles to each other by the connecting rod 123 coupling the two discs which are free to rotate on their centres.

The azimuth of the axes OX and OY is at the disposal of the sight operators, being fixed relatively to the training canopy 153 of the director sight 152, so that, in view of the large displacements which may possibly be found between the azimuth of the present target position on which the sight is laid and the azimuth of the gun axis position on which the gun has to be directed, these axes might not be convenient axes of reference for the gun. For this reason we leave the discs 121 and 122 free to rotate on their centres and we take the directions of their slots 119 and 120 to represent the directions in azimuth of a second set of axes O'X' and O'Y' which are displaceable in azimuth relatively to OX and OY by rotation of the discs, and to these new axes we refer the pins 115 and 116 in order to derive x' and y' coordinates of the gun axis position.

In Fig. 7 we show the mechanism of the disc 121, 122 being similar. The disc 121 has a diametral slot 119 in which slides the Oldham coupling slide 117' which has an external slot 117 to receive the pin 115 on the slide 111. An internal rack on the coupling meshes with a pinion 124 fixed to a spindle 125 pivoted on the axis of the disc and carrying at its other end a pinion 126. A pinion 126', similar to 126, is cut on the end of the sleeve 127 to which the disc 121 is fixed. Thus rotation of pinion 126 relatively to 126' represents movement of the Oldham coupling 117' along the slot 119. This movement is conveyed to a slide 128 by a differential slide 129 carrying a pin on which are pivoted the pinions 130, 130' engaging respectively with racks cut on the slides 131, 131' with which the pinions 126 and 126' respectively engage. Pinion 130' also engages with a fixed rack 132', while the pinion 130 engages with a rack 132 fixed to the slide 128. It will be seen that movement of the pin 115 in the outer slot 117 and rotation of the disc 121 can produce no movement of the rack 128, but movement of the Oldham coupling 117' in the slot 119 produces a proportionate movement of slide 128. It will also be seen that if the pin 115 is displaced radially on the disc 121 in any direction, this may entail only a sliding movement of pin 115 in slot 117, or a sliding of coupling 117' in slot 119, or a rotation of disc 121, or any combination of these movements according to the direction of motion of the pin and according to the relative friction of the turning and sliding movements. At low elevations of the gun axis position the radius of pin 115 will be comparatively large so that the resultant movement will be largely, or entirely, a rotary motion of the disc and a sliding movement of pin 115 in slot 117 without moving the Oldham coupling 117', while at medium and high elevations the radius of pin 115 will be shorter so that there will be less leverage to turn the disc and a greater tendency to displace the coupling 117'. With the two discs coupled together as in Fig. 1, of course, it is obvious that if in the case of one disc the pin moves only in the outer slot of the Oldham coupling, the pin on the other disc can only produce movement of the coupling on the other disc.

In the Fig. 1 arrangement, the slots 119 and 120 being representative of the directions of the new axes O'X' and O'Y', it will be seen that the movements of the Oldham couplings 117' and 118' in their respective slots give respectively the x' and y' coordinates of the gun axis position relatively to the axes O'X' and O'Y', while the azimuthal displacement of O'Y' relatively to OY is given by the rotation, if any, of the discs. The coordinate movements of the Oldham couplings are also communicated respectively to the slides 128 and 133.

We now require to fix the position in our conversion unit, as described in patent application Serial No. 428,177, of a vector member or ideal gun so as to point at the gun axis position. The conversion unit contains two horizontal trunnions representing the O'X' and O'Y' axes, each carrying a pivoted element, these representing X' and Y' tilting planes by whose angular rotations the position of the ideal gun is fixed. To operate this mechanism we therefore require to determine the requisite X' and Y' angles given by $y'=Hg.\tan X'$ and $x'=Hg.\tan Y'$. The mechanism is similar to that of the sight pointers 5 and 6 but operating in the reverse direction. The x' slide 128 carries a slotted arm 135 which engages with a crank pin in a slotted crank 136 (Fig. 4) immediately under the black pointer 137 and attached thereto, while the y' slide 133 similarly engages with a pin sliding in a slotted crank attached to the black pointer 138. A horizontal slide 139 carries a pointer 140 registering with the curves of $Hg(=R.\tan\phi)$ on the drum scale 61 and is set by handwheel 141 which engages with the slide through the bevel gears 142 and screw gear 143. The slide 139 carries two slotted arms 144 and 145 which engage respectively with the crank pins actuating the black pointers 137 and 138. At zero position of the pointer 140, these crank pins are exactly in line with the pivots of the pointers 137 and 138, so that as the pointer 140 is moved to the right to the appropriate value of Hg, the black pointers are swung by the slides 128 and 133 through the angles whose tangents are respectively Hg/x' and Hg/y', or the angles Y' and X' respectively. Follower pointers 137' and 138' are driven by motors 148 and 149 through the worm gears 146 and 147, the motors being controlled by contacts between their associated pairs of pointers. The motors also drive transmitters 150 and 151 which transmit the Y' and X' angles to the conversion unit where they are applied to fix the position of the ideal gun.

There remains the question of controlling the training of the guns. The training angle which has to be applied to them, or to receiver pointers at the guns, is compounded of three separate displacements, namely (a) the training of OY relatively to the ship, (b) the deflection of O'Y' from OY, and (c) a training correction, which we have fully explained in our co-pending application Serial No. 428,177, which may be required in some circumstances to allow the gun to accommodate itself to the application of a Y' angle or a cross-levelling correction when the cross-levelling gimbal trunnion of the gun is not coincident with, or parallel to, the O'Y' axis of the ideal gun. Of these three components the first is determined by the sight, the second by the predictor and the third by the conversion unit, and we prefer to combine them before application to the gun pointers. This can be done in several ways, but the method illustrated in Figs. 1, 8 and 15 is probably the simplest.

We are considering the case of an installation on board a ship in which the pedestal of the sighting and conversion units is fixed to the deck, the units themselves being trainable relatively to the pedestal. As shown diagrammatically in Fig. 1, the director pedestal 152 is fixed to the deck and the canopy 153 which contains the sighting unit and its OX and OY trunnions is trainable relatively to it by the handwheel 156, reduction gearing 157 and worm 158. To prevent disturbance of the azimuth of the OX and OY trunnions by yaw or change of course of the ship, a second control from the gyro compass 159 is introduced through the repeat motor 160, spur gear 161 and differential gear 162, so that as the ship yaws or changes course the canopy trains equally and oppositely and the sight datum axes remain fixed in azimuth except for any change of azimuth applied to them by the handwheel 156. The transmitter 154 therefore transmits the azimuth of OY, while transmitter 155 transmits the training of OY relatively to the ship, or the ship's bearing relatively to OY, and this latter transmission we utilize in controlling the training of the ideal gun in order eventually to control the gun training pointers.

In the predictor a training dial 195 carries a pointer or arm 163 which is fitted with a contact trolley 164 bearing against a segmental two-part commutator 165 on the dial. The pointer is controlled by a double epicyclic gear shown more fully in section in Fig. 8. It comprises two sun pinions 166 and 167 carried respectively by a spindle 168 and a sleeve 169 which houses the spindle, these carrying at their other ends the worm wheels 170 and 171 respectively. The planet pinions 172 and 173 of the epicyclic gears are pivoted respectively on discs 174 and 175, the former of which is carried by a loose sleeve fitted with a crank pin 176 which is connected by the connecting rod 134 to the swinging discs 121 and 122 of Fig. 1 so as to swing through the angle YOY'. The disc 175 is mounted on a short spindle 178, coaxial with spindle 168 and the pointer 163 is fixed to the other end of this spindle 178. All the epicyclic pinions 172 and 173 mesh with an internally toothed annulus 177. The worm wheel 171 is driven by the repeat motor 179 which is controlled by the transmitter 155 at the director so as to be rotated in proportion to the training of OY relatively to the ship, and the D. C. reversible motor 180 which drives the worm wheel 170 is controlled by the contact of the trolley 164 on the segments of the commutator 165. The gearing is arranged so that if the deviation of OY relatively to the ship, and of O'Y' relatively to OY are in the same sense, the two resultant displacements of the trolley 164 will be in the same direction and on the same scale. The trolley will therefore be displaced on the commutator through a distance proportional to the algebraic sum of the training angle of OY and the deflection of O'Y' from OY, and the motor 180, in restoring the trolley to zero drives a transmitter 181 (Fig. 1) which accordingly transmits to the conversion unit the training angle of the gun datum axis O'Y'.

In Fig. 15 we show how this transmission is utilized in the conversion unit. We have already described the conversion unit in co-pending application Serial No. 428,177 and we now show only a small part of it to explain the training control, this being part of Fig. 15 of our co-pending application modified somewhat to adapt it to ship use. The ideal gun pedestal 280 and the dummy gun pedestal 281 are both mounted on the same training axis provided by the main pedestal 152 and the hollow cylindrical pillar 152' rigidly mounted thereon. The ideal gun pedestal 280 carries a circular training rack 282 which gears with the repeat motor 283 controlled by the training transmitter 181 at the predictor (Fig. 1) to which we have just referred. The ideal gun pedestal 280, which supports the O'X' and O'Y' datum trunnions, is therefore trained so as to bring the O'Y' trunnion into the azimuth determined by the predictor, and the dummy gun pedestal 281 trains with it because the elevating trunnions of both the ideal and dummy guns are the same trunnion, as shown in Fig. 16 of our co-pending application referred to. This constraint between the ideal and dummy guns has the effect that if both are elevated from the horizontal and either a cross-levelling adjustment or a Y' angle is applied to the ideal gun, the dummy gun, in following the movement, must deviate its pedestal 281 through a small angle in training relatively to the ideal gun pedestal 280, and this is the additional training correction which we must apply to the actual guns. The dummy gun pedestal 281 carries a contact roller 284 bearing against a two-part commutator 285 on the toothed ring 288 which is pivoted coaxially with the dummy gun pedestal and is driven by a D. C. reversible motor 286 which also drives through suitable gearing a transmitter 287. It is clear, therefore, that the motor 286 will cause the ring 288 to follow all training movements of the dummy gun, whether these are due to training of the ideal gun pedestal 280 to the bearing of O'Y', or to the additional training displacement of the dummy gun pedestal relatively to the ideal gun pedestal. The transmitter 287 will therefore transmit to pointers at the actual guns the total training displacement required to point them at the gun axis position determined by the predictor.

For use in land fortresses where there is no yawing or change of course to be taken into consideration, the gyro compass 159, motor 160, differential gear 162 and transmitter 155 can all be eliminated, the handwheel 156 and transmitter 154 being connected direct to the director canopy training worm 158. The repeat motor 179 on the predictor training dial would then be controlled by the transmitter 154, and this motor could also be used to rotate the dials 31 and 65 instead of motor 287, as in the mechanism shown in Fig. 8 the worm wheel 171 must run in the same direction as dials 31 and 65 for a given change of azimuth of OY. If therefore a chain wheel of suitable size be attached to the worm wheel 171 it could be used to drive the dials 31 and 65, but this applies only in the case of use on shore where yaw has not to be taken into consideration. It will be seen in Fig. 1 that the motors 94 and 179 of dials 67 and 195 are controlled by the same transmitter, and it might be thought that one motor and a chain drive might serve the purpose. Examination will show, however, that the wheels controlled by these two motors run in opposite directions, so that a single motor can be used to drive both only if means are adopted to drive the dials in opposite directions.

The arrangement so far described works well so long as the target is at a fairly high angular elevation, but at low elevations the tangent mechanism controlling the pointers 5' and 6' does not function properly because of the very large variation in velocity ratio between the pointers and their controlling motors. At low elevations the most convenient method of operating the sight and the guns also changes because training becomes a more convenient means of dealing with change of azimuth than cross-tilting of either the sight or gun. The sight operator then has no need for the tilting Y plane and can control his line of sight by training and elevating

61.5

the X plane, the Y plane being kept vertical. Horizontal range is then a more convenient variable to select in place of target height, but since the range may change very rapidly and only spot readings can be obtained from the range-finder, we prefer to set the range pointer **104** moving at a rate representing the rate of change of horizontal range, i. e. dy/dt, by means of a constant speed motor **181** (Fig. 1) driving a continuously variable speed gear **182**, the output spindle of which drives through a differential gear **183** a worm which drives the worm wheel **184** compound with the pointer **104**. Electric contacts between the pointers **104** and **104'** are made to control the motor **101**, which, by driving slide **97**, drives the slide **8** and also the pointer **104'** through the rod **107** and rack **106**. The speed of the slide **8** is controlled by the arbor **185** of the variable speed gear which is moved by the lever **186**, this lever carrying on a pivot **187** a second lever **188** which engages at its ends with a pin **189** on slide **33** and a pin **190** on slide **78**. We have already seen that the motion of slide **78** is the y component of relative wind on a scale of half that applied to slides **72** and **74**, while the motion of slide **33** is the y component of target air-speed on the same scale as is applied to slides **72** and **74**; hence if the pivot **187** is placed relatively to the pins **189** and **190** in the ratio 2:1, the motion of the pin **187** will represent the sum of the y components of target air-speed, true wind and ship's speed on a scale one-third of that applied to slides **33**, **72** and **74** and will obviously be proportional to the rate of change of horizontal range. The motion of the arbor **185** of the speed gear **182** is therefore set in proportion to the rate of change of horizontal range and the speed ratio is chosen so that the motion of slide **8** is equal to the rate of change of range. When spot readings of range are obtained, corrections are applied to the pointer **104** by the handwheel **191**, worm gear **192** and differential gear **183**, these corrections being passed on to the slide **8** and pointer **104'** by the motor **101**. The height slide **15** is then controlled from the pointers **6**, **6'** so that it will not interfere with the smooth action of slide **8**. As the mechanism of the pointers **6**, **6'** is a true tangent mechanism, if the horizontal range is set correctly the height pointer **18'** must indicate the correct height on the dial **19**, so that if the latter reading is obviously wrong it indicates an error in the range setting and a correction can then be applied by the handwheel **191**. At low elevations the control of the Y pointer **5'** by the slide **7** may be defective when that pointer is vertical, and for that reason we may use synchronizing springs between the pointers **5** and **5'** so that they tend to keep together and a small force is required to separate them. These springs are shown in Fig. 3. Fixed to the spindle which carries the pointer **5'** and the slotted crank **11** is a disc **193**, and loose on the same spindle is another disc **194** to the hub of which are anchored two similarly-wound springs **195** and **195'**, the outer ends of these being fastened to pins fixed respectively to the spur wheel **3** of pointer **5** and the disc **193** of pointer **5'**. These pins project through a quadrantal notch cut in the periphery of the disc **194** and are normally kept pressed against the same side of the notch by the tension on the springs, thus holding the pointers **5** and **5'** in alignment. When the pointers are forced apart one or other of the pins is pulled away from the side of the notch, thus introducing a spring force tending to realign the pointers.

In normal working at intermediate target elevations and up to and through the zenith, the switch **108** is thrown over so that the motor **101** is controlled by the pointers **6**, **6'** and the pointers **104**, **104'** control nothing. The height pointer **18'** can then be set by hand, or preferably it is controlled by contacts between the pointers **18**, **18'** actuating the motor **26**. At low target elevations the director sight is conveniently worked by elevating and training only, the Y plane being kept vertical, which brings the pointers **5**, **5'** vertical. The switch **108** is then thrown over into the position shown in Fig. 1 so that the motor **101** is controlled by pointers **104**, **104'** and the height motor **26** is controlled by pointers **6**, **6'**. When working at low elevations if the swinging discs **121** and **122** were left entirely to their own devices, it might be possible for the sight operators to be working with zero Y angle, while the predictor worked out a Y' angle which it might be inconvenient to apply to the gun. To ensure therefore that in such circumstances the guns may also work with zero Y' angle, except for levelling adjustments, and that they will instead receive the full training deflection YOY', we may arrange a device to lock the Oldham coupling slot **117** centrally on its disc **121**, or more simply, to lock the slide **128** in its mid position so that the pointer **137** will be at zero and the motor **148** will transmit zero Y' angle to the conversion unit. This will not interfere in any way with the ideal gun determining and applying to the dummy gun and the actual guns the correct cross-levelling adjustment, but it will ensure that in circumstances in which training is preferable to cross-tilting of the gun, the guns will be deflected through the full training angle which will make it possible to dispense with cross-tilting, except for the cross-levelling adjustment which must be applied in any case to compensate for tilt of the training axis. The conditions may be determined by the sight operators who, by making a pre-arranged signal, say by closing a switch at the director which lights a lamp at the predictor, can warn an attendant at the predictor to lock the slide **128** and throw over the switch **108**. Alternatively the signal can be made at the gun when the gun crew find that training becomes preferable to cross-tilting, or it can be made at the predictor itself, say by the X' pointer **138** closing a contact on coming below a certain elevation which it is decided is the minimum elevation at which a Y' angle can be conveniently applied to the gun. In this connection it should be observed that there is nothing in the mechanism to become jammed even if the sight is operated by X and Y angles with the slide **128** in the predictor locked. In these circumstances the predictor will simply determine the correct elevation and training angles for the gun axis position from the X and Y angles of the line of sight received from the predictor. Alternatively, by leaving the slide **128** free, it is equally possible for the predictor to receive from the director a zero Y angle and a training displacement of OY, and derive therefrom, together with the X angle of the moment, an X' and a Y' angle for the gun, that is to say, the sight may be operated solely by laying and training while the gun can be operated by the movement of the X' and Y' planes, with or without a training displacement. The system is therefore exceedingly elastic and permits of the sight or gun being operated accurately on the method of operation most suited to the circumstances of the moment irrespective of the method of operation of the other.

In Fig. 1 we have shown two different types of multiplying levers. The lever 38 has a slot at one end and a pin at the other, the intermediate pivot being at a fixed distance from the pin. Lever 84, on the other hand, has its fulcrum at one end and a long slot engages with two pins which move along parallel paths. In the former case if p is the variable distance between pins 50 and 40, the lever multiplies the motion of slide 32 by the factor p/a, where a is the fixed distance between pins 36 and 40, but this applies only for small angular motions of the lever because the motion of one slide varies with the sine of the obliquity and the motion of the other with the tangent. In the case of lever 84 both slides move according to the tangent of the obliquity, but the lever multiplies by the factor $p/(b+p)$ where b is the fixed distance between the paths of the pins 88 and 90 and p is the variable displacement of the fulcrum 86. In order that the motion of slides 89 and 92 may be correct we plot the curves on drum 62 not as curves of the function $f=Hg.\text{cosec}\,\phi/V$ but as curves of $f/(1-f)$; which makes the motion of the slide proportional to f. In the case of lever 38 also the two slides which it connects move in opposite directions, whereas in the case of lever 84 they move in the same direction and the curves are plotted to allow for this difference. We may either have the approximate mechanism of lever 38 with the curves of the function, or the true mechanism of lever 84 with curves of $f/(1-f)$.

We shall now refer to certain alternative constructions illustrated in Figs. 10 to 14.

The method of introducing corrections by means of curves plotted on drums has the disadvantage that at every important change of range or target height the pointers have to be reset by hand, while the continuous operation of the predictor cannot be automatic. It is possible, however, by suitably shaped cams to dispense with the curves and to make the whole operation automatic. Suppose, for example, the "time of flight" drum 48, instead of being cylindrical, is shaped so that its outline on a cross-section at a distance z from one end is the polar curve of time of flight plotted against range for the particular target height corresponding to the distance z, the difference between the radius r at any point on the curve and the minimum radius r_0 being proportional to the time of flight for a range represented by the angle θ between the two radii. Then if a roller is held against the cam while the latter is moved axially through a distance z and rotated through an angle θ from its zero position, the radial displacement $(r-r_0)$ of the roller will be proportional to the time of flight for the range corresponding to θ and a target height corresponding to z. The application of this method is shown in Fig. 10 which represents an alternative to part of Fig. 1, corresponding parts being similarly numbered to facilitate comparison.

The three cam drums 48, 61 and 62, constructed as just described, are fixed to a spindle 215, one end of which is supported in a fixed bearing 216 and the other end is splined in the hub of the spur wheel 217 which is supported in the fixed bearing 218, so that the drums can be displaced axially by means of the fork 219 mounted on the screw 220 and engaging with the grooved pulley 221 on the shaft 215 and it can also be rotated through almost a complete revolution by means of the spur wheel 217. The screw 220 is connected through bevel gearing 222 or by any convenient means to the worm shaft 23 (Figs. 1 and 5) which drives the target height follower pointer 18′, so that the axial displacement of the cams from their zero position is proportional to target height. A rotational displacement proportional to range might be imparted to the cams directly by the cord 57, as in Fig. 1, but on account of the greater friction we prefer to employ a relay between the cord and the drums. The cord 57 is therefore connected merely to a spring-constrained pulley 223 carrying a contact pointer 224. A follower pointer 224′ is fixed to the worm-wheel 225 driven by the motor 226 controlled by contacts between the pointers 224 and 224′, and the pinion 228, which is fixed to the spindle of motor 226, meshes with the spur wheel 217 and therefore rotates the cams proportionally to the horizontal range of the future target position. Rollers 229, 230 and 231, pivoted on arms carried by loose sleeves 232, 233 and 234 on the fixed shaft 235 are held pressed against the cams by springs (not shown) and the profiles of the three cams are generated, as already explained, so that the rocking motions conveyed to the three sleeves are proportional respectively to the height Hg, the time of flight, and $Hg.\text{cosec}\,\phi/V$ or such functions of these quantities as may be necessary in the light of explanations already given in the case of drums 48 and 62 of Fig. 1. The first-mentioned displacement is conveyed to the slide 139 by the bevel wheels 236 and toothed sector 237 which engages with a rack cut on the slide. The second is conveyed to the vertical slide 43 by the toothed sector 238 fixed to the sleeve 233 and meshing with the rack 239 on the slide 43. The third is similarly communicated to the slide 82 by the toothed sector 240 fixed to the sleeve 234.

A mechanism which may be used to replace the cord 57 for conveying the cams of Fig. 10 or drums of Fig. 1 the required rotation proportional to horizontal range of future target position is shown in Fig. 11, the parts which already appear in Fig. 1 being similarly numbered. The fixed plate 58 carries a tube 241, the axis of which passes through the intersection of the 45° slots in the slides $54a$ and $55a$ when these are in their zero position. A piston 242 sliding in the tube is keyed to the sleeve 243, which slides on the tube 241 and carries the disc 244, by means of the pins 245 passing through longitudinal slots 246 in the tube 241. The piston is constrained by the compression spring 247 so that the disc 244 presses against the rim of a conical cup 248, while the ball 249, whose centre is on the intersection of the axis of the cup 248 and the plane of its rim, is pressed against an internal spherical seating in the end of the tube 241. A second ball 250 on the axis of the cup 248 engages without shake in a hole in the slide-block 251 which slides in the 45° slots in the slides $54a$ and $55a$ and follows their intersection. Thus when the slide 251 is displaced in any direction from its zero position, the piston 242 is given a proportional axial displacement which is conveyed by means of a rack 252 to a pinion 253 which may be either fixed to the drum spindle 215 (Fig. 10) or 59 (Fig. 1) or may carry the contact pointer 224 of the relay (Fig. 10), if a relay is used.

Fig. 10 also illustrates an alternative method of obtaining the x' and y' coordinates of the gun axis position. The slides 96 and 97, actuated as in Fig. 1, carry 45° slots 255 and 256 which engage with a double slide-block on which the pin 113 is centrally mounted. The discs 258 and 259 are arranged with their centres on the same horizontal line as, and equidistant from the pin 113 in its zero position, both discs being free to rotate and being linked together, as before, by the connecting rod 123. A section of one of the discs is shown in Fig. 12. The disc 258 is carried by a sleeve 260 in a bearing in the predictor case, and the sleeve is fitted at its other end with a pinion 261. Housed in the sleeve is a spindle 262 fitted at each end with pinions 263 and 264, of which 263 is at the same end as, and of the same size as, pinion 261, while pinion 264 meshes with an internal rack on the slide 265 which runs in a diametral slot on the face of the disc, the slide 265 carrying the pin 116. The pinions 261 and 263 mesh respectively at opposite sides with racks on the slides 266 and 267 which also mesh with an idle pinion 268 (Fig. 10) on the slide 133. If the disc 258 turns on its centre with no relative displacement of the slide 265, the slides 266 and 267 are moved equally in opposite directions so that there is no movement of slide 133, but if the radius of pin 116 is altered, there will be relative movement between pinions 261 and 263 and a proportionate sliding movement of the slide 133, the proportion being determined by the relative diameters of the pinions 264, 261 and 268. We link the three pins 115, 113 and 116 together by a pantagraph 269, shown dotted in Fig. 10. The guide slots on the discs 258 and 259 are at right angles to each other and represent, as indicated, the new axes O'X' and O'Y', and any movement imparted to the pin 113 produces either a sliding movement of either or both of pins 115 and 116, together possibly with a rotation of the discs 258 and 259. The displacements of pins 115 and 116 give the y' and x' coordinates of the gun axis position, while any rotation of the discs gives the angle YOY'. The displacements of the pins 115 and 116 on their respective discs are conveyed through the slides 128 and 133 to the crank pins associated with the pointers 137 and 138, as before, in order to determine the corresponding X' and Y' angles.

The pantagraph used to connect the pins 113, 115 and 116 may be of the ordinary type shown in Fig. 13 or of any mechanically equivalent type, such as the differential sliding type shown in Fig. 14. In this form the central pin 113 forms a pivot for the double-armed guide bar 270 and for a pinion 271 which meshes with two opposed racks cut on slides 272 and 273 which slide in opposite directions in the guide bar 270, the slide 272 being pivoted on the pin 116 and 273 on pin 115. With this arrangement the three pins are always in line, the end pins being equidistant from the centre one, while the line on which they lie can tilt about 113, or about 115 or 116. The coordinates derived in this manner by the pins 115 and 116 are twice the coordinate settings of pin 113, or $2/\sqrt{2}$ times the scale of movement of the slides 96 and 97.

We claim:—

1. Predictor mechanism comprising means movable in accordance with the height of the "gun axis position", the linear coordinates of said position along two horizontal coordinate axes other than the pivot axes of the gun, and means to determine mechanically from said height and said linear coordinates the angular coordinates of said position, being the angular displacements of two planes pivoted respectively on said coordinate axes and rotated from the vertical so as to intersect along the line joining the origin of said coordinate axes to said "gun axis position".

2. Predictor mechanism comprising means to determine mechanically and continuously the linear components, along two horizontal coordinate axes, of the present position of a moving aerial target, of the target traverse relatively to the air during the time of flight of the shell, and of the horizontal deflection of the point of burst of the shell due to the gyroscopic deflection of the trajectory caused by wind, and means to combine said components algebraically so as to determine the horizontal coordinates of the "gun axis position" along said coordinate axes.

3. Predictor mechanism comprising means to displace members in proportion respectively to the components, along two horizontal coordinate axes, of the present position of a moving aerial target, of the target traverse relatively to the air during the time of flight of the shell, and of the horizontal deflection of the point of burst of the shell due to the gyroscopic deflection of the trajectory caused by wind, and means to combine the displacements of said members mechanically so as to displace an element by an amount proportional to the horizontal component range, and in a direction representing the azimuth, of the gun axis position relatively to the said coordinate axes.

4. Predictor mechanism comprising means to displace members in proportion respectively to the components, along two horizontal coordinate axes, of the present position of a moving aerial target, of the target traverse relatively to the air during the time of flight of the shell, and of the horizontal deflection of the point of burst of the shell due to the gyroscopic deflection of the trajectory caused by wind, means to combine the displacements of said members mechanically so as to displace an element by an amount proportional to the horizontal range, and in a direction representing the azimuth, of the gun axis position relatively to the said coordinate axes, and means to derive mechanically therefrom the horizontal coordinates of said position along two other coordinate axes in the same plane as, but angularly displaceable relatively to, the first said coordinate axes.

5. Predictor mechanism comprising a vector element displaceable in a plane in any direction from a fixed centre, two slotted discs pivoted on their centres for rotation in said plane and linked together so that they rotate equally and in the same direction with their slots at right angles to each other, two members sliding respectively in said slots and linked to said element so that movement of the element displaces said members in proportion to the components of the radial displacement of the element relatively to two rotatable coordinate axes denoted by said slots.

6. Predictor mechanism comprising a vector element displaceable in a plane in any direction from a fixed centre by component movements applied in two intersecting directions representing coordinate axes, two slotted discs pivoted on their centres for rotary movement in said plane and linked together for equal rotary movement in the same direction with their slots inclined to each other at a constant angle, two members sliding respectively in said slots and linked to said element so that component displacements applied to the element produce respective displacements of said two members in proportion to the components of the radial movement of the element from its centre measured along the rotating co-

ordinate axes denoted by said rotating slots, and means to convey to other mechanisms the radial movements of each of said members along its respective slot and the rotary movement of said discs.

7. Predictor mechanism comprising mechanism adapted to be actuated continuously in accordance with the azimuth of one of two mutually perpendicular coordinate axes and the present position of a moving aerial target in relation to both of said axes, mechanism displaceable in proportion to the speed and course of the target relatively to the air, mechanism displaceable in proportion to the direction and velocity of the air relatively to the gun, and means cooperating with all said mechanisms to determine mechanically and continuously factors determining, in relation to two other horizontal coordinate axes, the direction of the gun axis position and the angular displacement between said first and second sets of coordinate axes.

8. Predictor mechanism for determining the horizontal displacement of the point of burst of a shell due to gyroscopic deflection of its trajectory caused by wind, comprising a mechanism displaceable in proportion to the direction and velocity of the air relatively to the gun, two members movable respectively in proportion to the linear components of said velocity along two horizontal coordinate axes, a device displaceable in accordance with variations in the instantaneous value of $Hg.\text{cosec}\ \phi/V$, in which Hg is the height of the gun axis position and ϕ its quadrant elevation, and V is the muzzle velocity of the shell, and means for multiplying the movement of each of said two members by the movement of said device to determine the linear components of said horizontal displacement.

9. Predictor mechanism comprising means to resolve the radial setting of a vector member into two components along directions inclined to each other, comprising two parallel slides each carrying a slotted arm, said slots being equally and oppositely inclined to their respective slides and inclined to each other at the angle of inclination of said directions, and engaging at their point of intersection with said vector member, whereby a setting of the vector member displaces the two slides parallel to each other in proportion respectively to the components of the vector setting along the two intersecting directions defined by the two slots when the vector setting is zero.

10. Predictor mechanism comprising means to adjust a vector member in radius and phase by two slides moving parallel to each other, said means comprising two slotted arms carried respectively by the two parallel slides, said slots being equally and oppositely inclined to their respective slides and inclined to each other and engaging at their point of intersection with said vector member so that the vector member is at its zero position when the slides are at their respective zero positions, whereby displacements applied to the slides in proportion to the components of the required vector setting along the directions defined by the slots in the zero position of the slides produce a displacement of the vector member in radius and phase proportional to the resultant of said components.

11. Predictor mechanism comprising a movable element adjustable in accordance with the angular elevation of a target, a follower element, a range pointer and a range follower pointer, a follower mechanism for causing said follower element and follower pointer to follow the first said element and range pointer respectively and having an independently adjustable coacting part, actuating means controlling movements of said follower mechanism and adapted to be controlled by relative displacements between said pointers, and other actuating means controlled by relative displacement of the said elements for adjusting said coacting part in accordance with the height of the target.

12. Predictor mechanism comprising a vector member settable in radius and phase to represent the wind velocity and direction relatively to the earth, a second vector member settable in radius and phase to represent the velocity and direction of the gun relatively to the earth, a third member displaceable in proportion to the instantaneous value of $Hg.\text{cosec}\ \phi/V$, and two elements displaceable by cooperation of the three said members in proportion respectively to components of $Hg.\text{cosec}\ \phi.W/V$, being the horizontal displacement of the gun axis position due to the gyroscopic deflection of the trajectory of the shell caused by the relative movement between the gun and the air.

13. Predictor mechanism comprising a vector member displaceable in a plane and in any direction from a fixed centre, two discs pivoted on their centres equidistant from, and on a line passing through, said centre, two vector members sliding in diametral slots on said discs, said slots being arranged at right angles to each other, a connection between said discs to permit them to rotate equally on their centres, and a pantagraph connecting said three vector members, whereby a movement of first said vector member may produce a diametral movement of either or both of said second and third vector members and/or a rotation of said discs, or any combination of said movements according to the direction of movement of first said vector member and the friction of said diametral movements of the second and third members and rotary motion of the discs, means to displace two elements in proportion respectively to the diametral movements of said second and third vector members and means to displace a third element in proportion to rotary movement of said discs.

14. Predictor mechanism comprising a vector member displaceable in any direction in a plane from a central zero position, and means to displace a member in proportion to radial displacements of said vector member irrespective of the direction of said movement comprising a clearance hole in said member at right angles to said plane, a ball sliding in said hole and carried by a stem pivoted on a fixed centre external to said plane, said centre being on a line at right angles to said plane through said zero position of the vector member, a conical cup carried by said stem, an element moving axially along said line, a disc parallel to said plane and moving axially with said element, and means to keep said disc constantly in contact with the rim of said cup, whereby said element is moved axially in proportion to radial movement of the vector member.

15. Predictor mechanism comprising two members movable respectively in proportion to the components of target speed and relative wind speed in the vertical plane of the line of sight to a target, a lever pivoted on both said members, a pin positioned on said lever so that the movements of said pin produced by movements of said two members are on the same scale, whereby the movement of said pin is proportional to the rate of change of the horizontal component of the

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range of the target, a range indicator, a constant speed device, a variable speed gear connecting said device and indicator for driving the indicator at a speed controlled by the device, and a connection between said device and said pin for controlling said indicator in accordance with the said rate of change of range.

16. Predictor mechanism having elements adapted to receive factors determining the present position of the target relatively to two horizontal coordinate axes, members adapted to be displaced in proportion to factors determining the position of the gun axis position relatively to two other horizontal coordinate axes, and a training dial having a part displaceable in proportion to movements in azimuth of one of said first coordinate axes relatively to a given direction, a part displaceable in proportion to the difference in azimuth between said two sets of axes, and a third member mechanically displaceable in proportion to the algebraic sum of the movements of the other two said parts.

17. Predictor mechanism comprising a receiver element adapted to be controlled from a distance, a follower element adapted to be kept in a fixed relation to said first element, a movable member for actuating said follower element and a plurality of other movable members adapted to be displaced independently by varying amounts, differential means for coupling all said movable members in series and a final member coacting with said movable members and differential means so that, said final member being fixed, the first said movable member is displaced by an amount proportional to the sum of the movements of the other movable members, power means controlled by relative displacements between said receiver element and follower element for displacing said final member whereby said final member is moved by an amount proportional to the sum of the movements of said plurality of movable members plus an amount varying with the movement of said receiver element.

18. Predictor mechanism comprising means to add together a number of independent displacements, comprising a receiver element, a follower element for same, actuating means for said follower element, a primary element connected to said actuating means, an output element connected to said primary element through a plurality of differential gears arranged in series, that is to say the said primary element is connected to the input member of the first differential gear and the said output element is connected to the output member of the last differential gear, the output member of each differential gear except the last being connected to the input member of the next following differential gear, means to apply independent displacements to the intermediate members of the differential gears so that, the output element being fixed, the said input element will be displaced in proportion to the sum of said applied displacements of the intermediate members, power means to displace the output element, said power means being controlled by the relative position of said receiver and follower elements, whereby the said output element is displaced by said power means so as to maintain the receiver and follower elements in a fixed relation to each other and by an amount proportional to the sum of the displacements of the intermediate members plus an amount varying with the displacement of the said receiver element.

19. Predictor mechanism comprising elements movable in accordance with data of the present position of the target, the course and speed of the target, and the velocity and direction of the wind, and three movable mechanisms controlled by movements of said elements, the first of said movable mechanisms having movement representing the change of azimuth of two horizontal coordinate axes, and the second and third having angular movements respectively proportional to the angles of tilt of two imaginary planes pivoted on said axes and inclined from the vertical so as to contain the required direction of a gun to hit said target.

20. Predictor mechanism comprising members displaceable respectively in accordance with the present position of a target, the speed and course of the target, and the velocity and direction of the wind, an element actuated by displacements of said first and second members in accordance with the horizontal range of the future target position, a second element actuated by said third member and first element in accordance with the horizontal range and azimuth of the "gun axis position", a part actuated by said first element and a second part associated with said first part and displaceable in proportion to the height of the said "gun axis position", and means to combine the movements of said second element and second part to determine the linear and angular coordinates of said "gun axis position" relatively to two horizontal coordinate axes.

21. Predictor mechanism comprising an element displaceable in direction and amount to represent the horizontal range and azimuth of the "gun axis position" relatively to the two horizontal coordinate axes, other means controlled thereby in accordance with the linear coordinates of said position along two other horizontal coordinate axes, a scale movable in proportion to said horizontal range, and a member associated with said scale and movable in proportion to the height of said "gun axis position".

22. Predictor mechanism comprising means actuable in accordance with the present position of a moving aerial target, means actuable in accordance with the velocity and direction of the wind relatively to a gun, means actuable in accordance with the movements of the target relatively to the air during the time of flight of a shell fired thereat from said gun, a rotatable mechanism representing two horizontal coordinate axes rotatable in azimuth and means actuated for rotating the said mechanism and comprising elements movable relatively to said mechanism in proportion to the linear coordinates, with respect to said axes, of a point on the direction through their origin with which a gun must be aligned in order to hit said target.

23. Predictor mechanism comprising elements displaceable respectively in accordance with (1) the present position of a target, (2) the target traverse relatively to the air during the time of flight of a shell fired at said target, and (3) the horizontal displacement of the point of burst of said shell relatively to the air due to wind, a member actuated by said first and second elements in accordance with the horizontal range of the future target position relatively to the air, a member associated with said first member and displaceable in accordance with the height of the "gun axis position", parts actuated by said three elements in accordance with the linear coordinates of the said "gun axis position" relatively to two horizontal coordinate axes and three other elements actuated by said last mem-

ber and said parts in accordance with the angular displacements to be applied to a gun in three intersecting planes in order to align the gun with said gun axis position.

24. Predictor mechanism comprising a movable primary element, a follow-up element for same, a train of differential gears connected in series, the output element of each gear except the last being connected to the input element of the next succeeding gear and the output element of the last gear being connected to the said follow-up element to actuate the same, means to apply independent displacements to the follow-up element by moving the intermediate elements of any of the differential gears, and power means actuated by relative displacements between the primary and follow-up elements and acting on the input element of the first differential gear for moving the follow-up element through the train of gears so as to cause the follow-up element to follow the primary element

25. Predictor mechanism comprising elements movable in accordance with data of the present position of a target, the course and speed of said target, and the velocity and direction of the wind, members representing the directions of two horizontal coordinate axes, a part associated with said members and controlled by movements of said elements so as to represent relatively to said members the direction and horizontal range of the "gun axis position" projected on to the plane of said axes, an element actuated in accordance with ballistic data pertaining to a gun, and two members actuated partly by said part and partly by said last element in accordance with the angular rotations of two imaginary planes pivoted respectively on two other horizontal coordinate axes and tilted from the vertical so as to contain the "gun axis position".

26. Predictor mechanism comprising members adjustable in accordance with received data of the present position of a target, the speed and course of said target, and the direction and velocity of the wind, an element movable by said members in proportion to the horizontal component of the range of the "gun axis position", a part movable in proportion to the vertical height of the "gun axis position", two elements controlled by said first element in proportion to the linear coordinates of the "gun axis position" relatively to two horizontal coordinate axes, and two angularly movable members actuated by said part and each of said last two elements respectively in proportion to the angular relation of the gun axis position relatively to each of said axes.

27. Predictor mechanism comprising members adapted to be actuated in accordance with received data of the present position of a target, the speed and course of said target, and the direction and velocity of the wind relatively to a gun, an element actuated by said first and second members in proportion to the horizontal component of the range of the future target position relatively to the air, a second element actuated partly by said third member and partly in accordance with known ballistic data pertaining to the gun and having movement in proportion to the horizontal displacement of the point of burst of a shell fired from said gun at the target due to the gyroscopic wind-deflection of its trajectory, a third element actuated by said first and second elements in proportion to the horizontal range of the "gun axis position", a fourth element actuated partly by said first element and partly in accordance with other ballistic data pertaining to the gun and having movement in proportion to the vertical height of said gun axis position, means controlled by said third and fourth elements for determining the relation of the gun axis position to two horizontal coordinate axes with their origin at the gun, and means associated with the said third element for determining the azimuth of said coordinate axes.

28. Predictor mechanism comprising members adapted to be actuated in accordance with received data of the present position of a target, the airspeed and course of said target, and the direction and velocity of the wind relatively to a gun, three elements controlled partly by movements of said first and second members and partly in proportion to different ballistic data pertaining to the gun, a part movable by the first and second members and one of said elements in proportion to the horizontal range of the future target position relatively to the air, a second part controlled by said first part, said second member and another of said elements in accordance with the horizontal range of the "gun axis position", a third part actuated by said second part in proportion to the azimuth of two horizontal coordinate axes, and a fourth and fifth parts actuated by said second and third parts and the third of said elements for determining the required direction of the said gun relatively to said coordinate axes in order to hit said target.

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