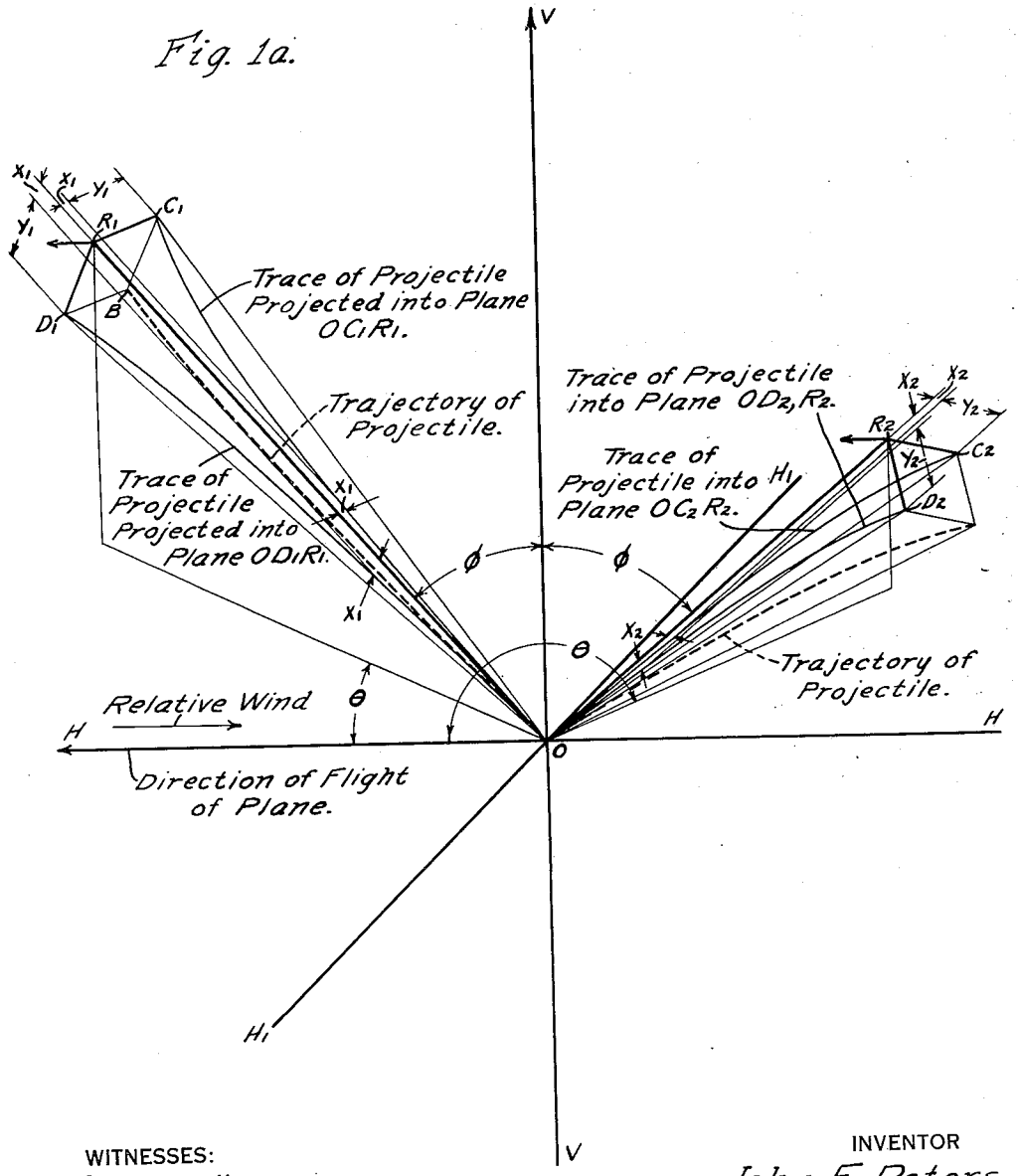
July 2, 1946. J. F. PETERS 2,403,117

GUNFIRE CONTROL SYSTEM

Filed Jan. 8, 1941 5 Sheets-Sheet 1

Fig. 1a.



WITNESSES:

Leon M. Garman

E. L. Oberheim

INVENTOR

John F. Peters.

BY

Paul E. Friedemann

ATTORNEY

July 2, 1946. J. F. PETERS 2,403,117

GUNFIRE CONTROL SYSTEM

Filed Jan. 8, 1941 5 Sheets-Sheet 2

Fig. 2.

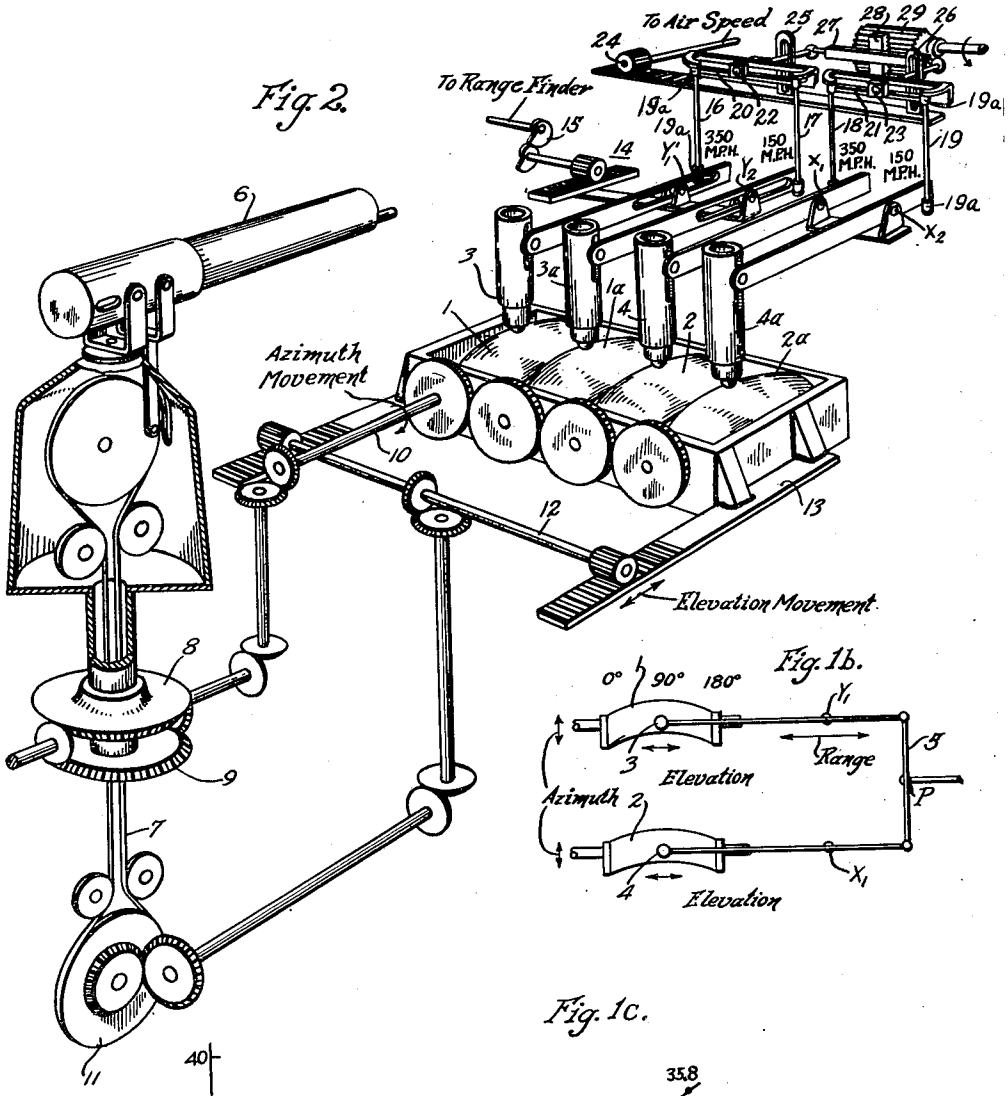
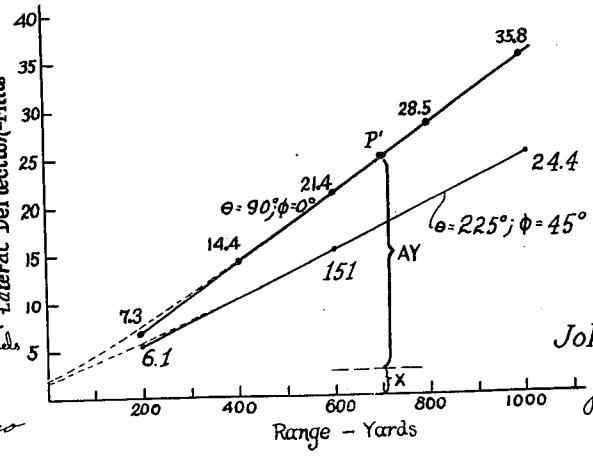


Fig. 1b.

Fig. 1c.



WITNESSES:
Edward Michaels
Wm. J. Ruano

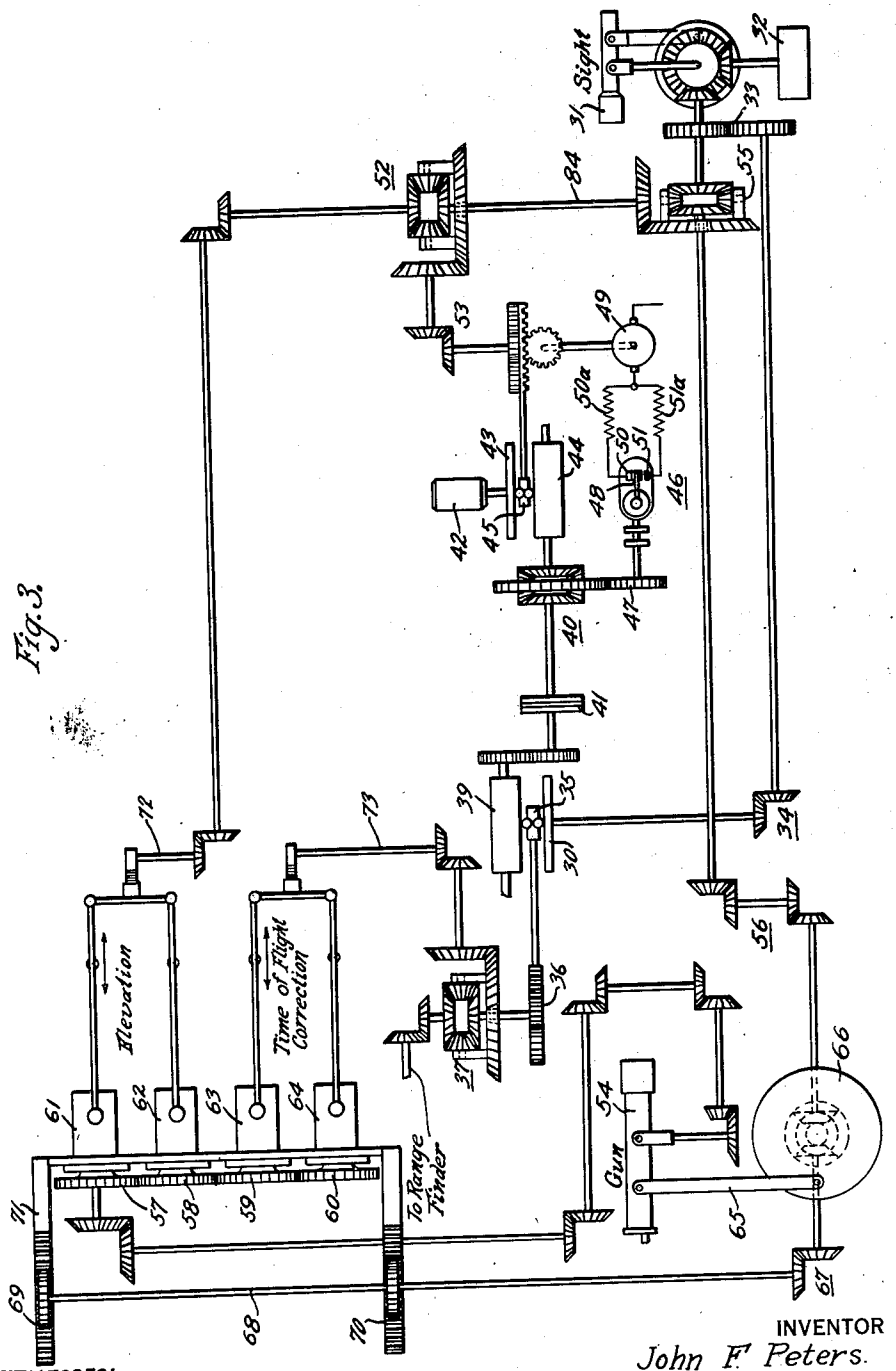
INVENTOR
John F. Peters.
BY
Paul L. Friedemann
ATTORNEY

July 2, 1946. J. F. PETERS 2,403,117

GUNFIRE CONTROL SYSTEM

Filed Jan. 8, 1941 5 Sheets-Sheet 3

Fig. 3.



WITNESSES:
Edward Michaels
Wm. J. Kuano

INVENTOR
John F. Peters.
BY
Paul E. Friedemann
ATTORNEY

July 2, 1946. J. F. PETERS 2,403,117

GUNFIRE CONTROL SYSTEM

Filed Jan. 8, 1941 5 Sheets-Sheet 4

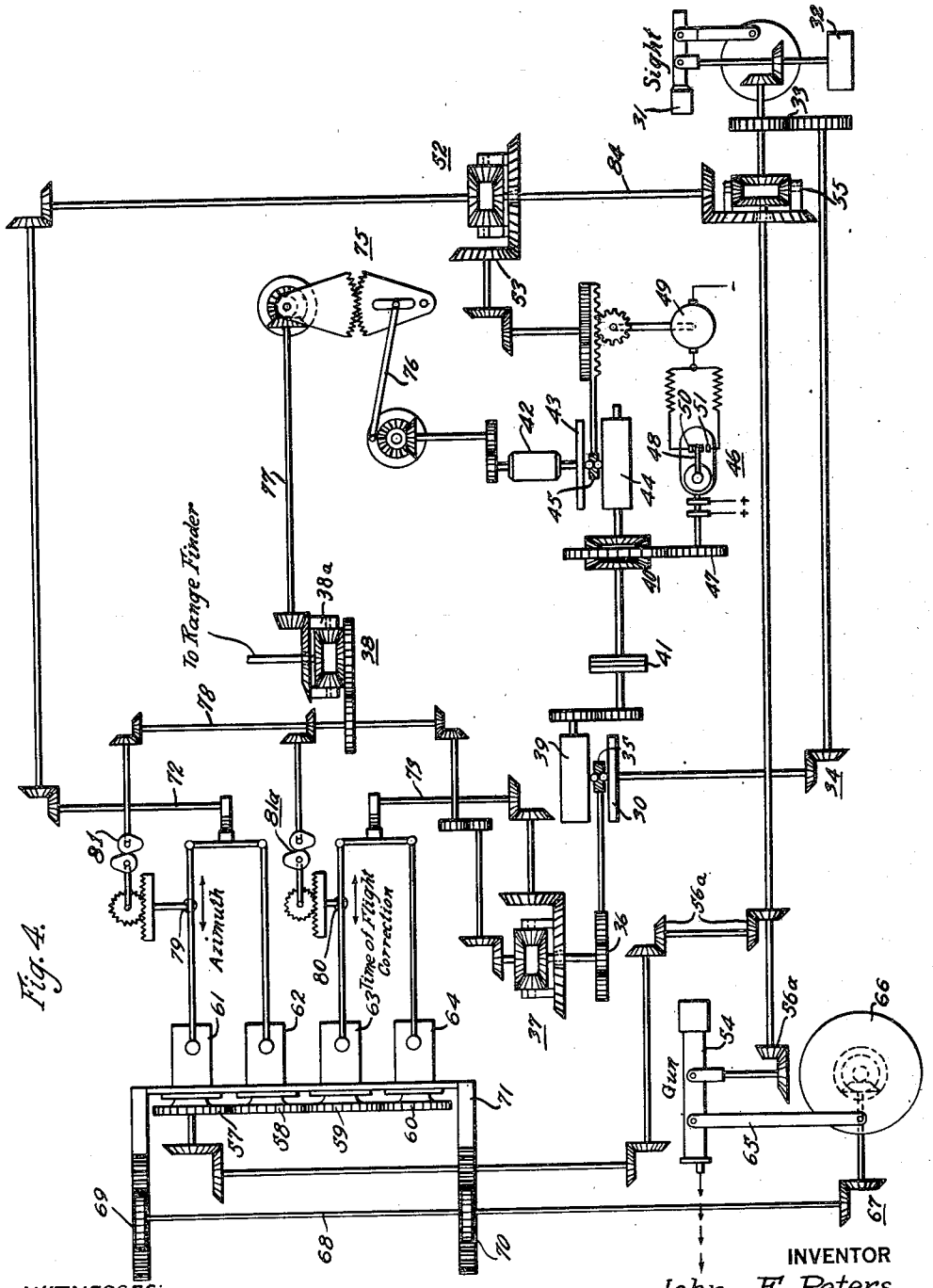


Fig. 4.

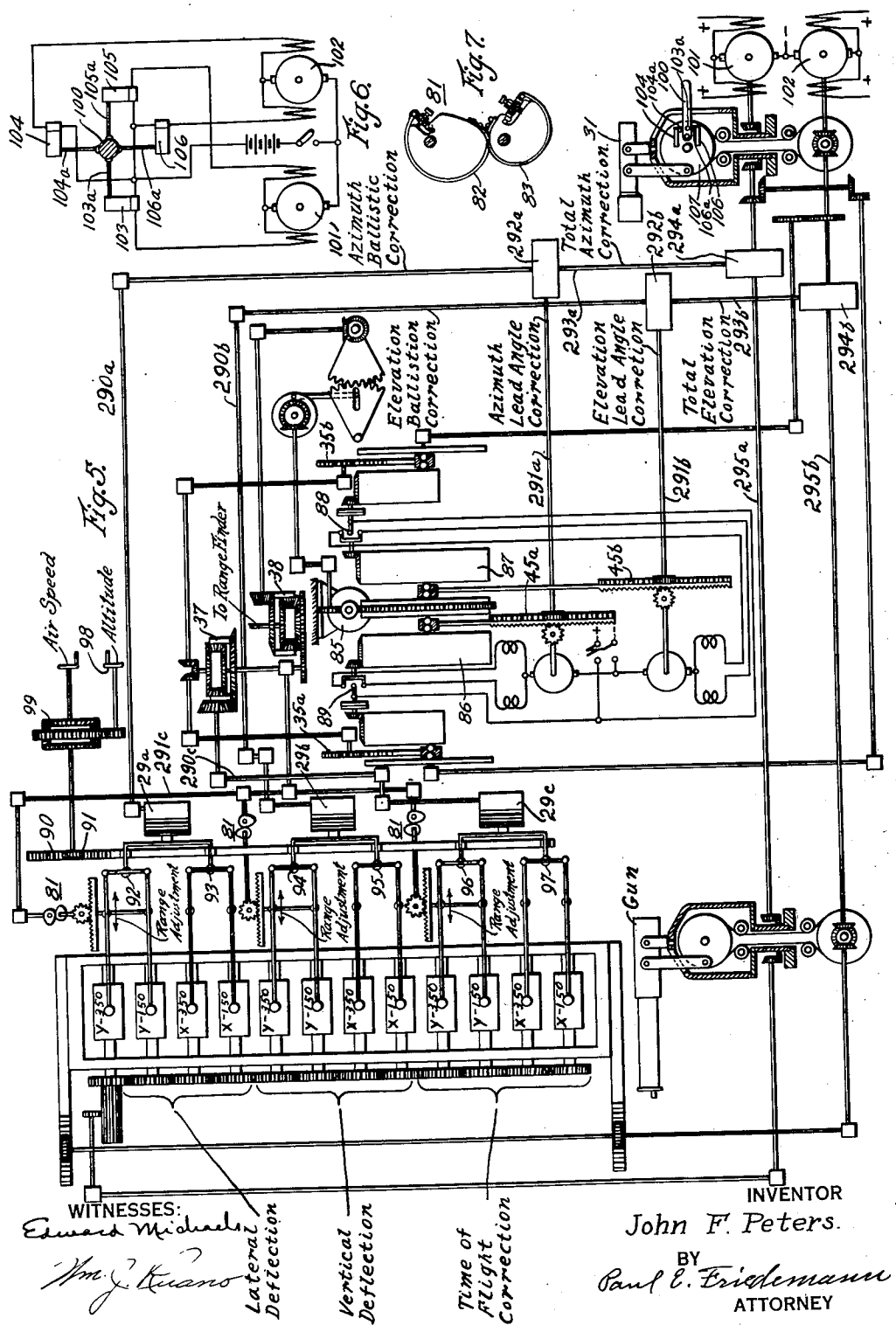
WITNESSES:
Edward Michaels
Wm. J. Kucano

INVENTOR
John F. Peters.
BY
Paul E. Friedemann
ATTORNEY

July 2, 1946. J. F. PETERS 2,403,117

GUNFIRE CONTROL SYSTEM

Filed Jan. 8, 1941 5 Sheets-Sheet 5



WITNESSES:
Edward Michaels
Wm. J. Kuano

INVENTOR
John F. Peters.
BY
Paul E. Friedemann
ATTORNEY

Patented July 2, 1946

2,403,117

UNITED STATES PATENT OFFICE

2,403,117

GUNFIRE CONTROL SYSTEM

John F. Peters, Edgewood, Pa., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Application January 8, 1941, Serial No. 373,699

27 Claims. (Cl. 89—41)

1

My invention relates to a gunfire control system which may be adapted to stationary guns on the ground, but which is more specifically useful for guns mounted on aircraft, that is, guns in flight. My invention specifically relates to means for automatically compensating for various errors which are introduced when a gun mounted on an airplane in flight is fired at a moving target such as another airplane in flight, which errors are affected by azimuth, elevation and range of the target, and which errors include ballistic errors, errors due to time of flight of the projectile in determining lead angles and errors due to air speed and altitude of the plane in which the gun is mounted.

An object of my invention is to provide a gunfire control system suitable for use on an airplane which will automatically compensate for all errors in the angular positioning of the gun introduced when such gun is fired at a moving target such as another airplane and which will provide the proper angle of lead when aiming at a moving target.

A more specific object of my invention is to provide a system including a pair of three-dimensional cams which cams are moved lengthwise and rotated in directions corresponding respectively to elevation and azimuth movements of the gun, each having a tracer, which tracers are interconnected by a suitable linkage means including a variably pivoted lever so that the ultimate output of the summation of effects of the two tracers as modified by the variable pivot will give corrections for any point in the volume of a sphere. The shapes of such cams may be made in accordance with precalculated ballistic data, so that corrections may be made for errors resulting from projectile ballistics, time of flight of the projectile, and the air speed and altitude at which the projectile is fired.

Another object of my invention is to provide a suitable follow-up system by which a gun may be moved in accordance with piloting movements of the sight (or of a piloting member which controls the movements of the sight and gun) together with means for automatically introducing in said follow-up system deviations between the gun and sight, so that only substantial rather than exact follow-up occurs in order to compensate for various errors which are introduced such as ballistic errors, time of flight errors, etc.

Other objects and advantages will become more apparent from a study of the following specification when considered in conjunction with the accompanying drawings, in which:

2

Fig. 1*a* is a three coordinate vector diagram illustrating a fundamental principle of this invention.

Fig. 1*b* is a diagrammatic representation of a system showing certain fundamental operations included in my invention.

Figure 1*c* is a pair of curves showing the relationship between a ballistic correction and range for a predetermined point in space.

Fig. 2 is a perspective view of a system of cams showing certain fundamentals of operation of a gunfire control system.

Fig. 3 is a schematic showing of the gunfire control system showing how corrections for time of flight of the projectile are introduced in determining lead angle in a follow-up system insofar as the elevation movements of the gun are concerned. The system is not a complete one and is merely shown to simplify the explanation of the complete system as represented in Fig. 5.

Fig. 4 is a schematic showing of the gunfire control system showing how correction for time of flight of the projectile are introduced in determining lead angle in a follow-up system insofar as the azimuth movements of the gun are concerned, but which, like Fig. 3, is also incomplete.

Fig. 5 is a schematic showing of a complete system by which the systems shown in Fig. 3 and Fig. 4 are combined, together with additional error compensating features, so that the system will automatically provide ballistic corrections for time of flight of the bullet in lead angle determinations, corrections for air speed, and corrections for altitude.

Fig. 6 is a schematic showing of the control system for the driving motors.

Fig. 7 is an enlarged side view of the cams shown in Figs. 4 and 5.

It is well known that ballistic errors of a gun fired from a high speed airplane vary widely depending upon the direction of fire. These large errors are due to various factors, the important ones consisting of relatively high wind velocity into which the shot is fired with a resulting effect on the spin of the bullet due to the rifling and to the fact that the actual flight is not directly in line with the surrounding air. To compensate for the ballistic errors introduced by the high air speed into which the projectile is fired, the gun must be displaced relatively to the sight in order that the relatively moving air will not, in effect, cause the projectile to deviate from its course of travel toward the target. In the case of the gun being mounted on an airplane, the

displacement of the gun with respect to the sight will vary in a manner dependent upon the position which the sight occupies with respect to the plane, the position of the sight being determined by the position of the target. In this respect, it will be apparent that a different displacement of the gun will be required in the case where the sight is pointed in an upward direction with respect to a horizontal plane than will be had in the case where the sight is pointed downwardly with respect to a horizontal plane. Likewise, it will be apparent that different deflections will be required dependent on whether the projectile is fired with or against the wind. Assuming that the airplane mounting the gun is operating at a constant speed and at a constant elevation, and that the target is flying at the same speed at a constant range with respect to the plane carrying the gun, the ballistic errors vary with the air speed and it is possible to figure out by complicated ballistic formulae both the azimuthal or lateral deflection of the gun and the vertical or elevational deflection of the gun with respect to the sight required to introduce the proper ballistic corrections when the target is at any point on a sphere measured by the range of the target from the gun. Assuming that all other factors remain constant and that a change in range only takes place, it will be apparent that a change in deflection must be had to compensate for the change in range. As pointed out, these calculations are based on the assumption of a constant elevation and identical air speeds of both the target and the gun. Obviously, changing conditions in an airplane are too rapid to permit the manual calculation or introduction of the required deflections into a driving system intermediate the gun and its sight.

As pointed out above, one of the principal objects of this invention is to provide mechanism for automatically introducing the required lateral and vertical deflections into the control mechanism intermediate the sight and gun. This is accomplished by means of an arrangement of cams which are rotated with movement of the sight and gun in azimuth and moved back and forth with vertical or elevation movement of the gun and sight in a manner to be described.

I have found that the ballistic errors or required deflection of the gun with respect to the sight in both azimuth and elevation can be expressed mathematically as $X+AY$, where X is a function of both azimuth and elevation, Y is a different function of azimuth and elevation and A is a function of range. The application of this mathematical expression in the gunfire control system to be hereinafter described will be best understood upon brief reference to the subject of ballistics. Exhaustive tests have been conducted on various projectiles and from these tests accurate ballistic data regarding the path of flight of a given projectile have been obtained. As a result the trajectory of a given projectile for all angles of azimuth and elevation in the sphere of gunfire with respect to relative wind for velocities thereof varying from zero to fairly high values are known. For the specific projectile to be fired from the gun to be controlled by the hereinafter described mechanism it was noted that within the first one hundred yards or so of projectile flight a certain deflection occurred. This deflection comprises two components one vertical or elevational and one lateral or azimuthal, each of which is designated X. This

initial deflection is different for different positions of the gun in azimuth and elevation with respect to the relative wind direction. However, the X component of deflection remains relatively constant for all working ranges to which the projectile travels, even though as the range becomes larger another component Y which varies with range is added. The deflection Y occurring beyond the first one hundred yards or so of projectile flight also varies with azimuth and elevation positions of the gun with respect to the relative wind direction. This latter deflection is made up of the original constant X component plus the value of Y for the particular range at which the deflection is measured. The projectile deflection in each of the lateral and vertical directions beyond that of the deflection X is designated Y. Hence, $X+Y$ represents the total component of deflection of the projectile either laterally or vertically for some predetermined range. Ballistic data obtainable further indicates the value of Y for variations in range. Thus, for example, if the value of Y at say 600 yards were known the value of Y at less than 600 yards would be some value less than the value of Y at 600 yards and for ranges of more than 600 yards the values of Y would be greater than the value of Y at 600 yards. All of the foregoing, of course, is based upon constant azimuth and elevation position of the gun with respect to a relative wind of constant velocity. It was thus observed that a value of Y for some particular range may be selected, for example, 600 yards, and that by multiplying this value of Y by a factor, such as A, which is a function of a known range, the value of Y for that particular range was obtainable. Thus at 600 yards, for the assumed conditions, the value of A would be unity, for ranges less than 600 yards the value of A is less than unity and the value of A at ranges greater than 600 yards is greater than unity. The mathematical expression is now, therefore, written as $X+AY$ in which X is a substantially constant function of azimuth and elevation A is a function of range and Y is a different function of azimuth and elevation.

The foregoing discussion of the significance of $X+AY$ may best be understood upon referring to the three coordinate vector diagram (Fig. 1*a*) which illustrates the projectile path to two target positions in the sphere of gun-fire for a projectile fired from a gun mounted on an airplane. In this illustration specific conditions are assumed insofar as airspeed, altitude and target position, velocity and direction with respect to the airplane on which the gun is mounted, are concerned. The target velocities as vectorially indicated are identical with each other and are identical to that of the plane. Azimuthal angular gun positions are defined by an angle θ measured in the horizontal plane defined by the axes H and H_1 intersecting at point O, with that portion of the H axis to the left of point O in the direction of flight of the plane as the line of zero reference. Vertical or elevational angles of the gun are defined by an angle ϕ and measured about point O in a plane vertical to the horizontal plane HH' having the portion of the vertical axis V above the point O as the line of zero reference. The various other reference characters will be understood with the description of this figure. It will be noted that the angles θ and ϕ as well as the various other reference characters are provided with subscripts. This is for the purpose of differentiating one target from the

other later in this disclosure. However, for the purpose of describing this figure such subscripts will not be employed since the general description applies equally to both targets. Thus, for example, when R is referred to both of the targets R_1 and R_2 are referred to, etc.

The paths of two projectiles to two different points in the sphere of gunfire are indicated by the curved dotted lines OB. This sphere of gunfire is of a diameter which varies with the range of the target and is defined by the azimuth angle θ, the vertical or elevational angle ϕ and the range OR to the target R.

DR is the vertical component of the projectile deflection at point R and is perpendicular to the line OR which is the line of sight to the target R from point O and lies in the plane defined by the angle ϕ. CR is the lateral component of the projectile deflection at point R and is perpendicular to both OR and DR. Assuming now that the projectile trajectory is projected into the plane defined by the points OCR it will be noted that the lateral component of the total deflection may be determined at any point along OR up to R. Thus the values of CR for all values of OR are determined. In the same manner the projectile trajectory may be projected into the plane defined by the points ODR and the values for DR for all values of OR determined. Each of the components CR and DR comprises the X and Y values giving the total lateral and vertical components of deflection each as $X+Y$. Thus $X+Y=CR$ and $X+Y=DR$. The X and Y values comprising the lateral and vertical components of deflection may not be the same, that is, the value of X and Y in a lateral direction may not be the same as the values of X and Y in the vertical direction. The values of X and Y will further be subject to wide variation by the different positions of the gun in azimuth and elevation with respect to the relative wind. The X values of deflection represent the initial deflections of the projectile upon leaving the gun which thereafter remains stantially constant with range and the Y values represent the additional deflection of the projectile caused by the changing range during the course of the projectile's travel towards the target.

As previously mentioned and as may be readily observed from the vector diagram the values of Y both laterally and vertically vary with the range of the target, for an assumed constant angular gun position with respect to a relative wind of constant velocity. In order to simplify the design of the cams and the mechanism associated therewith from which the Y values are to be taken, a value of Y is selected which may apply only, for example, at a range of say 600 yards for a particular angular gun position and wind velocity. The value of Y taken from the cam is therefore accurate only for a target range of 600 yards and for different ranges must be modified by the factor A which is a function of range. Thus the factor A is introduced into the mathematical expression $X+AY$. The lateral component of the deflection is plotted against OR as an abscissa as shown in Fig. 1c for the infinite number of points whose angular position in the sphere of gunfire are controlled by θ,ϕ and the velocity of the relative wind. The two curves shown in this figure are the result of such a plot for $\theta_1=90°$, $\phi_1=0°$ and $\theta_2=225°$ and $\phi_2=45°$ for a particularly indicated airspeed of 250 M. P. H. and an altitude of flight of 15,000 ft.

The value of A depends only on range and for ranges of 200, 400, 600, 800 and 1000 yards A respectively equals .18, .58, 1.00, 1.44 and 1.9. If these values are plotted they give a smooth curve showing that A is a function of range. The two solid curves on Fig. 1c indicate the lateral component of the projectile deflection plotted from actual ballistic data and it will be noted that each of the dotted curves obtained from the application of the expression $X+AY$ agrees exactly with the related solid curve except for the smaller ranges of from 0 to about 300 yards and even here the error is slight.

The method of using the known ballistic data from which the curves were plotted to find X_1 and Y_1 which are functions only of $\theta=90°$, $\phi=0°$ and the values of X_2 and Y_2 which are functions only of $\theta=225°$ and $\phi=45°$ is as follows:

For $\theta=90°$, $\phi=0°$ the values obtained from ballistic data of the lateral component of deflection at 200, 400, 600, 800 and 1000 yards are respectively 7.3, 14.4, 21.4, 28.5 and 35.8. For 600 yards and 1000 yards the expression $X+AY$ can then be written:

(1) $X_1+1.9Y_1=35.8$

(2) $X_1+1.0Y_1=21.4$

Solving this expression there is obtained $X_1=5.4$ and $Y_1=16.0$ for the specified conditions.

Similarly for the angular position in the sphere $\theta=225°$ and $\phi=45°$ from known ballistic data there is obtained $X_2=4.8$ and $Y_2=10.3$. These $X+Y$ values are then used in conjunction with the A's of desired values of range, and the points thus found connected to form the plots of Fig. 1c. Plots of the vertical components of deflection may be obtained in the same manner.

From the foregoing it is readily apparent that the expression $X+AY$ represents either the lateral or vertical component of projectile deflection and that the vectorial addition of $X+AY$ for the vertical component of deflection and $X+AY$ for the lateral component of deflection gives the total deflection of the projectile and thus the amount of correction necessary to obtain a direct hit on the target. It has also been shown by the curves of Fig. 1c that the expression $X+AY$ is correct insofar as the ballistics of the projectile are concerned since the only deviation from the plot of the actual ballistic curves occurs at short ranges where such errors are negligible. Any point on such curves such as P is a function of $X+AY$. The values of X are relatively small as will be noted from Fig. 1c. If the error represented by X is considered negligible, the X cams may be omitted from the system leaving only the Y cams.

For other points in space or on a sphere for a predetermined range, different curves of deflection would be obtained instead of those illustrated, because each point on the curves is influenced by two factors, namely, azimuth and elevation of the gun position with respect to the relative wind.

The mathematical expression $X+AY$ greatly simplifies the known formulae for obtaining or calculating the trajectory of a projectile. By employing such an expression for each of the lateral and vertical components of deflection to obtain the value of the total deflection the mechanics of the apparatus which is used to correct the position of the gun is greatly simplified thereby inherently increasing the overall accuracy of such a device.

As noted in applicant's statement of objects a system of three dimensional cams is provided which cams are moved lengthwise and rotated in two directions and the surfaces thereof traced by suitable cam tracers or followers. The cams are adjustable lengthwise in response to varying gun elevation angles and rotatable in response to varying azimuth gun positions. In one embodiment of this invention the cams may be located in side-by-side relationship, one cam being assigned the X values and the other cam being assigned the Y values for different angular positions of the gun. Each of the above-mentioned cam followers or tracers is provided with a pivotal link which at one extremity is connected to the cam follower and is pivotally moved by the vertical movements of its cam follower following the cam surface. The other extremities of the links are connected together by another link the movement which at its centermost or some other predetermined position indicates respectively the total vertical movement or the desired total vertical movement of the two cam followers and hence indicates the $X+Y$ value for the particular cam settings in azimuth and elevation, with respect to a known value of relative wind. To modify the value of Y by the factor A which is the function of range the pivot of the link connected to the cam follower scanning the Y cam is made adjustable. Thus for increasing ranges this pivot can be moved towards the cam follower thus increasing the transmission ratio of the link and increasing the value of Y taken therefrom and with decreasing ranges the pivot is moved away from the cam follower to decrease the transmission ratio of the link and thereby the value of Y taken therefrom. Hence the assembly indicates $X+AY$ for a given azimuth and elevation position of the gun when aimed at a target at a known range. Assuming that the foregoing correction provides lateral correction of the gun position a second set of two cams may now be provided to produce the vertical correction necessary. The function of this set of cams and associated linkages is identical to that of the foregoing set the only difference being that the vertical deflection is indicated. The vectorial addition of the lateral and vertical components of the total deflection thus obtained provides the total displacement of the gun in azimuth and elevation with respect to the line of sight to the target and is accomplished by means of driving mechanism interconnecting the azimuth drive of the gun with the set of two cams providing the lateral deflection values and by means of a driving mechanism interconnecting the elevation drive of the gun with the set of two cams providing the vertical deflection values. Thus the vectorial addition of $X+AY$ for lateral deflection and $X+AY$ for vertical deflection is accomplished in the position of the gun and the total correction for projectile deflection for given azimuth, elevation, and range of the target with respect to a known velocity and direction of relative wind is provided.

The above mentioned means by which this mathematical expression can readily be carried out mechanically is indicated by Figure 1*b*. Fig. 1*b* shows two three-dimensional cams 1 and 2 both rotated with azimuth movement of the gun and both move parallel to their axis with elevation movement of the guns. The cams 1 and 2 are so constructed that with changes of the position of the target in elevation only, the longitudinal movement thereof will change the X and Y values, and such X and Y values will likewise be changed by rotation of the cams with changes of the position of the target in azimuth only. Therefore, for any particular elevation, a complete circle of azimuth values can be established by cam followers 3 and 4 (shown in top view). Therefore, these two three-dimensional cams can represent the functions for X and Y over the entire sphere by introducing the factor A of range as will be seen. Values proportional to X and Y can be taken from the cam followers or tracers 3 and 4 through levers pivoted at points indicated as X_1 and Y_1 and taken off at point P, the Y value being taken from cam 1 and the X value being taken from cam 2. The variation of A for securing different ranges can be obtained by shifting the position of the fulcrum Y_1, thereby introducing the proper multiplying factor for the Y value. Therefore, Fig. 1 indicates a means of evaluating the ballistic errors for the entire sphere and for ranges (radii of the sphere) as fixed by the travel of the fulcrum at Y_1.

It will be noted that cams 1 and 2 must be shaped in accordance with precalculated data. For instance, if these cams are to be indicative of ballistic errors, it will be necessary to take some predetermined test data of such errors to define at least two points on the curve $X+AY$. The curve may then be completed as a function of $X+AY$ and the cams shaped accordingly. Fig. 1*b* shows the calibration in degrees of cam 1. The cams may be calibrated from zero degrees to 180 degrees. In some instances a complete circle or sphere or values is not available for the gun for example, as in the case where it is desired to shoot directly in a vertically upward or downward direction, because of the azimuth ballistic correction approaches 180° in value which is too large to be practical. Collar portions at the ends of the cams as shown in Fig. 1*b* may be provided to continue the same correction as the 0 or 180° value is approached. In such instances calibrations may be made for a range less than 180 degrees, say, between 22½ degrees and 157½ degrees. The cams may be blanked along portions corresponding to points in space in which the airplane structure presents an obstruction to the gun.

Azimuth is measured such that zero azimuth will be in the direction of the propeller that is the line of flight of the airplane and elevation is measured such that zero elevation will be in a vertically upward direction in the airplane.

Assuming that the target occupies a certain position with respect to the plane, the sight will be pointed at the target and will occupy a position with respect to the plane dependent upon the position of the target. Assuming further that the sight occupies a position pointing at a target located at 0° elevation and 90° azimuth with respect to the plane in accordance with the corresponding curve of Fig. 1*c*, the value of X may be taken from cam 2, and the value of Y taken from cam 1. The position of the pivot Y_1 gives the proper multiplying factor A for the value Y. The values X and AY may then be taken from the point P. Assuming that all other factors remain equal and that only a change in range takes place, no movement will be imparted to either of the cams 1 and 2, and the values of X and Y will remain the same. However, the change in the range will change the value of A by changing the pivot Y_1 and, therefore, alter the value of AY. If under these conditions the range is

changed from 700 yards, as shown in Fig. 1c on the curve for 0° elevation and 90° azimuth, to 1000 yards, the value of A will change sufficiently to change the total of $X+AY$ from 25 to 35.8 mils deflection in a lateral direction.

It will be noted that the arrangement shown in Fig. 1b will be accurate for only one speed of operation of the airplane. In order to make the system adjustable for different speeds, it is necessary to duplicate the system shown in Fig. 1b and to interconnect the two points P thus obtained by a link which is adjustably fastened along two links each such as link 5.

For certain velocities, for instance 150 to 350 miles an hour, the values of A which affect the fulcrum of Y_1 are the same for all speeds. Therefore, when setting the value of A for a particular range, both Y_1 and Y_2 will have identical settings. In order to simplify the mechanics of the combination, I propose putting the two Y branches side by side so that their fulcrums can be moved simultaneously and the same amount for range, thus simultaneously changing the value of A for both links. The end link from which the resultant X and Y values are taken will move over the range of Y_1Y_2 to X_1X_2.

The above arrangement is shown in detail in Fig. 2. A gun 6 is supported for vertical (i. e., elevation) movement and for horizontal (i. e., azimuth) movement as will be readily apparent from the mechanical structure shown in the figure. A flexible cord 7 is trained about a system of pulleys so as to allow either type of movement. When the gun moves in azimuth the rotation of gear 8 about a rotatable gear 9 will effect a drive through a system of beveled gears which, in turn, will rotate shaft 10 in accordance with the azimuth movement of the gun. In a like manner, when the gun is moved in elevation (by means not shown), gear 11 will rotate and drive a system of beveled gears which will, in turn, rotate a shaft 12, which shaft will drive a pair of rack and pinion combinations so as to effect reciprocal movement of the framework 13, which reciprocal movement will be in proportion to the elevation movements of the gun. A set of cams are pivotally mounted on the framework 13. In addition to cams 1 and 2, which are suitable for a particular speed of operation, say, 350 miles per hour, there are provided, in addition, cams 1a and 2a which correspond to a different speed of operation, say, 150 miles per hour. Likewise, in addition to the cam followers 3 and 4 there are provided similar cam followers 3a and 4a corresponding to the different speed. The arrangement is such that the adjustable pivots Y_1 and Y_2 for the two systems are arranged side by side, and the fixed pivots X_1 and X_2 are likewise arranged side by side. Thus, by a suitable rack and pinion arrangement 14, which is preferably driven by the range finder through a cam drive 15 (to be described later), pivot points Y_1 and Y_2 will be simultaneously movable along slots formed in the lever arms which are pivoted at such points. Links 16, 17, 18 and 19, each has one of its ends connected to an end of a cam following lever, and its other end to either of two slotted links 20 and 21. Adjustable pivots 22 and 23 are arranged to slide in such slots by virtue of the controlling movements of a rack and pinion 24 which reciprocates slotted members 25 and 26 integrally secured thereto and the pivot points 22 and 23.

The movements of rack and pinion 24 are preferably responsive to air speed, or altitude, or both,

as will appear later. The adjustable pivots 22 and 23 are interconnected by a linkage system 27 having a vertical rack 28 integrally connected thereto, which, in turn, imparts rotary movement to a pinion 29. The amount of angular rotation of pinion 29 is a measure of the total correction to be applied to the system as will appear hereinafter. Links 20 and 21 may be calibrated in terms of speed ranging from 150 to 350 miles per hour. The offsetting of the ball and socket joints 19a as shown allow a full range of movements of pivots 22 and 23, that is, allow movements to the extreme ends of the slots in links 20 and 21.

By the above-described construction, the cams 1 and 1a may cooperate or act individually to give the required Y values for any given speed intermediate the air speed for which the cam 1 is designed and the air speed for which the cam 1a is designed. Likewise, the cams 2 and 2a cooperate to give the required X values in the same manner. Assuming that the air speed is 350 M. P. H., the pivots 22 and 23 will be positioned adjacent the links 16 and 18. Thus the pivots 22 and 23 will be vertically moved only by the links 16 and 18 and will not be affected by movements of the links 17 and 19. If the speed drops to 150 M. P. H., the pivots are positioned adjacent the links 17 and 19, and the vertical movement of pivots 22 and 23 will not be affected by the movements of links 16 and 18 but only by movements of the links 17 and 19. For speeds intermediate 150 M. P. H. and 350 M. P. H., vertical movement of the pivots 22 and 23 will be an average function respectively of the vertical movements of the link pairs 16—17 and 18—19. Accordingly, the AY value will be measured by the vertical movement of the pivot 22, and the X value will be measured by the vertical movement of the pivot 23. These values are added together by the link 27 and converted into a rotary displacement of the segmental gear 29 to give the total lateral deflection of the gun with respect to the sight.

As will become apparent later, a second set of four cams similar to those shown in Fig. 2 is provided for giving the vertical or elevational deflection of the gun with respect to the sight. Similarly, a third set is provided for giving time of flight corrections.

In order to make the principles of my invention more easily understandable, I have shown in Fig. 3 a system for applying ballistic corrections and proper lead angle corrections only insofar as elevation movements of the gun are concerned. In Fig. 4 I have shown a similar system, that is, for interposing ballistic corrections and lead angle corrections, only insofar as azimuth movements of the gun are concerned. Neither Fig. 3 nor Fig. 4 in itself represents a complete system. However, Fig. 5 shows a complete system and shows how the systems in Figs. 3 and 4 can be combined. Fig. 5 also shows, in addition, other features as will appear hereinafter.

When firing at moving targets, that is, moving relative to the flight of the gun, it becomes necessary to introduce a lead angle to the gun position. The lead angle is measured by the product of angular velocity of the sight and the total time of flight of the projectile fired and may be either positive or negative, depending upon whether the target is flying faster than the gun, or whether it is flying slower than the gun.

Fig. 3 shows a system for introducing the proper

lead angle for the relative speeds of the guns and targets. Such system includes a disk 30 driven proportional to the angular speed of the sight 31 (mounted on a pedestal 32) through a system of gears 33 and 34. A ball assembly drive 35 is adjustable radially of the disk by virtue of a rack and pinion 36 such that the radial position of the ball assembly drive is fixed by the particular range through a suitable gear system including differential gear 37 which is driven by a range finder (not shown). Cylinder 39 is driven in one direction or another at variable speeds depending on the radial position of ball assembly drive 35. The driven cylinder 39 drives one side of a differential 40 through a slip clutch 41 (or centrifugal clutch if desired). The other side of differential 40 is driven by a constant speed motor 42 which drives a disk 43, which, in turn, drives a variable speed cylinder 44 through the ball assembly drive 45.

For any particular angular sight speed there is a position for the ball assembly 45 that will cause a differential 40 to have zero rotation. A gyroscopic regulator 46 is driven by differential 40 through gear 47 effecting a precessional movement of contact carrying arm 48, which is in proportion to the output rotation of the differential. The gyroscopic regulator controls the speed and direction of the regulating motor 49 by the contact relationship between contact carrying arm 48 and either of contacts 50 and 51 which energize the motor field windings 50*a* and 51*a*, respectively. The motor thereby drives an amount that is proportional to the lead angle correction and will transfer such correction by its drive into differential 52 by gears 53. This introduces into the driving mechanism of the gun (i. e. the follow up mechanism between the sight and gun) the proper angle lead and at the same time puts the ball assembly drive 45 between the constant speed motor and the variable speed substantially into such position that when the correct angle of lead is obtained the gyroscopic regulator will be in a balanced position. It will be understood that if no correction were applied to the system the sight 31 would drive the gun 54 directly through differential 55 and exact follow up movements in elevation will be obtained. Elevation movements of the sight effect rotation of the gear system 56 which will ultimately effect rotation of gear 66 and vertical movement of link 65 to effect elevation movements of the gun. Gears 57, 58, 59 and 60, each of which is rigidly secured to cams 61, 62, 63, and 64, respectively effect rotation of such cams, in response to azimuth movements of the gun. Rotational movements of the gear 66 controlling the gun elevation are transferred through the beveled gear assembly 67, through shaft 68 to rack and pinions 69 and 70. This will effect lateral movements of framework 71 which carries the plurality of cams 61 to 64, inclusive, thereby effecting movement in the elevation direction of such cams to provide the necessary correction for the predetermined point indicated by the sight in the sphere. It will thus be seen that the ballistic correction for elevation movements of the gun will be imparted through a rack and pinion to shaft 72 in the form of an angular rotation thereof. This angular rotation is then fed through differential 52 to differential 55 and thence through bevel gear assembly 56 to rotate gear 66 thus causing an angular displacement of the gun in elevation relative to the sight. The rotation of the shaft 72 is indicative of a ballistic correction necessary because of wind force and gravity, which correction takes into account solely elevation movements of the gun.

The theoretical lead angle correction for any particular range is a function of the relative movement between the sight and target or, in other words, a function of velocity of movement of the sight as it is held trained on a moving target at a fixed distance. Since the disk 30 rotates with an angular velocity in proportion to the velocity of movement of the sight, and since the radial position of ball assembly 35, caused by the range finder is a function of range (also indicative of total time of flight if the angular position at which the projectile is projected into the relative wind is known), the product of angular velocity and total time of flight in the drive results in a rotation of cylinder 39 through an angular value which is indicative of the theoretical lead angle. The range finder itself would impose on the differential 37 a rotation which is merely indicative of the theoretical time of flight. Actually the time of flight would be different for different directions of the sight of the gun in its movement within a sphere. The assembly including cams 63 and 64 is effective to give an angular rotation of shaft 73 which is indicative of a variation from the theoretical time of flight for each point in space, that is, for each point having a particular azimuth elevation as well as range. In other words, the rotation of shaft 73 is indicative of the correction to be applied to the range finder indication in order to give the true time of flight movement to ball assembly 35. The variations or loss in time of flight for different directions in the sphere also fit the expression $X+AY$ where X, Y and A are similar functions as described in connection with the ballistic errors. Thus the design of the time of flight cams may be based upon obtainable ballistic data so that proper correction values are obtained therefrom for correcting the position of the ball assembly 35 as determined by range whereby the correct lead angle in elevation for a particular target position and velocity is obtained.

The showing of Fig. 3 is for only one speed of operation of a plane-mounting gun and for giving the required deflection of the gun with respect to the sight in a single direction, namely, elevation. In this showing, the cams 61 and 62 may correspond to either the cams 1 and 2 or the cams 1*a* and 2*a* of Fig. 2 where such cams are constructed to give the vertical ballistic correction. The cams 63 and 64 give the required time of flight correction which is used with the correction required by range and by the speed of angular movement of the sight to secure the proper lead angle. In this arrangement, the cams 61 and 62 give the theoretical vertical ballistic correction which is fed into the mechanical differential 52. The time of flight correction is fed into the mechanical differential 37 with the necessary range correction for imparting movement to the ball assembly 35. Vertical movement of the sight 31, as explained above, rotates the disc 30 which rotation through the speed-matched cylinders 39 and 44, together with the differential 40, and gyro control 46 is effective through proportional movement of the ball assembly 45 to introduce the proper vertical correction to the differential 52. This correction is added to the theoretical vertical ballistic correction and introduced into the differential 55. The total correction is thus mechanically intro-

duced by the differential 55 to the total amount of movement imparted by the sight through the gear 56, wheel 66, and link 65 to the gun. The gun is thus deflected vertically or in elevation with respect to the sight an amount equal to the sum of the theoretical vertical ballistic correction and the lead angle correction as determined by the speed of movement of the sight and the time of flight correction.

It will be noted that the time of flight correction of the cams 63 and 64 which is fed into the differential 37 for imparting a true time of flight movement to the ball assembly 35 is not effective to introduce a lead angle correction unless accompanied by a movement of the sight. In other words, the sight must first rotate the disc 30 in order that the differential 40 will be effective through the gyro control 48 to impart movement to the assembly 45 to introduce the proper lead angle correction.

Fig. 4 shows a system by which angular lead corrections are introduced for azimuth movements only of the gun. Most of the structure shown is a duplication of the structure shown in Fig. 3 and is represented by the same reference numerals. Hence, detailed description is deemed unnecessary. The outstanding difference is that the sight 31 drives through differential gear 55 and gear 56a to rotate the gun in azimuth instead of in elevation, as shown in Fig. 3. Another outstanding difference is that an automatic cycler 75 has been added. Lead angle corrections are introduced through shaft 84 into the drive between the sight and the gun so as to effect slight departure from exact follow-up of the gun as a consequence of azimuth movements of the sight. The showing of Fig. 4 is similar to that of Fig. 3, except that the lead angle correction is for lateral or azimuthal deflection instead of for vertical or elevational deflection. In this showing, the cams 61 and 62 may correspond to either the cams 1 and 2 or the cams 1a and 2a of Fig. 2, the correction being for a single speed of operation. It will also be noted that this showing illustrates the manner in which the time of flight correction is added to the range adjustment to give the correction for loss of speed of the projectile which is equivalent to a theoretical increase in range. This latter feature is had by cooperation of the mechanical differentials 38 and 37. The range finder will first operate the differential 38 to vary the pivots 79 and 80 to introduce the proper multiplying factor A for the Y values obtained from the azimuth and time of flight cams. The time of flight correction is taken off the shaft 73 and fed into the differential 37. Movement of the differential 37 is effective to impart movement to the ball assembly 35 which, together with rotation of the disc 30, is effective to introduce the proper lateral lead angle correction into the differential 52.

Often times it is desirable to avoid having the gun maintain a fixed aimed position at a target when a number of shots are to be fired. In order to avoid the possibility of shooting projectiles at a particular spot when it may happen to be slightly off the target and may result in completely missing of the target, it is often desirable to effect a slight vibratory movement of the gun to spread or spray the shots through a given area so that the possibility of one or more hits is considerably increased. In order to effect such spraying of the shots fired, I have provided and introduced an automatic cycler 75 which is driven by motor 42. If the motor 42 rotates it effects reciprocating movement of the connecting rod 76 which will effect reciprocation of the arcuate segments of the cycler 75, thereby ultimately driving shaft 77, first in one direction and then another. This vibratory movement of shaft 77 is introduced into differential 38 by the element 38a thereof and transmitted to shaft 78. By a suitable drive, as shown, this vibratory motion will cause a vibratory motion of the adjustable pivot points 79 and 80 as indicated by the arrows. Such drive includes a pair of cams, such as, 81 and 81a, the construction of which is shown enlarged and in detail in Figure 7; namely as comprising a pair of flexible ribbons 82 and 83 which are axially offset with respect to each other and each of which has one end anchored on one cam and the other end anchored on the other as shown in Fig. 7. The purpose of this arrangement is to obtain a curvilinear instead of a straight line relation between the rotative movement of shaft 72 and linear movement of pivot points 79 and 80.

Fig. 5 shows a system in which the apparatus in Fig. 3 and in Fig. 4 is combined so as to include ballistic correction, time of flight correction, and angular lead, using the fundamental systems hereinbefore described in Figs. 3 and 4. It will be seen that the two systems have been duplicated with the exception that a single driving motor 85 is used for driving the two variable speed cylinders 86 and 87 (corresponding to cylinder 44 of Figs. 3 and 4) instead of using two motors for effecting the same purpose. A simpler regulator circuit is shown, namely, one in which the gyroscope is omitted. Instead of depending upon the processional movement of a gyroscope, contact carrying arms 88 and 89 are driven directly by the movement of the sight. The system in Fig. 5, in addition to providing for corrections noted in Figs. 3 and 4, provides for variable speed adjustment in the manner shown in Fig. 2. In other words, each unit of the four cams is of the type shown in Fig. 2, one set of four designating azimuth, the other set of four, elevation corrections, and the third set of four, time of flight corrections. Each unit in itself, however, includes the additional correction for variations in speed over a range, say, for example, from 150 miles per hour to 350 miles per hour. A long rack 90 which may be manually slidable by rotation of pinion 91 is effective to adjust the pivot points from 92 to 97, inclusive, the details of which are shown more clearly in Fig. 2 for a single unit. If desirable, pinion 91 may be connected to the air-speed or air-flow dial so that the pivots will slide automatically in accordance with speed of the plane. To correct for altitude, an altitude dial 98 is made to rotate to a position corresponding to the altitude at which the plane operates, thereby introducing a rotative movement to the differential 99 which will modify the air speed rotation of pinion 91. The reason that air speed and altitude can be combined this way into a single correction is that they are effected by the same phenomena, particularly air density.

In the showing of Fig. 5, the top set of cams give the required ballistic correction for the gun in a lateral direction; the middle set of four cams give the required ballistic correction for the gun in a vertical direction and the bottom set of cams give the required time of flight correction. In the interest of simplicity, the various sets of cams have been bracketed together and the deflection given thereby has been appropriately designated.

It will be further noted that each set of cams is provided with two X cams and two Y cams, each pair of cams respectively corresponding to the upper and lower speed limits by which appropriate X and Y values may be taken off and added together to give the required deflection for a selected air speed.

In the operation of the apparatus shown in Fig. 5, the rack 90 is first adjusted by the air speed through the differential 99 to position the pivot points 92 through 97 in the same manner that the pivot points 22 and 23 of Fig. 2 are adjusted in order that the proper X and Y values for the air speed will be had. The differential 99 will also be adjusted by the dial 98 to introduce the proper correction for altitude, the altitude correction being a function of air density and, therefore, correctable or variable in terms of air speed. The range finder through the differential 38 and cams 81 is made to adjust the pivot points for the Y cams and thereby alter the AY values which are taken off at the points 92, 94 and 96. After these corrections are made, the segmental racks 29*a*, 29*b* and 29*c* will respectively function to give the theoretical, lateral, vertical and time of flight ballistic corrections. The lateral ballistic correction from the rack 29*a* is taken off through the shaft 290*a* and the corrections provided by the racks 29*b* and 29*c* are similarly taken off through the shafts 290*b* and 290*c*.

In the event that the target is not moving relative to the gun, the corrections taken off through the shafts 290*a* and 290*b* represent the total lateral and vertical deflections to be introduced intermediate sight and the gun. However, in the event that the target is moving relatively to the gun, it is necessary to introduce a lead angle correction as explained above. This is done through the rack 29*c* and the shaft 290*c* which feeds the time of flight correction into the differential 37 where it is differentially added to the movement imparted to the differential 37 by the differential 38 as controlled by the range finder. The differential 37, as explained in connection with Figs. 3 and 4, functions to position the parts 35*a* and 35*b* which corresponds respectively to the part 35 in Fig. 4 and the part 35 in Fig. 3.

The setting of the part 35*a* does not effect the azimuth or lateral ballistic correction unless the target is moving relatively to the gun in azimuth. In the event that the target is moving relatively to the gun in azimuth, a movement will be imparted to the part 45*a* proportional to the velocity of relative movement in the same manner that the part 45 in Fig. 4 is moved. This movement is taken off through the shaft 291*a* and represents the azimuth lead angle correction which is added to the lateral or azimuth ballistic correction by the differential 292*a*. The total correction from the differential 292*a* is transmitted through the shaft 293*a* to the differential 294*a* where it is introduced into the drive intermediate the sight 31 and the gun. Except for the correction introduced in the differential 294*a*, the gun would be moved by the shaft 295*a* so as to exactly follow the movement of the sight 31 in azimuth. Movement of the shaft 295*a* therefore represents the sum of movement of the sight 31 in azimuth and the total azimuth or lateral ballistic corrections.

The parts 35*b* and 45*b* function similarly to the parts 35*a* and 45*a* in introducing an elevational or vertical lead angle direction in the event that the target is moving relative to the gun in a vertical direction. Movement of the part 45*b* is taken off through the shaft 291*b* and represents the vertical lead angle correction. This correction is introduced into the differential 292*b* where it is added to the theoretical vertical ballistic correction provided by the rack 29*b* and shaft 290*b*. The total vertical correction is then transmitted through the shaft 293*b* to the differential 294*b* where the corrective value is differentially added to the vertical movement of the sight 31. The differential 294*b* thus causes, through the shaft 295*b*, the gun to be moved to a position having the proper amount of vertical deflection with respect to the sight 31.

Instead of having the sight 31 drive the gun directly, which would require considerable force, it is possible to have the sight operate a regulator which will control a power amplifying means which will in turn drive the gun. Going a step further, it is also possible to have a pilot handle, such as 100, operate a plurality of Silverstats (i. e. variable resistor units) which will control the energization of the field windings of train and elevation driving motors 101 and 102 of Fig. 5, in the manner more clearly shown in Fig. 6. Four Silverstat units 103, 104, 105 and 106 are provided in circuit with the field windings of motors 101 and 102. The handle 100 has four spider arms 103*a*, 104*a*, 105*a* and 106*a* projecting therefrom which are preferably slightly resilient, or better still, which have ball and socket joints with the handle in order to permit slight rotative movements thereof relative to the handle. It will be obvious that as the handle is moved upwardly, it effects energization of one field winding only, of motor 102 to drive the motor in one direction; and if it is moved downwardly, it will effect energization of the other field winding of motor 102, and that the number of Silverstat contact arms shunted or the amount of resistance shunted is in proportion to the amount of upward or downward movement. Inasmuch as handle 100 is pivotally mounted on wheel 107, the control of the sight and gun by the operator is facilitated because the operator will have the feeling that he is manually moving sight 31 since handle 100 follows the sight in both azimuth and elevation. The operator will be unaware that he is merely piloting the movement of the sight and gun by controlling a power amplifying circuit which includes motors 101 and 102 which actually drive both the sight and the gun, as shown. Instead of controlling motor field windings, the Silverstats could equally as well control shunt field windings of a generator in a variable voltage system (not shown) in a manner well known in the art.

I am, of course, aware that others, particularly after having had the benefit of the teachings of my invention, may devise other devices embodying my invention, and I, therefore, do not wish to be limited to the specific showings made in the drawings and the descriptive disclosure hereinbefore made, but wish to be limited only by the scope of the appended claims and such prior art that may be pertinent.

I claim as my invention:

1. In a control for a system having a gun, a sight, and follow up mechanism for effecting movement of the gun in accordance with movement of the sight, error compensating means interposed in said follow up mechanism so as to introduce a deviation between gun and sight so that substantial instead of exact follow up occurs, said error compensating means including a pair

of three dimensional cams each having a tracer associated therewith, means responsive to movements of the gun in azimuth for rotating the cams, means responsive to movements of the gun in elevation for longitudinally moving the cams whereby said tracers are moved, and means for adding the movements of said tracers whereby the errors to be compensated for are indicated.

2. Apparatus as recited in claim 1 in which said adding means is represented by the curve $X+Y$ where X and Y are each different functions of azimuth and elevation and are represented by the two separate cams, one of said cams being shaped according to the X values and the other of said cams being shaped according to the Y values.

3. Apparatus as recited in claim 1 in which said adding means includes two levers, each having an end movable by the corresponding tracer and one of said levers having a movable pivot, and linkage means for interconnecting the other ends of said levers, said adding means being represented by the expression $X+AY$ where X is indicative of any point on one cam and is indicative of a precalculated error which is a function of azimuth and elevation for all points of a sphere as contained on one cam and Y is indicative of a precalculated error and is a different function of azimuth and elevation for all points of a sphere of gunfire as contained on the other cam, and A is a function of range which may be modified by moving said adjustable pivot point.

4. A gun fire control system comprising, in combination, a sight, a gun, follow up mechanism for moving said gun in accordance with movements of said sight, means for introducing gun fire corrections in the follow-up mechanism including a pair of three dimensional cams, means for rotating said cams about their axes in accordance with azimuth movements of said gun, means for moving said cams along their axes in accordance with elevation movements of said gun, a tracer for each of said cams, which are biased into continuous engagement therewith and linkage means for interconnecting said tracers and for providing a corrective movement which is applied to said follow-up mechanism.

5. In a gun fire control system, apparatus for interposing a correction to the position of a gun comprising, in combination, a pair of three dimensional cams, means for rotating said cams about their longitudinal axes and means for propelling said cams along said axes, a follower associated with each cam, linkage means interconnecting said followers, take-off means operated by said linkage means to give a movement which is proportional to the summation of movements of both of said followers, and means for adjusting said take-off means along said linkage means interconnecting said followers.

6. Apparatus as recited in claim 1 in which said errors are ballistic errors of the gun and in which each of the cams is so shaped as to be indicative of ballistic errors for substantially all points in a sphere of gunfire.

7. A gun fire control system comprising, in combination, a gun, a sight, piloting mechanism for effecting movement of the gun in space in accordance with movements of said sight, means for introducing variable deviations to the gun position which are different for different points of the sphere and which compensate for ballistic errors, said means comprising a pair of three dimensional cams which are each shaped in accordance with precalculated ballistic error data so

that for each point in space of the gun there is a corresponding point on one cam which is a function of azimuth and elevation and which is proportional to the amount of required ballistic compensation of error for a particular gun position, and there is a corresponding point on the other cam which is a different function of azimuth and elevation and likewise proportional to the amount of required compensation of error for such particular gun position, and means for following the cam surface variation along two dimensions of each of said cams, adding the results and applying them to said piloting mechanism, and means for adjustably modifying said last mentioned means in accordance with range of a target.

8. Apparatus as set forth in claim 7 in which each cam is provided with a lever which is movable in proportion to the surface variations of the associated cam, one of said levers including an adjustable pivot which is adjustable in accordance with the range of the target and is included in the last mentioned means of claim 7 so that the total ballistic correction may be represented by the expression $X+AY$ where X and Y are different functions of azimuth and elevations for corresponding points on each of said cams and A is a function of range which is applied in the form of said adjustable pivot.

9. Apparatus as set forth in claim 7 together with a duplicate set of cams and means for following the cam surfaces, which cams, however, are of different shapes than the ballistics cams, being shaped in accordance with precalculated data on time of flight of a projectile fired, and means responsive to the velocity of movement of the sight as it is held on a moving target and to the range of the gun for adding a lead angle correction to said ballistic correction so as to further modify the relative position in space of said sight and gun.

10. Apparatus as set forth in claim 7 in which the gun and sight are mounted on a moving vehicle and which said compensating means includes a duplicate set of cams and means for following the cam surfaces, which cams, however, are of different shapes than the ballistic cams, being shaped in accordance with precalculated data on corrections for time of flight of a projectile fired for different points in a sphere of gunfire, and means responsive to the relative velocity of movement of the sight as it is held on a moving target and to the range of the gun for adding or subtracting a lead angle correction to said ballistic correction so as to further modify the relative position in space of said sight and gun, said last mentioned means being modified by said duplicate set of cams so as to include compensations for errors due to time of flight determination.

11. Apparatus as recited in claim 1 in which said adding means is represented by the curve $X+AY$, where X and Y are different functions of azimuth and elevation and are represented by the two separate cams and where A is a function of range of the gun, together with a duplicate pair of cams and an additional adding means which may be represented by the curve $X_1+A_1Y_1$, where X_1 and Y_1 are different functions of azimuth and elevation and are indicative of the correction to be added because of differences in time of flight of the projectile for different directions of fire within a sphere, and means for totalling the effects of both of said adding means so as to provide a corrective displacement of gun

with respect to the position in space of the sight so as to compensate for both ballistic errors and errors due to variable time of flight of the projectile for different directions of fire.

12. In a gun fire control system, a gun, a sight, gun position regulating means including a differential gear for driving said gun in accordance with movements of said sight, including rotatable means driven by said sight, a second rotatable means, a constant speed motor and a variable speed transmission for driving said second rotatable means, a regulator, differential means operable in response to relative rotation between said two rotatable means to control said regulator so as to vary the speed ratio between said variable speed transmission so as to effect speed matching between said two rotatable means and to simultaneously introduce in said position regulating means a lead angle displacement so that only substantial and not exact follow up occurs between said sight and gun.

13. Apparatus as set forth in claim 12 in which a variable speed drive is provided between said sight and said first mentioned rotatable means which is varied in accordance with range as determined by a range finder.

14. Apparatus as set forth in claim 12 in which a variable speed drive is provided between said sight and said first mentioned rotatable means which is varied in accordance with range as determined by a range finder and means including a pair of three dimensional cams which are shaped in accordance with time of flight corrections of a projectile and means for following the cam surfaces in two directions and to add the effects thereof and to interpose a time of flight correction between said sight and variable speed drive.

15. Apparatus as set forth in claim 12 in which a variable speed drive is provided between said sight and said first mentioned rotatable means which is varied in accordance with range as determined by a range finder and means including a pair of three dimensional cams which are shaped in accordance with time of flight corrections of a projectile and means for following the surfaces of said cams in two directions and to add the effects thereof and to interpose a time of flight correction between said sight and variable speed drive and a second pair of three dimensional cams shaped in accordance with ballistic corrections for the gun, together with means for interposing said ballistic corrections to said differential gear in the gun drive in order to effect a deviation between the sight and gun which is in proportion to the ballistic correction.

16. A gun fire control system comprising, in combination, a sight, a gun, means for piloting the gun in accordance with movements of the sight, compensating means for introducing a displacement between said sight and gun so that substantial instead of exact follow up occurs therebetween including means responsive to the velocity of movement of the sight for determining lead angle, said compensating means also including a device for compensating for ballistic errors of the gun in both azimuth and elevation, a second device for compensating for time of flight errors of a projectile fired by the gun in the determination of lead angle, each of said devices including a pair of three dimensional cams, each pair being shaped in accordance with precalculated values of ballistic errors and time of flight errors, respectively, and means for tracing the cam surfaces in both azimuth and elevation and for introducing adjustable values of range.

17. Apparatus as set forth in claim 16, in which both said devices are provided with means for adjusting their output depending upon the velocity of the relative wind.

18. Apparatus as set forth in claim 16, in which both said devices are provided with means for adjusting their output depending upon the density of the air.

19. Apparatus as set forth in claim 16, in which both said devices are provided with means for adjusting their output depending upon the velocity of the relative wind and the density of the air.

20. In combination, a gun, a sight movable in azimuth and elevation for imparting similar movements to said gun, and means operated depending upon movements of the sight for automatically displacing said gun in azimuth and elevation with respect to said sight to introduce azimuth and elevation projectile ballistic corrections according to the ballistic characteristics of the projectile to be fired by said gun depending upon the particular position of said sight in azimuth and elevation with respect to the relative wind.

21. In combination, a gun, a sight movable in azimuth and elevation, follow-up mechanism for moving said gun in azimuth and elevation with said sight, and means for adjusting said mechanism as an automatic function of movement of the sight to displace said gun in azimuth and elevation with respect to said sight to introduce projectile ballistic corrections according to the ballistic characteristics of the projectile to be fired by said gun for the particular position of the sight in azimuth and elevation with respect to the relative wind.

22. In combination, a gun, a sight movable in azimuthal and elevational directions, follow-up mechanism for moving said gun in accordance with movement of said sight, and camming means rotatable depending upon movement of said sight in one of said directions and shiftable axially depending upon movement of said sight in the other of said directions, said camming means being operative to automatically introduce into said follow-up mechanism a projectile ballistic correction for a predetermined relative wind velocity depending upon the position of said sight in azimuth and elevation, with respect to the relative wind, thereby displacing said gun with respect to said sight in at least one of said directions.

23. In combination, a gun, a sight movable in azimuthal and elevational directions, follow-up mechanism for moving said gun in accordance with movement of said sight, and a pair of cams respectively rotatable depending upon movement of said sight in one of said directions and shiftable axially depending upon movement of said sight in the other of said directions, each of said cams having an element displaceable thereby, means adjustable according to range for varying the displacement of one of said elements in accordance with changes in range, and means for adding the displacement of both of said elements to secure a ballistic correction in one of said directions for a predetermined velocity of relative wind depending upon the position of said sight in azimuth and elevation with respect to the relative wind, and means for introducing said correction into said follow-up mechanism to displace said gun in at least one direction with respect to said sight, movement of said cams depending upon movements of said sight being effective to con-

tinuously and automatically change said added displacement and give the required projectile ballistic correction of the gun for all positions of said sight with respect to the relative wind.

24. Apparatus as claimed in claim 23 together with an additional pair of cams for giving the required projectile ballistic correction for a predetermined velocity of relative wind different from the first mentioned predetermined velocity of the relative wind, and means interconnecting said cams for giving the required projectile ballistic corrections for velocities of the relative wind intermediate the predetermined velocities.

25. Apparatus as claimed in claim 23 wherein said projectile ballistic correction is according to the expression $X+AY$, one of said cams being shaped according to the X values of projectile deflection, the other of said cams being shaped according to the Y values of projectile deflection, and said means adjustable according to range being constructed according to the A values which are functions of range.

26. In a control for a system having a gun, a sight, and follow-up mechanism for effecting movement of the gun depending upon movement of the sight, error compensating means interposed in said follow-up mechanism so as to introduce a deviation between the gun and sight so that substantial instead of exact follow-up occurs, said error compensating means including a three dimensional cam dimensioned according to ballistic errors of the projectile to be fired by said gun and having a cam follower associated therewith, means for rotating the cam depending upon movement of the sight in azimuth, means for longitudinally moving the cam depending upon movement of the sight in elevation, means for producing a quantity indicative of movements of the cam follower, and means for varying said quantity independently of the cam follower.

27. In a device for controlling the movements of a gun depending upon movements of a sight, the combination of means for producing a quantity indicative of movements of said sight, means operated depending upon movement of said sight for producing a quantity indicative of a ballistic characteristic of the particular projectile to be fired by said gun, means for producing a quantity indicative of the velocity of the relative wind, means for modifying said quantity indicative of relative wind depending upon the density of the air, means for modifying said quantity indicative of a ballistic characteristic of said bullet depending upon the value of said last named modified quantity, and means for utilizing the resulting quantity in conjunction with said quantity indicative of movements of said sight to angularly position said gun with respect to said sight.

JOHN F. PETERS.