BALLISTIC APPARATUS ADJUSTABLE FOR DIFFERENT TYPES OF PROJECTILES
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This invention relates to a ballistic computer and more particularly to a ballistic computer which may be used to solve ballistic deflections for any of several predetermined projectiles.

An object of the invention is the provision of a ballistic computer in which the same computing elements can be used for a plurality of different projectiles.

Another object of the invention is to provide a ballistic computer in which the computing elements have selectable input functions, the computing elements being so designed that on selecting predetermined input functions, the computer will solve the deflections for a projectile with which such functions are associated.

A further object is to provide an arrangement by which a known computer may be converted for use with any one of several different projectiles which may be of the same type with a different muzzle velocity and different ballistic coefficient, or of different caliber.

Present airplanes often carry automatic ordnance of various calibers ranging from machine guns of .30 and .50 caliber to small bore cannon having calibers of 20 mm. and upwards. It is desirable that such guns be provided with suitable computing sights. Sights of known construction cannot be used interchangeably with guns of different caliber, as each computing sight is limited to use with the particular type projectile for which its ballistic solution is designed, and consequently gun crews must be instructed in the operation of a number of different sights.

Maintenance of several of different sights is also a problem at airfields because a suitable number of spare sights of each kind must be kept on hand for replacements. The present invention provides a sight which may be used on any of several guns of different types and with different types of projectiles, thus simplifying the problems of instruction and maintenance.

The invention will now be described with the aid of the accompanying drawings, of which Figs. 1, 2 and 3 are diagrams used in describing the invention;

Figs. 4 and 5 taken together, show schematically, a computing gun sight of the prior art;

Fig. 6 is a schematic drawing of a ballistic computer in accordance with one embodiment of the present invention; and

Figs. 7, 8 and 9 show a group of ballistic curves.

The basic characteristics of most projectiles are ballistic coefficient, related to air density, and muzzle velocity related to air speed.

An accurate ballistic solution gives deflections as functions of air speed, air density, range (or time of flight), gun azimuth and gun elevation. Generally, a "total windage deflection" is solved for, and then modified for gun position and gravity. For design simplicity, total windage is considered to be the product of functions of three independent variables, namely, of range (or time of flight), air speed and air density. In practice, the functions of these independent variables is obtained conven-

ently by adding the logarithms of these functions by means of differentials.

From a study of the ballistic tables it has been found that with a given projectile taken as a standard, it is possible to write a characteristic expression, empirical in form, as a function of time of flight (or range), density-altitude, and air speed; and that by changing some of the constants in this empirical expression it is possible to have an expression that is characteristic of a projectile other than that taken as standard. The change in the values of the various constants, which in every case is determined empirically from government supplied ballistic tables, allows for the fact that various projectiles are not similar in all dynamic and geometric particulars.

Generally, if only the ballistic coefficient, (C), of a projectile is changed, then the ballistic may be corrected very simply. Ballistics vary directly with (C), which enters into ballistic computations with relative density, , as the ratio C/a. Thus, a change in the ballistic coefficient has the effect of modifying density. Therefore, a correction for change in the coefficient C may be made by applying a multiplying factor to the density function, that is, by displacing, for example, in rotation an altitude dial, which is calibrated in logarithms of the function of density.

Generally, a change in muzzle velocity requires the derivation of the new true air speed function. This new function may or may not be related as a power function to a previously determined air speed function. If the air speed functions of different projectiles are related as power functions, then the correction for different muzzle velocity values may be made by appropriate gear adjustment, or its equivalent, from the air speed dial. If this cannot be done, then it may be necessary to provide a change in the calibration of the air speed dial according to the logarithms of the air speed functions of the respective projectiles.

If indicated air speed is used as the input to the computer, the problem becomes more complicated because the relationship between true and indicated air speed involves air density. Also, if changes other than ballistic coefficient and muzzle velocity are made, further complications result.

Various known ballistic computers may be modified in the manner suggested above, in order to use the computing elements therein with other projectiles than those for which the computer was originally designed.

The invention will be described in detail as applied to a ballistic computer of the kind disclosed in the accompanying application of Edward J. Nagy and Edmund B. Hammond, Serial Number 563,068, filed November 11, 1944, now Patent No. 2,579,510, in which three dimensional eams are used to represent functions of independently variable quantities that are used in the ballistic correction computation. However, it will be apparent that the invention is equally applicable to other computers in which different devices are used to represent functions of data essential to the solution of the ballistic deflection problem.

In order to more easily understand the present invention, a computer of the type disclosed in the above-mentioned application will first be described, and following this description will be one disclosing the selectable arrangement of the present invention by which the input functions are varied according to the projectile used.

The ballistic cells of the computer of the present invention shown in Fig. 6 are considered similar to those of the above mentioned application for the purposes of this description, and bear corresponding reference characters. The output from the computer may be used in the known manner to furnish data for the positioning of a gun or to control automatically in the known manner
the relative displacement according to lead angles of a gun and a desired line of sight defining means which may be a known radar equation for a specific system, one of the latter being shown in the above-mentioned application which is of a type generally used in certain of the so-called "K" sights, many of which are now being used by the armed forces. For purposes of illustration, a known prediction computer is disclosed herein, but it is to be understood that any other suitable prediction computer arrangement may be used in connection with the invention.

Referring to Fig. 1, assume that a gun at O is pointed along OA, the gun being at zero azimuth and elevation and further consider that the projectile is not acted upon by any wind. If the gun has zero air speed, then after a time $T_0$, a projectile would reach the position A with respect to the gun at O. The range represented by OA is the range at zero air speed referred to hereinafter as range $D_1$. When the gun has a velocity in the direction indicated by the arrow, the position of the projectile is represented by A. The distance OB represents the present range of the projectile relative to the gun after a time $T_0$, hereinafter referred to as the range $D_0$.

The gun at O in Fig. 2 is represented positioned at some elevation angle $\theta$. If the azimuth angle of the projectile, $\phi$, at zero air speed the projectile after a time $T_1$ will reach the point A. If a velocity is imparted to the gun, in the direction of the arrow, the relative position of the gun and projectile after a time $T_0$ is indicated by the point B on OB. Then, as before, the distance OB represents the present range $D_0$ and the course of the projectile relative to the gun after a time $T_0$. The distance OB represents the range $D_1$ at zero air speed, and AB represents the total linear windage deflection relative to the gun, and AC the range deflection hereinafter referred to as $D_2$. Since the trajectories of aircraft projectiles are essentially flat, the equality of OB and OC may be assumed. Hence

$$OA = OB + CA \quad (1)$$
$$D_1 = D_0 - D_2 \quad (2)$$

For any input time of flight, the computer determines the fixed coordinate range. This range is dependent only on time of flight and air density. It is the distance the projectile would travel in a given time when the gun is fired from a fixed point in space. This range alone is often used in aircraft gun-firing problems where the gun is moving, since it is attached to an airplane moving with a definite velocity. The position of the projectile relative to the gun when the gun is moving at a given velocity is different from the position of the projectile relative to the gun when the gun is stationary, for the same time of flight. The distance between the gun and projectile for a given time of flight $T$ in the case where the gun is moving is $D_0$. The distance between the gun and the projectile for a given time $T$ in the case where the gun is stationary is $D_1$. The difference between $D_1$ and $D_0$ is due to the fact that the gun is not fixed but is moving at a definite velocity.

The magnitude of the range deflection is dependent upon gun velocity, density, time of flight, gun azimuth and gun elevation. When the gun is moving its effective muzzle velocity $V_m$ has been changed and that, relative to the gun, the distance the projectile travels is changed as compared to the case where the gun is stationary. The total linear ballistic deflection may be projected upon the gun line. This projection is what is called the range deflection $D_0$ and is the difference between $D_1$ and $D_2$. In the ballistic mechanism disclosed herein, the values of $D_0$ and $D_2$ are known for all time of flight values and therefore the corresponding range value $D_0$ can be readily determined and since time of flight $T_0$ depends on range, an accurate measure of $T_0$ is obtained which in turn provides more accurate prediction.

The ballistic portion of the computer is based upon the following three premises:

1. That the total ballistic deflection relative to the gun may be expressed as a function of time of flight, air speed, and density;
2. That the total ballistic deflection may be resolved into three components which are the lateral, vertical, and range deflections; and
3. That the range deflections may be used to determine range.

The lateral deflection $\delta_x$ is the projection of the total ballistic deflection angle $AOB$ on the lateral plane of the gun. The vertical deflection $\delta_y$ is the projection of the total ballistic deflection angle $AOB$ on the elevation plane of the gun. The range deflection $D_0$ is the projection of the total linear ballistic deflection $AB$ upon the gun line.

These deflections are shown in Fig. 3 where OR is the line of flight of an airplane carrying the gun. OA is the gun line; OS is the projection of the gun line in a horizontal plane; and AB is the total windage deflection in yards. This latter deflection when divided by range gives total windage in mils.

EAO defines a lateral plane perpendicular to a vertical plane defined by OAD which extends through the gun. Angle DOC is a measure of vertical deflection $\delta_y$ and angle EOC is a measure of lateral deflection $\delta_x$. As in Fig. 2, the distance OB is a measure of present range $D_0$; AC is equal to range deflection, $D_0$, and OA is equal to the zero air speed range $D_1$.

Time of flight, $T_0$, depends on present range $D_0$, the range deflection $D_0$, and the zero air speed range $D_1$. In general the deflections are

$$\delta_x = TR \cos \theta \cos \gamma \cos \phi + K_x \sin \phi \quad (3)$$

where $R$ is a function of air density and air speed, as given below and $K_x$ is a gravity constant. Likewise the azimuth and elevation ballistic deflections may be expressed as functions of time as

$$\delta_y = TR \sin \theta \cos \phi \quad (4)$$

and

$$\delta_z = TR \sin \theta \sin \phi + K_z \cos \phi \quad (5)$$

The total angular windage deflection $\phi$ may be expressed as a product of the functions of the variable time of flight, indicated air speed, IAS (or true air speed, TAS), and density, $\sigma$

$$\phi = f_1(\phi)f_2(\text{TAS})f_3(\text{T}) \quad (6)$$

or

$$\phi = f_2(\phi)f_3(\text{TAS})f_3(\text{T}) \quad (7)$$

The function of .50 caliber M2 projectile

$$f(T) = T \quad (8)$$

Since

Thus

$$\phi = f_2(\phi)f_3(\text{TAS})f_3(T) = T \quad (9)$$

The function of air speed and density comprising $R$ are determined empirically from the values of $R$ obtained from the tabulated values of ballistic deflection in the ballistic tables for the .50 caliber M2 projectile supplied by the Government. From the ratio of the windage deflection to time of flight, the functions of $f_1(\phi)$ and $f_2(\text{TAS})$ are determined.

Tables of range deflections as such are not supplied by the Government and the values of $D_0$ and $D_1$ were obtained from plots of time against range at zero air speed. These plots and Equation 2 were used to obtain all of the necessary data for the construction of the charts of the ballistic mechanism described below.

The following equations suitable for mechanical solution are the result of empirical determination, as stated below, based on Equations 3, 4 and 5:

$$\delta_x = TRF_x(R, T, \phi_0) \quad (10)$$

where $F_x$ is a function of range and time

$$\delta_y = F_y(E_0) + T \phi_0 + K_y F_y(E_0) \quad (11)$$

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\[
\frac{D_n}{D_o} = F(S(E_p\phi)) + T_k K_3 \sigma(E_o)
\]
(12)

where

\[
\phi = T_R F_\phi(A_R, \phi T) \quad \text{for} \quad \gamma = TRF(\phi T)
\]
(13)

\[
R = f_2(x) f_3(\phi x, IAS)
\]
(14)

and \(K_3, K_4\) are constants.

The functions \(F\) are not known as equations. They are obtained by designing cam surfaces to fit the data graphically.

The computing mechanism is shown as being used in connection with portions of a well known computing gun sight mechanism of the "K-3" type which has been altered to include a mechanism for solving ballistic deflections and providing a measure of time of flight.

Referring to Figs. 4 and 5, a gun 20 supported for movement about elevation and azimuth axes transmits its movements in the known manner, such as by flexible elevation shaft 21 and a similar azimuth shaft 22 to the computing mechanism of a sight, the computing mechanism being adapted in response to the angular displacement of the gun to effect automatically such relative displacement of the gun and a line of sight defining means that a projectile from the gun will strike a relatively moving target.

The computing mechanisms includes ballistic and prediction computers, the outputs of which effect a relative offset of the line of sight defining means according to the algebraic sum of prediction and ballistic deflections in azimuth and elevation respectively.

A cam assembly including three dimensional cams I and II are rotated in proportion to the gun azimuth angle \(A_R\) by means of gear 23 integral with the cam which meshes with long pinion 24 on shaft 25 coupled by gears 26 and shaft 27 to the azimuth input shaft 22.

This cam assembly is translated by a pivottally connected cam 30, having a cam groove 31 formed therein in which a fixed cam follower 32 is positioned. Hence rotation of cam 30 translates cams I and II in accordance with the contour of the cam groove 31, but due to the pivotal connection no rotary movement is transmitted between cam 30 and cams I and II.

Cam 30 is rotated by shaft 34 connected with an output of a differential 35. One input of the differential is displaced in accordance with air speed by a knob 37. The other input of the differential is controlled by a shaft 38 which is the output shaft of a differential 39. One input of this differential is shaft 40 displaced by knob 41 according to altitude which introduces an air density value into the circuit. The other input for differential 39 is a shaft 42 connected by gears 43 to shaft 44 which is displaced by some suitable arrangement such as a known range motor 45 according to the logarithmic time of flight, \(T_o\), value, to be described. The range motor may be operated in the known manner, such as by a push button on control grips 47, or by any other suitable device.

Knob 37 is provided with an index 50 on a transparent arm 51 which is set with reference to a logarithmic scale 52 so laid out that when the index 50 is positioned over the appropriate indicated air speed value, the displacement of shaft 36 is proportional to a logarithm of the function of the air speed value, the function being identified as \(f_2\) in Equation 14.

Altitude knob 41 is provided with an index 55 on a transparent arm 56 connected thereto which is positioned with reference to dial 57 laid out in altitude values, the dial being calibrated according to a logarithm of a function of air density such that when the index 55 is positioned, the shaft 40 is displaced according to a logarithmic function of density, \(\sigma\), the function in the present embodiment being \(f_2(\phi)\) of Equation 14. As already mentioned, input shaft 42 of differential 39 is displaced in accordance with a logarithmic value of time of flight \(T_o\) and this quantity is added to the logarithmic functions of air speed and density in differentials 39 and 35, the output shaft 34 being displaced together with cam 30 in rotation by the sum of these logarithmic functions.

The combined functions of density and air speed is the quantity \(R\) in the various equations. Cam 30 is an anti-logarithm cam which when rotated translates cams I and II according to \(T_R\). These cams, as already described, are rotated in gun azimuth \(A_R\). Cam 31 is laid out empirically according to data from ballistic tables, the cam itself being in effect a mechanical ballistic table. Cam I is laid out so that when actuated as described its lift pin 60 is displaced according to \(T_R F_\phi(R T A_9)\) which is the lateral ballistic deflection. The lift pin has a rack 61 formed thereon meshing with a gear 62 on an input shaft 63 of a differential 64. This differential adds the azimuth prediction and ballistic deflections to obtain a total lateral deflection value for offsetting the optics of the sight in azimuth and will be more fully described further on.

Cam II has the same input displacements as cam I and is laid out so that its lift pin 65 is displaced according to \(T_R F_\phi(R T A_9)\), which function \(f_3(\phi)\), is common to both vertical and range deflections. Lift pin 65 translates elevation cam III. The latter cam is rotated by gear 66 formed thereon which meshes with a long pinion 67 on shaft 68 connected by gears 69, 70, gears 71 and shaft 72 to the elevation input shaft 21. The cam is so laid out that with the inputs described, lift pin 73 will be actuated according to \(F_3(E_p\phi)\). This deflection need only be corrected for gravity, \(G\), to give \(\phi_o\), the elevation ballistic deflection as will be described.

Lift pin 73 has a rack 74 formed thereon which meshes with a gear 80 on shaft 81 which is an input for differential 82. Elevation ballistic and prediction deflections are added by differential 82 whose output effects a corresponding deflection of an elevation member in the optical system which defines the line of sight to be described.

On comparing Equations 3 and 5 and also 11, 12 and 13, it will be seen that the equations for the elevation ballistic deflection \(\phi_o\) and for the ratio of range deflection to present range have the common term \(\phi\). A separate cam could be fixed to cam III to be operated by the same inputs and this added cam could be laid out to give the lift pin displacement required for range deflection. Since \(\phi\) is common to both equations, an added cam is not necessary because by providing a second lift pin 85 for cam III displaced \(180^o\) from lift pin 73, the cam can be modified to displace lift pin 85 to give the logarithm of

\[
\frac{D_o}{D_i}
\]
(2)

with the described inputs. The layout is accomplished by graphical procedure and results in lift pin 85 being displaced in accordance with a logarithmic value of

\[
\frac{D_o}{D_i}
\]
(3)

for all conditions of range, density, air speed and gun position.

Lift pin 85 has a rack 86 formed thereon meshing with a gear 87 on shaft 88 coupled by gears 89 to the input shaft 90 of a differential 100. The output shaft of this differential operates a range measuring device to be described.

A cam IV is translated according to the logarithm of the function of density \(f_3(\phi)\) by means of rack 105 attached to the cam and gear 106 meshing with the rack. Gear 106 is driven from the altitude knob 41 by an arrangement of shafts 107 and 108 and gears 109 and 110 which couple gear 106 to the shaft 40 of the altitude knob.

Cam IV is rotated according to the logarithm of
of flight, $T_p$ by a long pinion 111 on shaft 44 which meshes with gear 112 on the cam. The cam is so laid out as to displace the lift pin 113 thereof according to the logarithm of $D$. This layout is such that for every time of flight value by which shaft 44 advances, lift pin 113 on shaft 44 is displaced in accordance with a measure of range at zero air speed and at any given air density. The density of course depends on the translation input of the cam. The range value as already described is represented in the drawings by the distance OA and in the equations by $L$. The motion of lift pin 85 of cam III corrects this value $D$, to obtain $D_0/D_1$ as now described. The lift pin 113 has a rack 114 formed thereon meshing with a gear 115 on a second input shaft 116 of differential 100. Since the other input shaft 90 of the differential is displaced according to the logarithm $D_0/D_1$

the output shaft 117 is displaced in accordance with the logarithm of present range $D_p$.

Shaft 117 is shown as controlling a range finding device of substantially the same type used in the various sights of the "K" series of sights which are well known to the armed forces, and therefore will only be briefly described.

Shaft 117 is coupled by means of gears 118, shaft 119 and gears 120 to a shaft 121 on which is mounted a range dial 126 calibrated to de-log the input shaft displacement. The dial is read with reference to index 127.

Shaft 125 drives through gears 130, an input shaft 131 of a differential 132. A second input shaft 133 of this differential has a target dimension scale 134 mounted thereon together with a knob 135. The scale is calibrated in logarithms of target dimensions such that when set by knob 135 with reference to index 136, the displacement of shaft 133 is in accordance with the logarithm of the target dimension value. The displacement output shaft 138 is equal to the sum of the input displacements, and is used to rotate a de-logging cam 139 whose cam follower is displaced according to the product of range $D_0$ and target dimensions. The cam follower 140 is shown schematically as displacing a rack 141 coupled by gear 142 and shaft 143 to a light guide indicated by the oblongs 144. The light guide may be any suitable variable reticle arrangement. The light guide and optical system used herein are known devices.

Light from a light bulb 150 shines on light gate 144 and an image of the reticle of the light gate which is adjustable in size falls on elevation mirror 151 which reflects the image onto a transparent mirror 152, displaceable according to total azimuth deflection. The operator observes the target through the mirror 152 and orients the sight until the target is centered in the image of the reticle.

When target dimension knob 135 is adjusted to position scale 134 according to a known dimension of the target and the air speed and altitude is set in by positioning knobs 37 and 41, the light gate is thereafter adjusted by operating the range motor to effect such displacement of shaft 44 as to cause the adjustable reticle of the light gate to bracket the target. Under these conditions, the mirrors 151 and 152 are so positioned that the line of sight and the gun bore are relatively offset according to the lead angles required for the projectile to strike the relatively moving target being tracked by the sight. The lead angles include a gravity correction, and also a prediction component, a portion of the mechanism shown for computing the latter being generally similar to that of a known "K" sight by $D_0/D_1$ and the method of making both corrections are to be described.

Elevation mirror 151 is supported by a sector 153 pivoted on a horizontal axis and provided for adjustment purposes with gear teeth which mesh with those of gear 154 on output shaft 155 of differential 82.

Azimuth mirror 152 is supported on a plate 156 pivoted on a vertical axis. The mirror is positioned according to total lateral deflection by the following mechanism. The plate is provided with gear teeth in mesh with those of a gear 157 on shaft 158 connected to output shaft 159 of differential 64 by means of gears 160 and 161 and shaft 162. Differential 64 has already been described as adding the lateral ballistic and prediction deflections.

The prediction solution of the mechanism shown in the drawings is based on the use of angular gun rates multiplied by time of flight to the present position of the target. The prediction range angle is determined by the angular travel method in which the angular velocity of the guns is multiplied by time of flight of the projectile to the present position of the target.

The prediction solution is accomplished by means of azimuth and elevation variable speed units. The discs of these units are rotated in proportion to the reciprocal of the time of flight $(1/T_p)$ by the drum of a master variable speed unit. The disc of the master unit rotates at a constant speed and its ball carriage is positioned in proportion to $(1/T_p)$ by a grooved cylindrical cam coupled with shaft 44 whose displacement is proportional to the logarithm of $T_p$.

The correction for gravity is accomplished by any suitable means such as a cam 165, Fig. 5, coupled by gears 166 to the gun elevation $E_p$, shaft 72. The cam has a follower 167 which displaces the ball carriage 168 of a variable speed drive having a disc 170 driven at constant speed. The cylinder is coupled to input shaft 171 of differential 172. The other input shaft 173 of the differential is driven from the gun elevation shaft 72 by means of gears 174. Output shaft 175 of differential 172 drives an input for the elevation equating differential 176. Shaft 175 connects cylinder 169 and a disc 170 driven at constant speed. The elevation variable speed unit to another input of differential 176. The output shaft 179 of this differential is connected to cam 180 and also to an input of differential 82. The displacement of shaft 179 represents a measure of the elevation prediction angle corrected for gravity, and this displacement is added by differential 177 to the elevation ballistic deflection to adjust the angular position of mirror 151 in accordance with the sum of prediction and ballistic deflections.

Cam 180 has a follower 181 which displaces the ball carriage 182 of the elevation variable speed drive. The disc 183 of this variable speed drive is coupled in proportion to $1/T_p$ by cylinder 184 of a master variable speed drive referred to above which has a disc 185 driven at constant speed and a ball carriage 187 displaced by a de-logging cam 186 rotated in accordance with the logarithm of time of flight $T_p$ by shaft 44 through a train of gears and shafts, including shafts 190, 192, 193 and 194.

When the target is being tracked in elevation, cam 165 displaces ball carriage 168 of the gravity rate variable speed drive in accordance with the gravity correction required for the elevation angle of the gun. The cylinder 169 displaces the associated input differential 172, whose second input 173 is displaced in accordance with the changing gun elevation angle. These displacements are added by the differential whose output shaft displaces an input of differential 176 causing cam 180 to turn and move ball carriage 182 of the elevation variable speed drive. The gun carriage then advances and drives the equating rate shaft 177 which displaces the second input of equating differential 176. The ball carriage will continue to be displaced until the rate of the equating rate shaft and the rate of rotation of shaft 175 are equal and cancel out in the equating differential 176. When this condition is attained, output shaft 179 of the differential which displaces the ball carriage via cam 180 becomes stationary and the angular position of the shaft 179 is a measure of elevation prediction, corrected for gravity.

Drum 184 also rotates disc 197 of the azimuth variable
speed drive which has a cylinder 198 coupled by equating rate shaft 199 to an input of azimuth equating differential 200. The output shaft 201 of the differential rotates cam 202 which displaces ball carriage 203 of the variable speed drive.

Since the line of sight is in a slant plane, it is necessary to convert azimuth velocity in a horizontal plane to azimuth velocity in a slant plane before multiplication by $1/T_a$. This is accomplished by a variable speed drive having disc 204 connected by shaft 205 to the gun azimuth $A_\phi$ input shaft 207 and a cylinder 206 connected to input shaft 207 of equating differential 200.

The ball carriage 205 is displaced by a cam 209 driven from the gun elevation shaft 72 by shaft 210 and suitable gearing. Cam 209 is so laid out as to position ball car- rige 205 in proportion to the cosine of gun elevation and thus drum 206 is caused to rotate in gun azimuth rate in a slant plane.

The operation of the azimuth variable speed drive is similar to that of the elevation variable speed drive. The output of the cylinder 206 is fed through differential 200 to the variable speed multiplier where it is multiplied by $1/T_a$ in the same manner as for the elevation prediction. The product of the two input values is the azimuth pred- iction deflection represented as a displacement of shaft 201 which is connected to an input of differential 64 where it is added to the azimuth ballistic deflection, a total lateral deflection value appearing as a displacement of the differential output shaft 159 which controls the angular position of azimuth mirror 152.

From the foregoing it will be understood that the com- puter solves for lead angles and automatically effects relative displacement of a gun and line of sight according to the lead angles. The computer described is designed for use with a specific projectile. By means of the present invention the computer may be used with other projectiles by varying the inputs thereof in accordance with the ballistic characteristics of the respective projectiles. The particular computer shown in Figs. 4 and 5 lends itself readily to such adaptation on account of the IV cam which solves for range $D_i$ at zero air speed for all input time of flight and air density values.

In studying the ballistics for the M2 .50 caliber, 20 mm. and 37 mm. projectiles, their time and range values at zero TAS (true air speed) were plotted on double logarithmic paper. The curves for the respective projec- tiles were found to be similar in nature. Two sets of such curves are shown in Figs. 7 and 8, respectively. As far as the eye could determine, the sets of such curves for the projectiles just mentioned could be made to co- incide by simply moving one set an amount $M$ along the abscissa and an amount $N$ along the ordinate as indicated in Fig. 9, which suggested that cam IV might serve in a universal ballistic solution as a common denominator, as it were, for a number of projectiles. This, of course, means that the curves for the different projectiles bear a definite relationship to one another and that the IV cam for one projectile may be used for another. All that need be done is that the input time for which the cam is designed be multiplied by a suitable constant $K_p$ for each projectile, which result may be achieved by displacing in rotation the input logarithm of time shaft for the IV cam (for $1/K_p$), and by suitably displacing the output shaft from the lift pin of the IV cam accor- ding to a constant $K_o$ (for $1/K_o$). The constants $K_p$ and $K_o$ are determined empirically for the ballistic tables for the respective projectiles, and as used herein, as far as zero air speed conditions are concerned, include cor- rection for changes in ballistic coefficient and muzzle velocity by means of $K_p$ and $K_o$. Hence, by offsetting cam IV in one dimension by an amount equal to $K_p$ and varying the output of the cam according to a function $K_o$ the cam may be used with a different projectile than that for which it was orig- inally designed.

Assume that the computer of Figs. 4 and 5 has been designed for projectile $A$, and that it is to be converted for use with any projectile $B$. Such a computer is shown in Fig. 6 which will now be described in detail.

It is necessary to correct the rotation of air speed shaft 36 according to the characteristics of projectile $B$. For this purpose shaft 36 is coupled by a rack 216 to one end of a lever 217. A rack 218 at the opposite end of the lever meshes with a gear 219 that drives through gear 220 and input 221 of a differential 35 which corresponds to the similar differential 35 in Fig. 4. A knob 226 on shaft 228 carries an arm 229 having an index 230 thereon which can be adjusted with reference to scale 231 calibrated according to the constant $K_o$ for the air speed values of the various projectiles. Gear 232 on shaft 228 meshes with a rack 233 which adjusts the position of a fulcrum 234 for lever 217. With this arrangement, fulcrum 234 can be positioned according to the particular value of constant $K_o$ of a given projectile to effect a corresponding multiplication of the displace- ment of shaft 36.

Dial 57 is calibrated in the logarithm of the function of density for projectile $A$. The IV cam must translate in the same function of density regardless of the pro- file as will be explained below. Accordingly, the circular rack 105 attached to cam IV is driven directly from shaft 40, associated with dial 57, as in Fig. 4 by means of gear 106 which meshes with the rack and shafts, including shafts 107 and 108, and gearing including gears 110.

Altitude shaft 40 controls a second input to differential 35 as it does in Fig. 4 but a multiplying arrangement is provided to introduce the density function of projectile $B$ into the differential.

Shaft 40 carries a gear 235 meshing with rack 236 pivoted to lever 237. Rack 238 pivoted to the opposite end of the lever drives gear 239 connected to a second input of the differential 35. A gear 240 on shaft 241 is provided with a transparent arm 242 marked with an index which cooperates with a scale 243 calibrated in logarithms of density constant $K_o$. A gear 244 on shaft 241 meshes with rack 245 that positions a fulcrum 246 for lever 237. By suitably positioning arm with refer- ence to scale 243, the density function of projectile $B$ may be introduced into the computer by the resulting multiplication of the value by which shaft 40 is displaced.

The shaft 44 shown in the center portion of Fig. 6 is displaced in accordance with the logarithm of time of flight as is the corresponding shaft 44 of Fig. 4 for the same purpose. As described above, the input for the ballistic cams is the product of the functions of relative density $\sigma$, air speed, and time of flight $T_a$. The product of these functions has been referred to herein as $\sqrt{T_a}$ which represents total windage deflection for the input conditions and is used to translate ballistic cams I and II. In Fig. 6 for convenience, the connections for differentials are somewhat different than in Fig. 4, but the operation of the circuit is essentially the same.

In Fig. 6 the time of flight shaft displaces an input of differential 39 similar to that of Fig. 4, but in Fig. 6 it is necessary to provide a variable gear ratio for a projectile $B$ because the time function required is a power function of time, $T_a$, and this power varies from projectile to projectile. For this purpose, shaft 44 carries a gear 250 that meshes with a rack 251 pivoted to an arm of a lever 252. The lever drives input gear 254 of differ- ential 39 when displaced on its fulcrum by shaft 44, through a train of mechanism including gears 255, 256, and 257, the latter being in mesh with a rack 253 pivoted to the second arm of lever 252. Lever 253 has a mov- able fulcrum 258 positioned by lead screw 259 on shaft 260 on which is mounted a knob 261, carrying a trans- parent arm 262 having an index 263 thereon that co- operates with a stationary scale 264.

The adjustment of shaft 260 and knob 261 affects only
the function of time for the quantity RT by which cams I and II are translated.

A second input 270 for differential 39 is connected by a rack member 271, and gear 272 to the output 273 of differential 35. Thus the output 274 is equal to the sum of the logarithms of the functions of TAS, air density, and T0, which is the logarithm of the quantity RT. It has been found that the quantity RT when so derived requires correction which is always proportional to a constant in order to give correct displacement of the ballistic cams. The constant is introduced by means of knob 275 to which is attached an arm 276 carrying an index 277 which cooperates with a scale 278 which may be calibrated according to the respective constants of a number of different projectiles. The knob is connected by shaft 279 to gear 280 that displaces the input 281 of a differential 282. The other input 283 is displaced by gear 284 on shaft 274 in accordance with the logarithm of RT and thus the output shaft 285 of the differential is displaced according to the corrected value of RT. Shaft 285 carries a pinion 286 which meshes with a gear 287 attached to a cam 30 pivoted to the assembly of cams I and II. As in the computer shown in Fig. 4, cam 30 is provided with a cam groove 31 which rides on a stationary follower 32. The cam groove 31 is so formed as to delog its rotary input from gear 286 and translate cams I and II according to RT.

The rack 251 which is displaced by shaft 44 according to the input time of flight is pivotally coupled with a worm 292 secured to shaft 291 which carries a gear 292 meshing with long pinion 293 connected to a knob 294. The knob is provided with an arm 295 having an index 296 formed thereon which cooperates with a scale 297.

Worm gear 290 drives worm wheel 300 on shaft 301 carrying long pinion 302 which drives gear 112 attached to cam IV. The arrangement is such that displacement of shaft 44 translates worm 290 turning gear 300 and cam IV while rotation of knob 294 effects rotation of worm 290 which also turns gear 300 and cam IV. Rotation of knob 294 does not translate rack 251 and hence does not affect the time input to the ballistic cams I and II. Knob 294 is provided for the purpose of introducing the constant Kp by which cam IV is offset selectively in rotation in accordance with the range characteristics of a given projectile at zero true air speed referred to above. The output of cam IV (and also cam III) must be further corrected by the constant Kd, also referred to above for each projectile which will now be described.

Liftings 85 and 113 of cams III and IV respectively are pivoted to opposite ends of lever 305. A framework 306 is formed in the lever, and supported on pivots within the framework is a block 307 provided with a threaded bore into which a threaded portion 308 of a shaft 309 is screwed.

On one end of shaft 309 a circular rack 310 is formed that meshes with gear 311 on shaft 117 which corresponds to the shaft of Fig. 4 bearing the same reference character whose displacement is a measure of present range Dp as described above. It will be understood that lever 305 will be variably positioned by means of cam IV and shaft 309 will be translated accordingly, thereby adjusting the position of gear 311 and shaft 117 according to present range, Dp.

Shaft 309 carries a long pinion 315 coupled with knob 316 by shaft 317 and gear 318. The knob carries an arm 319 with an index 320 thereon which is translated according to the constant of the scale 321. When knob 316 is adjusted, turning of shaft 309 due to the threaded portion 308 thereon causes the shaft to translate turning shaft 117 in one direction or another. Knob 316 causes the output of cam IV to be multiplied by the constant Kd.

As in the computer shown in Figs. 4 and 5, cams I and II are displaced in rotation by means of a gear 23 formed on the cam which meshes with a long pinion 24 on a gun azimuth input shaft. The displacement of lift pin 60 is the lateral ballistic deflection ± which will be used by suitable means not shown in Fig. 6 displaced according to the lateral prediction deflection to provide a measure of total lateral deflection. Likewise, cam III is translated by lift pin 65 of cam II and rotated by means of a gear 66 formed thereon which meshes with long pinion 67 on the gun elevation input shaft 68. The displacement of lift pin 73 represents the vertical ballistic deflection φ.

For purposes of illustration, gravity correction is introduced in a somewhat different manner than shown in Fig. 4 and 5. Cam 325 on shaft 68 displaces its lift pin 326 and rack 327 attached thereto. The rack actuates a gear 328 and shaft 329. Cam 325 is so laid out as to provide a correction for gravity which may be combined by suitable means (not shown) with that of lift pin 73 to give a measure of vertical ballistic deflection corrected for gravity (φ) which may be combined by means (not shown in Fig. 6), such as a differential, with a measure of vertical prediction, derived from any suitable means to give a measure of total vertical deflection. Any suitable means for measuring the prediction angle may be used with the ballistic mechanism described above. Likewise any suitable means other than the two different arrangements shown in Figs. 5 and 6 may be used for gravity correction.

It is thought that the foregoing description of Fig. 6 will give an understanding of one arrangement by which the various inputs for a ballistic mechanism may be varied for different projectiles and it is contemplated that the various dials will be calibrated for a number of projectiles with which the sight is likely to be used. One method by which the dials are calibrated according to the different input functions of the respective projectiles will now be discussed.

Assuming that the computer of Fig. 6 has been designed for projectile A and that its inputs are calibrated for a projectile B, the same procedure being followed for any other projectile X, the projectiles being, for example, .50 caliber, 20 mm., and 37 mm. As stated above, the air speed input shaft, in the present embodiment of the invention, must be displaced in terms of the logarithm of the air speed function associated with projectile B, where B projectile is used. This is accomplished by a suitable adjustment of knob 226 with reference to dial 231 which provides for the proper input drive ratio for the empirically determined function required for projectile B.

When true air speed S is used as a computer input, it is possible to write the air speed function G of projectile B as a power of the air speed function of projectile A, that is

\[ G_A(S) = [G_B(S)]^{K_B} \]  

(15)

where \( G_A(S) \) is the true air speed function from projectile A, and \( K_B \) is the associated exponent.

It is desirable to have functions related as powers because it is possible to introduce computer inputs that are logarithms of the functions of air speed, air density, and time, all empirically derived from studies of the ballistic tables.

Exponents such as \( K_B \) above, then, are simply multiplied by the input function, since

1n[G_A(S)] = 1n[G_B(S)]^{K_B} \]  

(16)

In the computer of Fig. 6 (1n[G_A(S)]) is multiplied directly by \( K_B \). Here dial 52 is calibrated in the logarithm of the function \( G_B(S) \) adapted to the second projectile B, and the computer is provided with means of the linkage multiplier shown. It is to be understood that any suitable means may be used to effect the various multiplying operations described herein, the linkage arrangement being shown on account of its simplicity. This is merely a means for effecting a gear ratio change. A minor modification in construction an actual change of gears might be desirable. Dial 231 is calibrated in values of \( K_B \) for the respective projectiles designated thereon and the fulcrum 234 of the
multiplier is positioned according to the setting of $K_a$ knob 226 so that the output on rack 218 of the multiplying linkage is $K_a n F_A(n S)$. In this manner it is possible to obtain the proper function of air speed input to the computer for each projectile.

The logarithm of the air speed function is added to the logarithm of the air density function in differential 35. The altitude, or air density dial 257, is calibrated in the logarithm of the function of density $F_D(\sigma)$ for projectile A. The IV cam must translate in the same function of density regardless of the projectile because it must always be properly positioned in density so that the multiplying constants $K_D$ and $K_D'$, mentioned below may be applied correctly.

Since the density function of projectile B may be expressed as a power of the density function of projectile A as

$$F_B(\sigma) = F_A(\sigma)^{K_{\sigma}} \quad (17)$$

the logarithm of the density function of projectile B may be introduced into the computer by means of a gear ratio change which is accomplished, in effect, by the multiplying linkages of Fig. 6. From Equation 17 we have

$$1n F_B(\sigma) = K_{\sigma} 1n F_A(\sigma) \quad (18)$$

where $K_\sigma$ is the value of the gear ratio introduced by knob 240 for any of the projectiles for which its dial is calibrated.

In Fig. 6, dials 57 and 243 are calibrated in $1n F_\sigma(\sigma)$ and $K_\sigma$ respectively. The multiplier unit is similar to the air speed multiplier. Fulfurcam 246 is positioned in $K_\sigma$ and rack 238 is translated in $1K_\sigma 1n F_\sigma(\sigma)$: Cam IV is geared directly to altitude knob 41 and is unaffected by the constant $K$, referred to below. The logarithms of the functions of density are summed in differential 35 whose output is combined with the logarithm of the function of time in differential 39.

In the present embodiment of the invention, the time function required as a ballistic input is a power function of time $T_0$ and the power varies from projectile to projectile. Since it is the logarithm of time that is fed into the computer, the value of the exponent may be introduced as a gear ratio.

$$1n H_5(T_0) = C = 1n H_4(T_0) = C \{k1n T_0\} \quad (19)$$

$$1n H_5(T_0) = K1n T_0 \quad (20)$$

where $C$, $k$, and $K$ are constants, and $H_4$ and $H_5$ are the density functions for projectiles A and B set into the computer by knobs 57 and 240.

Shaft 44 rotates in $1n T_0$. This feeds into a linkage multiplier unit whose fulcrum 258 is positioned in $K$ by knob 261 to give as output on rack 253 $K1n T_0$. Dial 264 is calibrated in terms of $K_\sigma$ and knob 261 associated therewith positions fulcrum 258 for the various projectiles.

The constant $K_\sigma$ referred to above in connection with Figs. 7, 8, and 9 is introduced as an additional rotation of the input shaft 301 for turning cam IV. The rotational value of $1n T_0$ on shaft 301 comes from worm 290 which is translated by $1n T_0$ from input shaft 44.

Cam IV rotates in

$$1n K_\sigma T_0 = 1n K_\sigma + 1n T_0 \quad (20)$$

The value of $1n K_\sigma$ is added to the rotation of shaft 301 when worm 290 is rotated by $1n K_\sigma$ knob 294.

The lead screw 308 from knob 316 with 308 is displaced in an endwise direction according to the sum of the lifts of $1n D_1$ from lift pin 113 of cam IV and

$$1n D_2 \quad (21)$$

from lift pin 85 of cam III. Thus the rotation of shaft 117 is the logarithm of range $D_0$, the multiplying factor $K_D$ having been accounted for as a further displacement in the output of the differential linkage operated from the lift pins of cams III and IV.

In operation, the various function knobs will be positioned initially according to the projectiles used, and this position remains unchanged until the type of projectile is changed. Knobs 37 and 57 are kept adjusted for changing altitude and air speed values. If the ballistic computer is incorporated in a sight according to that shown in Figs. 4 and 5, the operation thereof is the same as described. However, it is to be understood that a ballistic unit is only an element or a part of a complete computer and the specific embodiment as described will be understood by those skilled in the art for aiming devices of other types wherein a ballistic computer of high efficiency is desirable.

What is claimed is:

1. A ballistic computing mechanism for an airborne gun including a cam laid out to compute azimuth windage correction according to the ballistic characteristics of a predetermined projectile to be fired by the gun, gear means driven by the gun for turning the cam about its axis in accordance with the angular position of the gun in azimuth, computing means for translating the cam along its axis in accordance with the projectile of predetermined discrete functions of time of flight of the projectile, indicated air speed and altitude of the supporting aircraft, means for adapting the cam for use with a projectile having ballistic characteristics different from those of the first-mentioned projectile comprising a plurality of members settable at will respectively according to predetermined constants to vary the extent of translation of the cam by the computing means in accordance with said constants.

2. In a ballistic computer for an airborne gun, means for computing the product of predetermined functions of air speed and altitude of the supporting aircraft, and time of flight peculiar to the ballistic characteristics of a predetermined projectile, means to multiply said functions by predetermined constants to obtain functions peculiar to the ballistic characteristics of a projectile of a type different from the first-mentioned projectile, a ballistic cam operatively connected to the output of the computing means for axial movement thereby according to the computed product, and means for turning the cam on its axis in accordance with the angular position of the gun.

3. In a ballistic apparatus for an airborne gun, means for computing the product of predetermined functions of time of flight, altitude and air speed in accordance with the ballistic characteristics of a first kind of projectile to be fired from the gun, means to multiply said functions by predetermined constants to change the magnitude of the computed product in accordance with the ballistic characteristics of another kind of projectile, and a cam controlled by the output of the computing means for providing ballistic deflections suitable for either kind of projectile.

4. In a ballistic apparatus for airborne ordnance for use with any of a number of predetermined projectiles, means for computing the product of predetermined functions of time of flight, altitude and air speed, respective mechanisms for setting air speed, altitude and time of flight into the computing means, each mechanism including a gear drive and a ratio changing device thereon, the respective ratio changing devices being adapted to be set initially in fixed position in advance of firing in accordance with predetermined said functions according to the ballistic characteristics of the projectile to be used, a cam providing ballistic deflections designed for use with any of the predetermined projectiles operatively connected to the output of the computing means for displacement in one dimension thereby, and means driven according to a gun angle for displacing the cam in another dimension.

5. In a ballistic apparatus for airborne ordnance for use with any of a number of predetermined projectiles,
means for computing the product of predetermined functions of time of flight, altitude and air speed, respective mechanisms for setting into the computing means discrete functions of air speed, altitude and time of flight, each mechanism including a multiplying linkage, means for adjusting the multiplying linkages into any of a number of predetermined positions depending on the projectile to be used, the linkages when set appropriately being effective to multiply the respective functions associated therewith by a suitable constant to modify the functions in accordance with the ballistic characteristics of the projectile to be used, a cam for computing ballistic deflections suitable for any of said projectiles operatively connected to the output of the computing means for displacement in one dimension thereby and means for displacing the cam in another dimension in accordance with the angular position of a gun.

6. In a ballistic apparatus for airborne ordnance for use with any of a number of predetermined projectiles, means for computing the product of predetermined functions of time of flight, altitude and air speed, respective mechanisms for setting into the computing means discrete functions of air speed, altitude and time of flight, a multiplying linkage for each mechanism including a lever having a movable fulcrum, means for adjusting the respective fulcrums into any of a number of predetermined positions, each position corresponding to a different projectile to vary the respective functions according to the ballistic characteristics of the projectile to be used, and ballistic computing means controlled by the output of the first-mentioned computing means.

7. In a ballistic apparatus for airborne ordnance for use with any of a number of predetermined projectiles, means for computing the product of predetermined functions of time of flight, altitude and air speed, respective mechanisms for setting into the computing means discrete functions of air speed, altitude and time of flight, a multiplying linkage for each mechanism including a lever having a movable fulcrum, means for adjusting the fulcrums into any of a number of predetermined positions, each position corresponding to a different projectile, the linkages being effective to multiply the functions by constants effective to vary the functions according to the ballistic characteristics of the projectile to be used, a cam for computing ballistic deflections suitable for all of the predetermined projectiles operatively connected to the output of the computing means for displacement thereby in one dimension, and means driven according to a gun angle for displacing the cam in another dimension.

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