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Sept. 20, 1960 — E. J. NAGY ET AL — 2,953,299

BALLISTIC APPARATUS ADJUSTABLE FOR DIFFERENT TYPES OF PROJECTILES

Filed Dec. 29, 1944 — 4 Sheets-Sheet 1

Fig. 1.

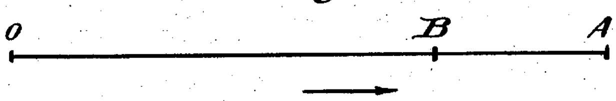


Fig. 2.

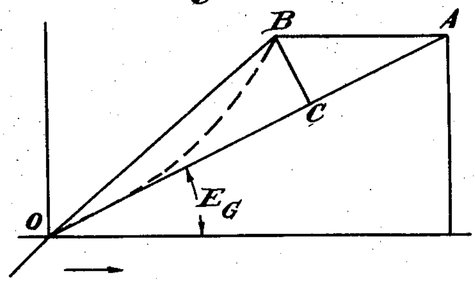


Fig. 3.

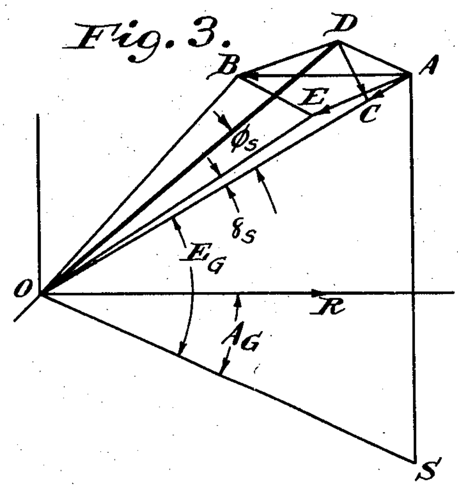


Fig. 7.

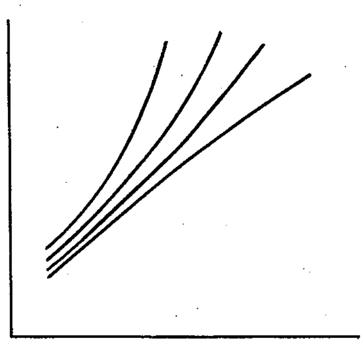
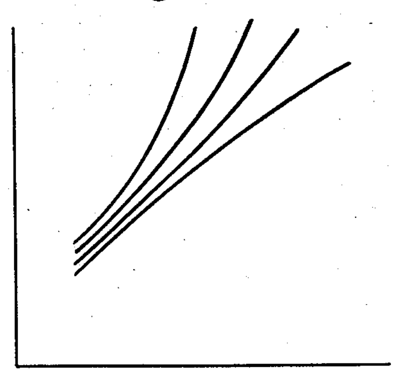


Fig. 8.



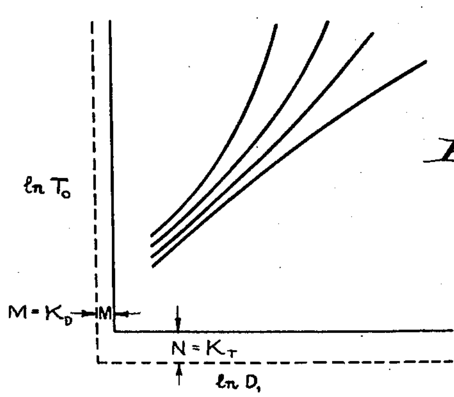


Fig. 9.

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Fig. 4.

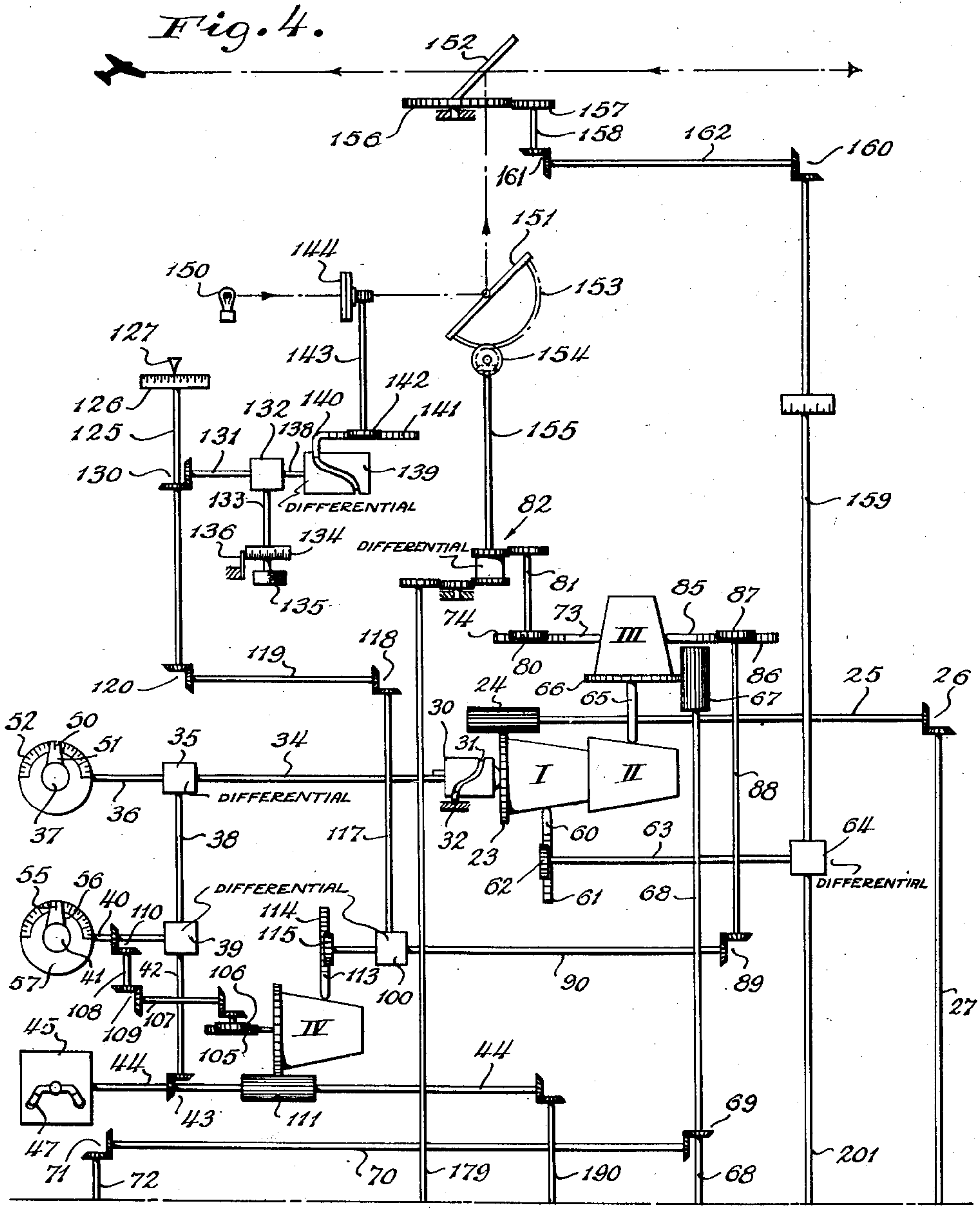

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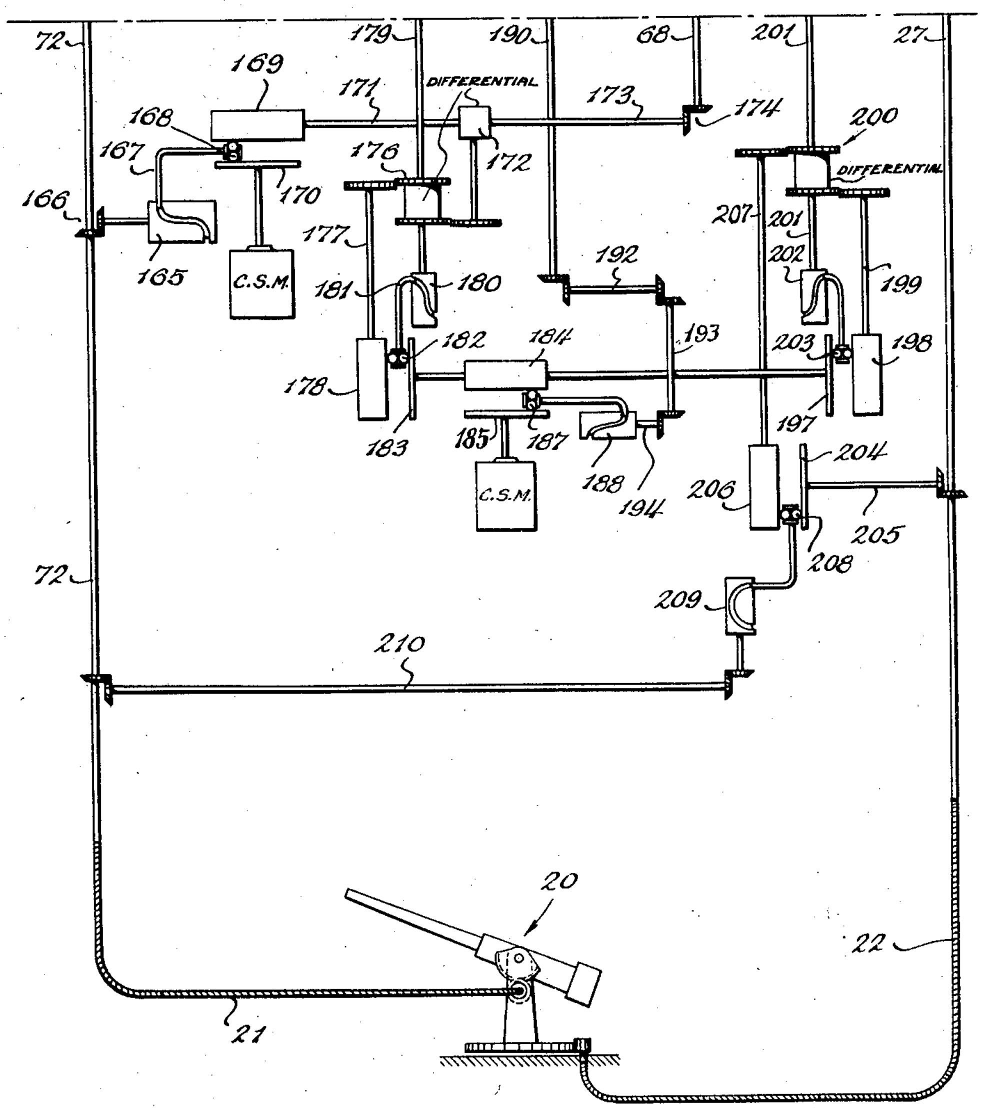
Fig. 5.



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BALLISTIC APPARATUS ADJUSTABLE FOR DIFFERENT TYPES OF PROJECTILES

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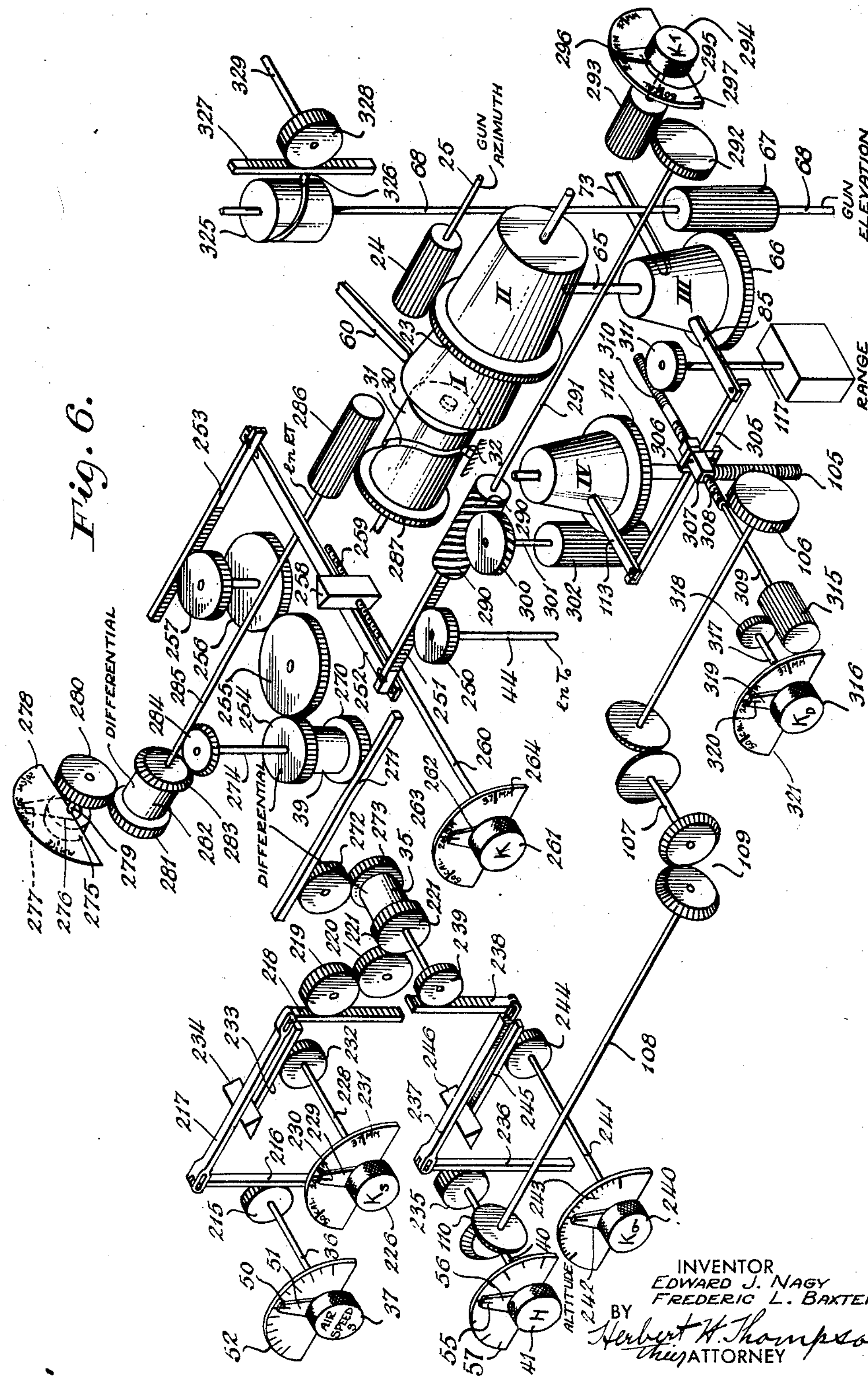

Fig. 6.

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BALLISTIC APPARATUS ADJUSTABLE FOR DIFFERENT TYPES OF PROJECTILES

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Filed Dec. 29, 1944, Ser. No. 570,400

7 Claims. (Cl. 235—61.5)

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 fractions, 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 conveniently 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 ballistics coefficient, (C), of a projectile is changed, then the ballistics may be corrected very simply. Ballistics vary directly with C, which enters into ballistic computations with relative density, σ as the ratio C/σ. 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 the 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 copending 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 cams 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 cams 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 equipment or a suitable optical 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 computing 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 gravity. If the gun has zero air speed, then after a time T_1, 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, then the position of the projectile with respect to the gun, after a time T_0 is represented by B. 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 E_g. If the azimuth angle is zero, 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 of the projectile relative to the gun after a time T_0. The distance OA represents the range D_1 at zero air speed, AB represents the total linear windage deflection relative to the gun, and AC the range deflection hereinafter referred to as D_d. Since the trajectories of aircraft projectiles are essentially flat, the equality of OB and OC may be assumed. Hence

$$OA=OB+CA \quad (1)$$

$$D_1=D_0-D_d \quad (2)$$

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 as such has no meaning in aircraft gun-fire 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 the range deflection D_d, and 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 has been changed and therefore, 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_d and is the difference between D_1 and D_0. In the ballistic mechanism disclosed herein, the values of D_d and D_1 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 deflections 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 δ_s is the projection of the total ballistic deflection angle AOB on the lateral plane of the gun. The vertical deflection ϕ_s is the projection of the total ballistic deflection angle AOB on the elevation plane of the gun. The range deflection D_d 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 ϕ_s, and angle EOC is a measure of lateral deflection δ_s. As in Fig. 2, the distance OB is a measure of present range D_0; AC is equal to range deflection, D_d, 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_d and the zero air speed range D_1. In general the deflections are

$$\frac{D_d}{D_o}=T_o[R \cos A_g \cos E_g+K_g \sin E_g] \quad (3)$$

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

$$\delta_g=T_0R \sin A_g \quad (4)$$

and

$$\phi_g=T_0[R \cos A_g \sin E_g+K_g \cos E_g] \quad (5)$$

The total angular windage deflection θ 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, σ

$$\theta=f_1(\sigma)f_2(TAS)f(T_0) \quad (6)$$

or

$$\theta=f_3(\sigma)f_4(IAS)f(T_0) \quad (7)$$

For the .50 caliber M2 projectile

$$f(T_0)=T_0 \quad (8)$$

Hence

$$\theta=T_0f_3(\sigma)f_4(IAS)=T_0R \quad (9)$$

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 $f_3(\sigma)$ and f_4(IAS) are determined.

Tables of range deflections as such are not supplied by the Government and the values of D_d 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 cams of the ballistic mechanism described below.

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

$$\delta_s=T_0RF_1(RT,A_g) \quad (10)$$

$$\phi_s=F_3(E_g,\phi)+T_0K_aF_4(E_g) \quad (11)$$

$$\frac{D_d}{D_o}=F_5(E_g,\phi)+T_oK_bF_6(E_g) \quad (12)$$

where

$$\phi=T_0RF_2(A_g,RT) \quad (13)$$

$$R=f_3(\sigma)f_4(IAS) \quad (14)$$

and K_a, K_b 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_g by means of gear **23** integral with the cams 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 pivotally 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 **36** 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 a 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_0 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_4 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, σ, the function in the present embodiment being $f_3(\sigma)$ of Equation 14. As already mentioned, input shaft **42** of differential **39** is displaced in accordance with a logarithm value of time of flight

T_0, 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 antilogarithm cam which when rotated translates cams I and II according to T_0R. These cams, as already described, are rotated in gun azimuth A_g. Cam I 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 $T_0RF_1(RT,A_g)$ 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 so laid out that its lift pin **65** is displaced according to $T_0RF_2(RT,A_g)$, which function (ϕ), 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**, shaft **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 $F_3(E_g,\phi)$. This deflection need only be corrected for gravity, G, to give ϕ_s, 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 ϕ_s and for the ratio of range deflection to present range have the common term ϕ. 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 ϕ is common to both equations, an added cam is not necessary because by providing a second lift pin **85** for cam III displaced 180° from lift pin **73**, the cam can be modified to displace lift pin **85** to give the logarithm of

$$\frac{D_0}{D_1}$$

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

$$\frac{D_0}{D_1}$$

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 $f_3(\sigma)$ 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 time of flight, T_0, 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_1. This layout is such that for every time of flight value by which shaft **44** displaces the cam, the lift pin **113** 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 D_1. The displacement of lift pin **85** of cam III corrects this value D_1 to obtain present range D_0 as will now be 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

$$\frac{D_0}{D_1}$$

the output shaft **117** is displaced in accordance with the logarithm of present range D_0.

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 **125** 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 gate indicated by the oblongs **144**. The light gate may be any suitable variable reticle arrangement. The light gate 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, 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 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 $(1/T_0)$ 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 $(1/T_0)$ by a grooved cylindrical cam coupled with shaft **44** whose displacement is proportional to the logarithm of T_0.

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_g, shaft **72**. The cam has a follower **167** which displaces the ball carriage **168** of a variable speed drive having a cylinder **169** and 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 **177** connects cylinder **178** of 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 **82** 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 turned in proportion to $1/T_0$ 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 **188** rotated in accordance with the logarithm of time of flight T_0 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 from the center of the disc, thus causing cylinder **178** to turn and drive 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 $1/T_0$. This is accomplished by a variable speed drive having disc **204** connected by shaft **205** to the gun azimuth A_g input shaft **27** and a cylinder **206** connected to input shaft **207** of equating differential **200**.

The ball carriage **208** 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 carriage **208** 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 $1/T_0$ in the same manner as for elevation prediction. The product of the two input values is the azimuth prediction 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 computer 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_1 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 ploted on double logarithmic paper. The curves for the respective projectiles 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 coincide 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_T for each projectile, which result may be achieved by displacing in rotation the input logarithm of time shaft for the IV cam (for $1n\ K_T$), and by suitably displacing the output shaft from the lift pin of the IV cam according to a constant K_D (for $1n\ K_D$). The constants K_T and K_D 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 correction for changes in ballistic coefficient and muzzle velocity. Hence by offsetting cam IV in one dimension by an amount equal to K_T and varying the output of the cam according to a function K_D the cam may be used with a different projectile than that for which it was originally 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 gear **215** and 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 may be adjusted with reference to scale **231** calibrated according to the constant K_s 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_s of a given projectile to effect a corresponding multiplication of the displacement 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 projectile 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 knob **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 $K\sigma$. A gear **244** on shaft **241** meshes with rack **245** that positions a fulcrum **246** for lever **237**. By suitably positioning arm with reference 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 and for the same purpose. As described above, the input for the ballistic cams is the product of the functions of relative density σ, air speed, and time of flight T_0. The product of these functions has been referred to herein as RT 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_0, 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 differential **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 **252** has a movable fulcrum **258** positioned by lead screw **259** on shaft **260** on which is mounted a knob **261**, carrying a transparent arm **262** having an index **263** thereon that cooperates 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 T_0, 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 **290** 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 that 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 K_T 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 K_D also referred to above for each projectile which will now be described.

Lift pins **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 D_0 as described above. It will be understood that lever **305** will be variably positioned by cams III and IV and shaft **309** will be translated accordingly, thereby adjusting the position of gear **311** and shaft **117** according to present range, D_0.

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 adapted to be positioned with reference to stationary 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 K_D.

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 δ_S 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 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_S) 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, when the 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_B of projectile B as a power of the air speed function of projectile A, that is

$$G_B(S)=[G_A(S)]^{K_s} \quad (15)$$

where $G_A(S)$ is the true air speed function from projectile A, and K_s 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_s above, then, are simply multiplied by the input function, since

$$1nG_B(S)=K_s 1n(G_A(S) \quad (16)$$

In the computer of Fig. 6 $[1nG_A(S)]$ is multiplied directly by K_s. Here dial **52** is calibrated in the logarithm of the function of true air speed. The multiplication of $[1nG_A(S)]$ by K_s is performed by 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 and in some constructions an actual change of gears might be desirable. Dial **231** is calibrated in values of K_s for the respective projectiles designated thereon and the fulcrum **234** of the multiplier is positioned according to the setting of K_s knob **226** so that the output on rack **218** of the multiplying linkage is $[K_s 1nG_A(S)]$. 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 **57**, is calibrated in the logarithm of the function of density F_A (σ) 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_T, 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

$$1nF_B(\sigma)=K\sigma 1nF_A(\sigma) \quad (18)$$

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 $[1nF_A(\sigma)]$ and $K\sigma$ respectively. The multiplier unit is similar to the air speed multiplier. Fulcrum **246** is positioned in $K\sigma$, and rack **238** is translated in $[K\sigma 1nF_A(\sigma)]$: 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.

$$1nH_B(T_0)=C[1nHA(T_0)]=C[k1nT_0] \quad (19)$$

$$1nH_B(T_0)=K1nT_0 \quad (20)$$

where C, k and K are constants, and H_A and H_B are the density functions for projectiles A and B set into the computer by knobs **57** and **240**.

Shaft **44** rotates in $[1nT_0]$. This feeds into a linkage multiplier unit whose fulcrum **258** is positioned in K by knob **261** to give as output on rack **253** $[K1nT_0]$. Dial **264** is calibrated in terms of K_1 and knob **261** associated therewith positions fulcrum **258** for the various projectiles.

The constant K_T 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 $[1nT_0]$ on shaft **301** comes from worm **290** which is translated by $[1nT_0]$ from input shaft **44**. Cam IV rotates in

$$1nK_T T_0=1nK_T+1nT_0 \quad (20)$$

The value of $1nK_T$ is added to the rotation of shaft **301** when worm **290** is rotated by $1nK_T$ knob **294**.

The constant K_D is introduced through the lead screw **308** from the $1nK_D$ knob **316**. Lead screw **308** is displaced in an endwise direction according to the sum of the lifts of $1nD_1$ from lift pin **113** of cam IV and

$$\left[1n\frac{D_0}{D_1}\right]$$

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 shown may be adapted as 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 deflection 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 product 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 therefor, the respective ratio changing devices being adapted to be set initially in fixed position in advance of firing in accordance with predetermined constants to modify 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 characteristis 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, alttitude 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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