June 10, 1947. G. B. DANTZIG 2,421,745

COMPUTER FOR SOLVING BOMBING PROBLEMS

Filed Sept. 16, 1942 6 Sheets-Sheet 1

FIG. 1.

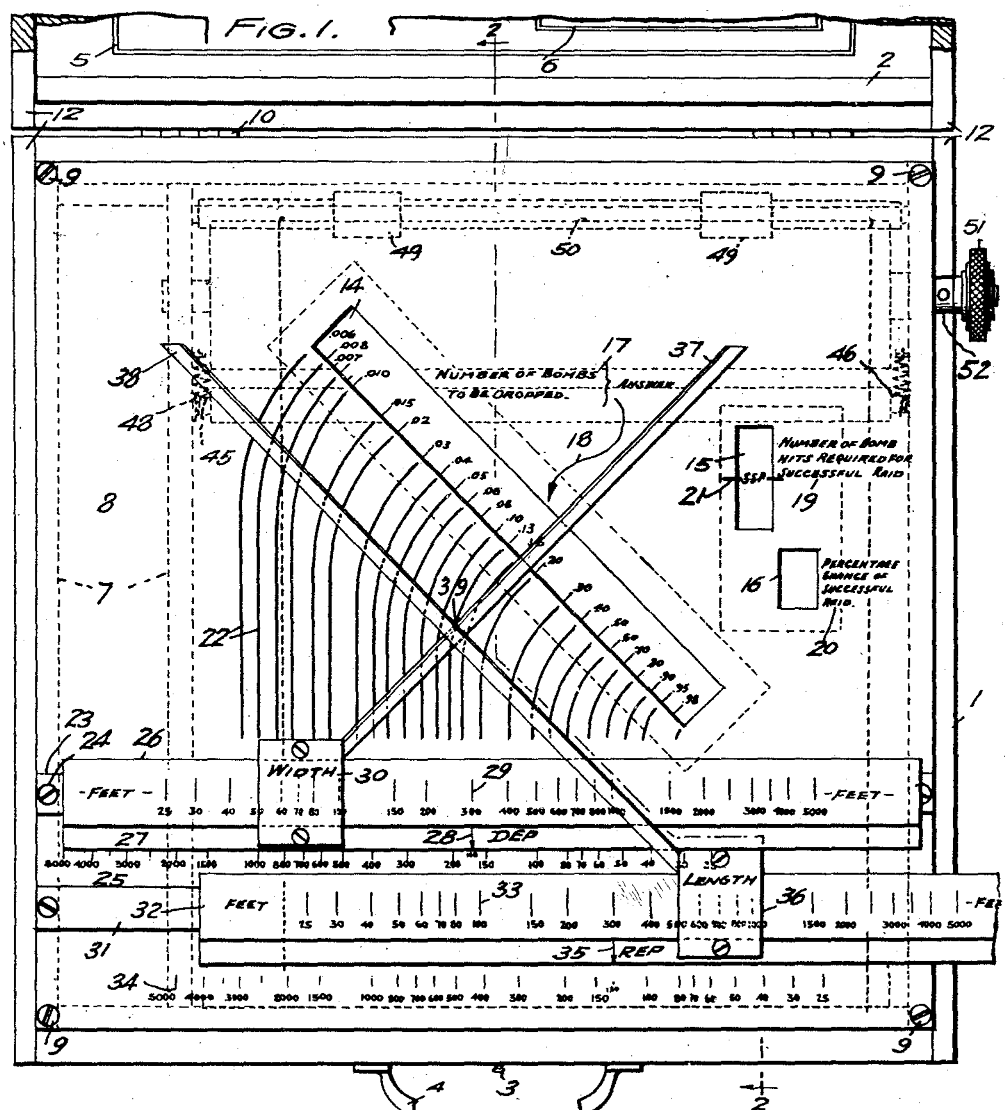
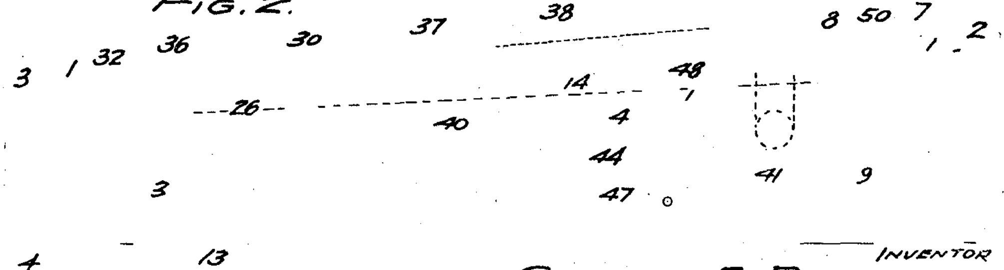


FIG. 2.



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COMPUTER FOR SOLVING BOMBING PROBLEMS

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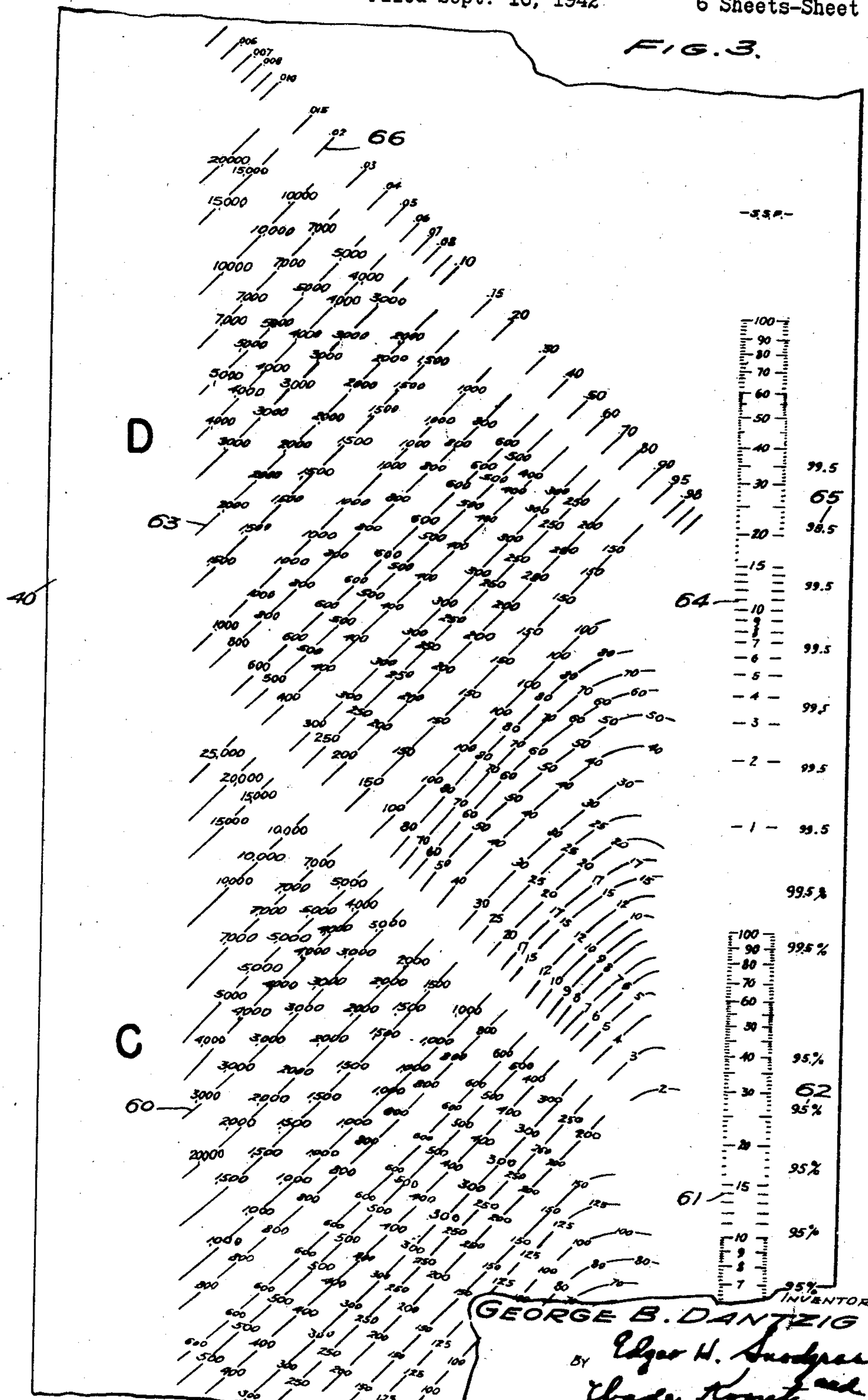
FIG. 3.



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COMPUTER FOR SOLVING BOMBING PROBLEMS

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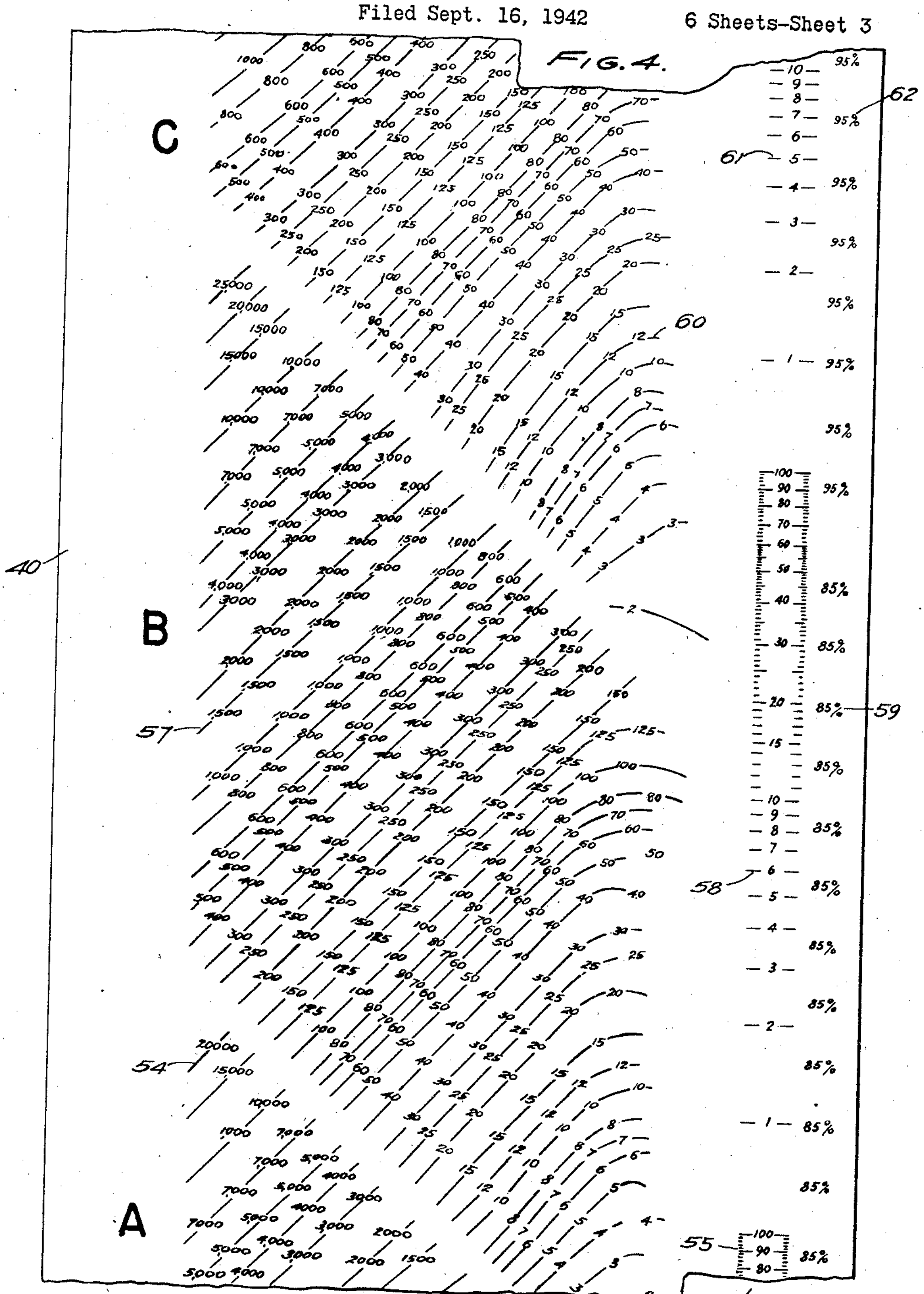

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FIG. 5.

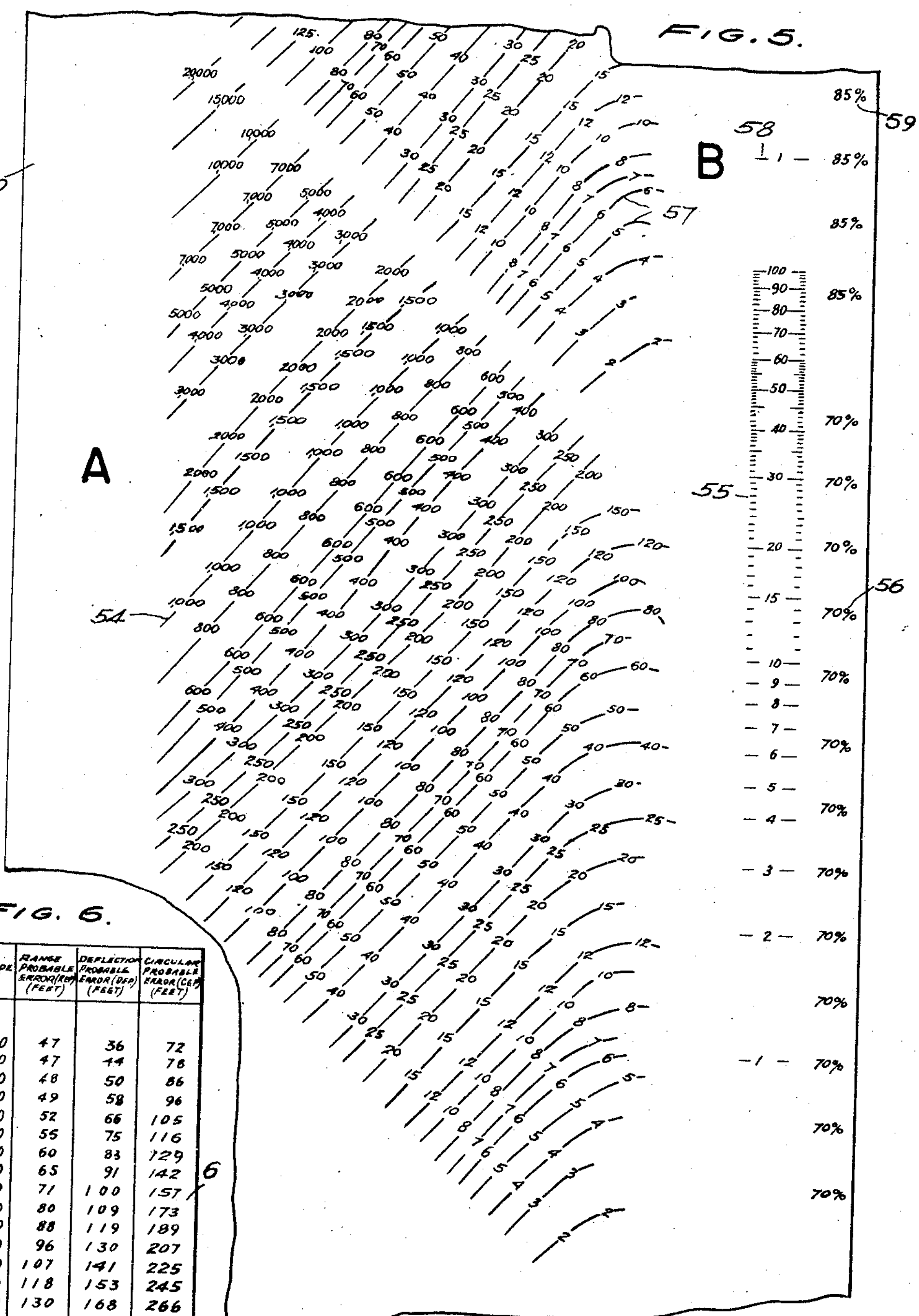

FIG. 6.

ALTITUDE (FEET)	RANGE PROBABLE ERROR (REP) (FEET)	DEFLECTION PROBABLE ERROR (DEP) (FEET)	CIRCULAR PROBABLE ERROR (CEP) (FEET)
1,000	47	36	72
2,000	47	44	78
3,000	48	50	86
4,000	49	58	96
5,000	52	66	105
6,000	55	75	116
7,000	60	83	129
8,000	65	91	142
9,000	71	100	157
10,000	80	109	173
11,000	88	119	189
12,000	96	130	207
13,000	107	141	225
14,000	118	153	245
15,000	130	168	266
16,000	142	182	287
17,000	155	198	311
18,000	170	215	336
19,000	186	233	362
20,000	201	250	392

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COMPUTER FOR SOLVING BOMBING PROBLEMS

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FIG. 7.

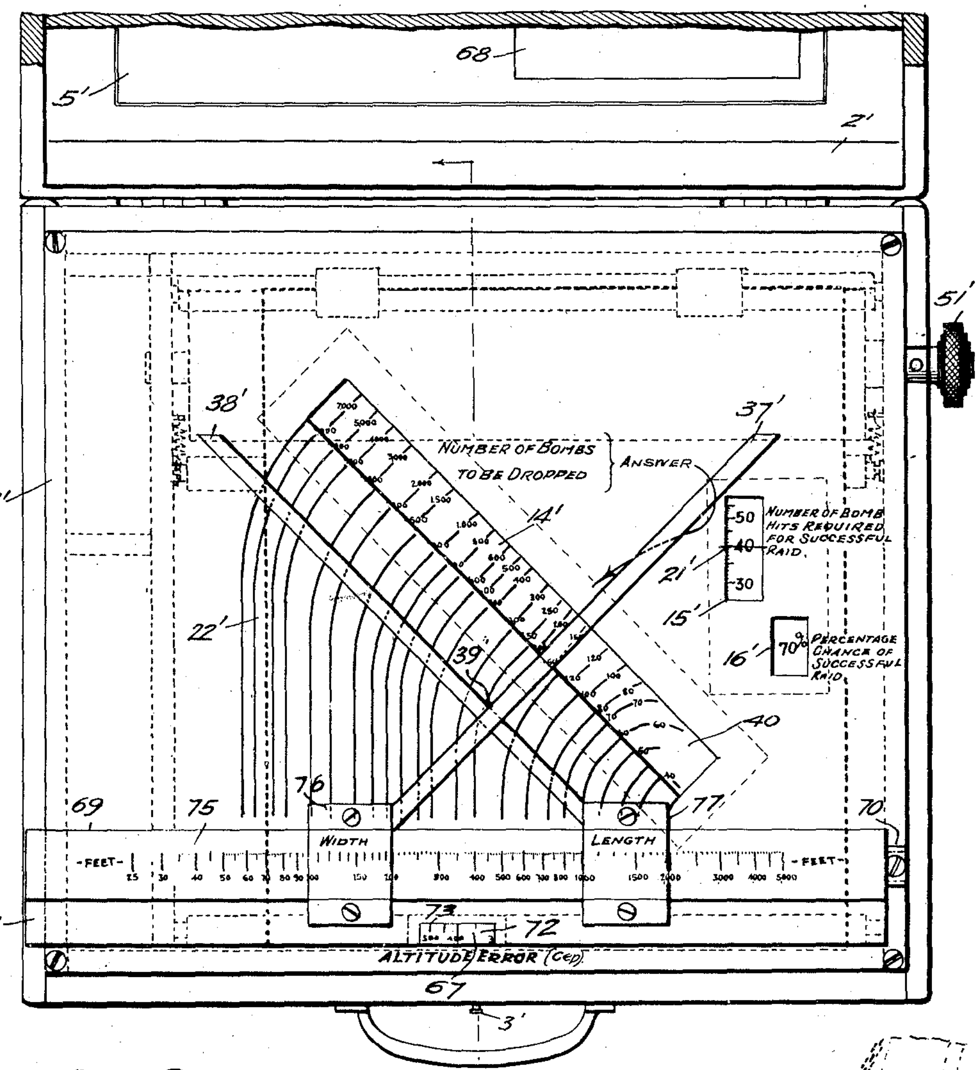
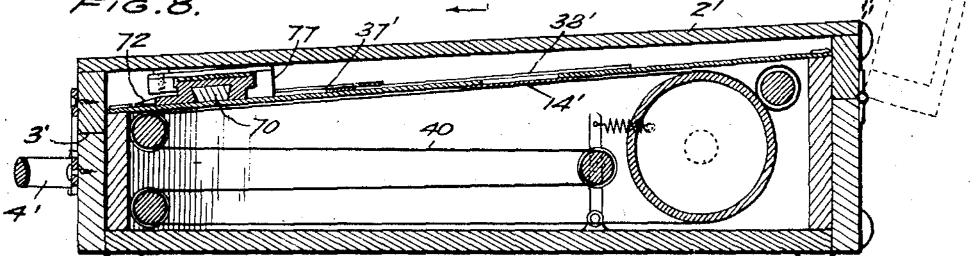


FIG. 8.



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COMPUTER FOR SOLVING BOMBING PROBLEMS

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FIG. 9.

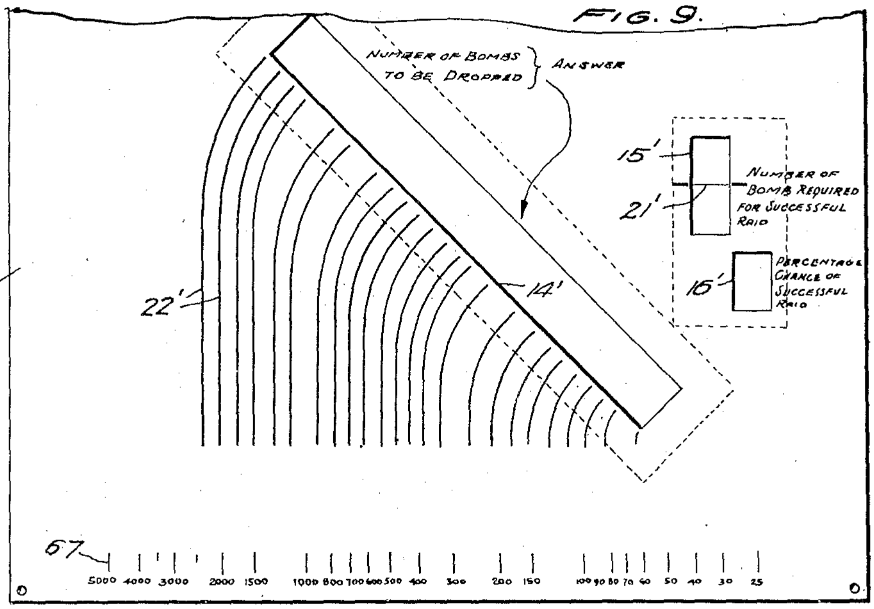

FIG. 11.

ALTITUDE (FEET)	CIRCULAR PROBABLE * ERROR (CEP)
500	
1 000	72
2 000	
3 000	
4 000	
5 000	
6 000	
7 000	
8 000	
9 000	
10 000	173
11 000	
12 000	
13 000	
14 000	
15 000	266
16 000	
17 000	
18 000	
19 000	
20 000	392
20 300	400
25 000	
30 000	

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FIG. 12.

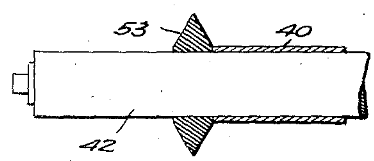
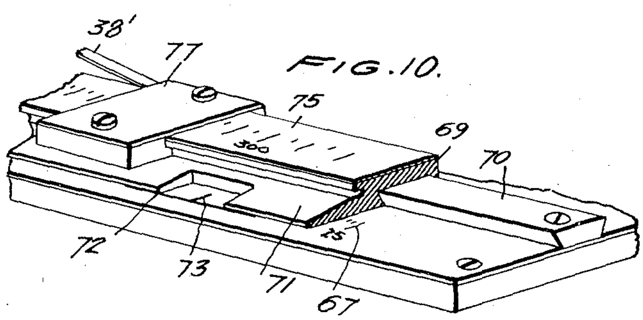


FIG. 10.



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Patented June 10, 1947

2,421,745

UNITED STATES PATENT OFFICE

2,421,745

COMPUTER FOR SOLVING BOMBING PROBLEMS

George B. Dantzig, Arlington, Va.

Application September 16, 1942, Serial No. 458,585

20 Claims. (Cl. 235—86)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

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The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

The invention relates generally to a computer for solving mathematical problems and specifically to a bombardier slip stick or slide-computer for evaluating, by mechanical means, bombing probability formulae for calculating the number of bombs to be dropped under given conditions on a target. It is herein described with reference to its use for solving aviation bombardment problems.

In bombing operations conducted by aircraft, economy of force indicates the dropping of the smallest practicable number of bombs required to provide a certain percentage degree of assurance of securing one hit or a given number of hits on the target. The number of bombs required may, for some conditions, be determined from existing tables, charts and curves of bombing probability values calculated in accordance with the mathematical law of errors. These bombardment probability tables, curves, and charts are available to the bombardment commander (bombardier) through published texts on bombing probabilities but the calculated values cover only a narrow scope of conditions and the practical use thereof for the solution of bomb requirements is limited and involves definite and time-consuming procedure.

The primary object of the invention is to provide a more convenient and rapid means for the solution of bomb requirements. To that end, the data is combined with and arranged on a slide instrument to provide a mechanical bombing probability calculator or computer which (1) is readily operable to give a direct reading of the answer to a given problem and (2) has a greater range of possible values than the tables found in published texts. Two species of the invention are disclosed, the preferred one of which is based on a simplifying assumption that the probable error in range is equal to the probable error in deflection, both of which are expressed in terms of the more convenient circular probable error, as hereinafter explained.

Other objects and advantages of the computer will appear from the following detailed description of the construction and operation of the same, considered with reference to the accompanying drawing of the device, wherein:

Figure 1 is a fragmentary top plan view of one species of the invention;

Figure 2 is a vertical cross section on line 2—2 of Figure 1;

Figures 3 to 5 inclusive are detail views of substantially different sections of the data-bearing tape common to both illustrated species of the invention and collectively showing the arrangement and grouping thereon of the various curves and scales;

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Figure 6 is a detail view of a table of probable errors for use in connection with illustrated solutions;

Figure 7 is a view similar to Figure 1 but showing another and preferred species of the invention;

Figure 8 is a vertical cross section on line 8—8 of Figure 7;

Figures 9 to 11 inclusive are detail views of elements of the particular species of the invention shown more completely in Figure 7, and

Figure 12 is a detail view of a guard-bearing end of one of the tape-supporting cylinders.

The values of bombing probability calculations, together with the formulas for computing probable errors, as applied to the present invention, are herein defined and explained by way of preface to the detailed description of the instrument.

The accuracy of individual bombing units for different altitudes is determined from tables of average errors representative of actual results of dropping a large number of bombs. Each bomb which does not fall on the center of the target has an error in range or in deflection or in both. Range error is defined as the distance from the center of the target to the point of impact, measured in feet parallel to the direction of approach to the target. Deflection error is defined as the distance from the center of the target to the point of impact, measured in feet perpendicular to the direction of approach. The values of range and deflection errors may be combined in the form of a circular error which is the radial distance from the center of the target to the point of impact of the bomb. Average errors in range (Rea), deflection (Dea), or radial distance (Cea) are equal to the arithmetic sum of the error in range, deflection, or radial distance, respectively divided by the number of bombs dropped. In determining average errors, the actual errors in feet is desired without regard to "overs" and "shorts" or "rights" and "lefts." For example assume a total number of six bombs to be dropped from a given altitude. The point of impact of each bomb is carefully plotted and the distance in feet from the point of impact to the center of the target in the direction of approach (range error) and perpendicular to the direction of approach (deflection error) is recorded. Assume, also, that the recorded arithmetic sum of the range errors of the individual bomb impact points totals 540 feet. Then, this sum divided by 6 (number of bombs dropped) equals 90 feet which represents the range arithmetic mean or average error (Rea). In similar manner, the arithmetic mean or average deflection error (Dea) and the arithmetic mean or average circular error (Cea) are determined. From recorded average errors for different altitudes, tables of probable errors for those altitudes are prepared. Since various bombing units have different accuracies and since the accuracy of bombing is less at higher altitudes, the computed probable error may differ from one unit to the next. These tables give the general precision at various altitudes in terms of Range probable error (Rep) and Deflection probable error (Dep) and Circular probable error (Cep). A specimen table of probable errors is shown in Figure 6. In reading the table, the indicated Cep accuracy for a given altitude is interpreted in terms of the radial dimensions of the circular area or target upon which will fall half of the number of bombs dropped. For example, the Cep accuracy of 173 feet at 10,000 feet altitude means that on the average half the number of bombs dropped at that altitude will fall in a circular target of 173 feet radius and half will miss the target.

The formulas for computing probable error are:

(1) Range probable error (Rep) = 0.845 Rea

(2) Deflection probable error (Dep) = 0.845 Dea

(3) Circular probable error (Cep) = 0.939 Cea

(4) $Cep = 1.746\sqrt{Rep \times Dep}$ (where Rep = Dep)

Probable error is defined as that error or deviation which is as likely to be exceeded as not. In other words, a probable error of an indicated value, for example—72 feet, does not mean that 72 feet is the most probable value of the error, either in range or deflection, but simply that there is a 50–50 chance or probability that the error of 72 feet may or may not be exceeded. The probable errors (Rep-Dep-Cep) for a given altitude are used in connection with the target dimensions to determine the vulnerability factor for that target and the given altitude. The formulas for computing the vulnerability factors are as follows:

(5) Range vulnerability factor

$$(RVF) = \frac{\frac{1}{2}RDT \text{ (allowable error)}}{Rep \text{ (probable error)}}$$

(6) Deflection vulnerability factor

$$(DVF) = \frac{\frac{1}{2}DDT \text{ (allowable error)}}{Dep \text{ (probable error)}}$$

in which RDT represents the length or range dimension of the target and DDT represents the width or deflection dimension of the target. The distance from the center of a given target to the edge thereof represents the largest allowable error that can be made in bombing the target and still obtain a hit thereon. The allowable error applies to both range and deflection and is equal to one-half the dimensions of the target in range or deflection.

The vulnerability factors, sometimes referred to as probability factors, are used to determine the single shot probability (SSP) for the given altitude, probable error and target dimensions. Each vulnerability factor has a calculated percentage value representing the probability of a hit with a single bomb dropped on a target of the dimensions used in determining the vulnerability factor and under conditions for which the average error, measuring the efficiency and effectiveness of the particular bombing team or unit, is applicable. For example, if RVF=1, it means that there is a 50% probability of a hit. A hit by a single shot requires the concurrence of two events, i. e., a hit in range and a hit in deflection. Hence, when using rectangular errors (range and deflection errors) separate probabilities must be found for a hit with respect to both range (RSSP) and deflection (DSSP). The product of the range single shot probability (RSSP) and the deflection single shot probability (DSSP) gives the probability of both events occurring with a single bomb and, hence, the combined single shot probability (SSP) of a hit on the target. The values of the single shot probabilities have been calculated and are readily determined from tables and curves of vulnerability factors and probabilities published in well known ordnance texts. Example of such tables are shown on page 471, Chapter 15, of "Ordnance and Gunnery" by Earl M. McFarland. The single shot probability (SSP) is the basis upon which calculations may be made to determine the number of bombs required to provide a certain percentage degree of assurance of securing a given number of hits on the target. The results of some bombing probability calculations covering different percentage values of single shot probability and assurances of success for one or more hits are shown in tables and charts in standard text books on ordnance and the principles and methods governing the plotting thereof are well understood. The curves and tables described in connection with the instant invention are in accordance with these well known principles but are of wider scope and cover a greater combination of events than the published charts and tables.

As shown in Figures 1 to 6 inclusive, illustrating one form of the invention, the instrument is cased within a receptacle or box **1** having a hinged cover **2** and cover-latching means **3** as well as a handle **4** for conveniently carrying the case. Upon the inner surface of the hinged cover is suitably affixed a sheet **5** preferably containing a table **6** of probable errors, such as shown in Figure 6. The table may be accompanied by printed instructions for the use of the instrument. Within and fixedly secured to the receptacle **1** and extending upwardly and slightly above the same is the body of the instrument which includes a framework **7** upon the top of which is mounted and supported a flat face plate **8**. The face plate is attached by screws **9** or other suitable fasteners to the framework and together with the latter, completely covers the interior opening of the receptacle. The depth of the frame work and the receptacle is greater at the back or hinge-bearing end **10** of the case than at the front or handle-bearing end **11**. Hence, the face plate and the mutually contacting edges **12** of the box and cover are disposed in parallel planes slightly inclined to the horizontal when the device is resting on its bottom or base **13**, as depicted in Figure 2 of the accompanying drawings. This inclination of the face plate facilitates the viewing of data and the manipulation of the movable parts associated therewith, as hereinafter described, and provides also compactness and reduction in the overall dimensions of the case.

The face plate is provided with a long narrow window **14** extending diagonally across its central portion and a pair of relatively smaller windows **15** and **16** to the right of the diagonal window and elongated in a direction parallel to the side edges of the face plate, as shown in Figure 1. Adjacent the diagonal window is a legend **17** and an arrow mark **18** indicating that the answer as to the number of bombs to be dropped for a given condition will be found from data exposed through the window. Similarly, appropriate legends **19** and **20** adjacent the smaller windows **15** and **16** indicate that other interdependent data, such as the number of bomb hits required for a successful raid and the percentage chance of a successful raid are to be viewed therethrough. The larger of the two small windows is provided with a hairline or an index mark 21. A series of guide curves 22 of "equiprobability" extend from the lower longitudinal edge of the diagonal window to points in a line adjacent and parallel to the top edge of a guide rail 23 fastened, as at 24, to the face plate 8 inwardly of and in parallelism with the bottom edge of the plate. Provided on the face plate in spaced relation to the lower edge of the guide rail 23 and fixed in parallelism therewith is an altitude error scale 25 in which the values of deflection probable errors (Dep) in feet corresponding to a given range of altitudes is expressed logarithmically. Dove-tailed with the guide rail 23 and adjustable lengthwise thereof is a slide 26 having a lateral extension 27 bordering the scale 25. The extension is provided with an arrow 28 or other index mark for setting the slide to a given graduation on the scale. The slide 26 caries a scale of allowable errors in deflection, in feet, expressed logarithmically. The allowable error in deflection is equal to one-half the deflection dimension or width of the target. For convenience, however, the scale reads directly in width dimensions of target which are twice the allowable error in deflection. This scale is shown at 29 and is designated hereinafter as the target deflection scale. Each of the scales 25 and 29, as laid off, covers a range from twenty-five (25) to five thousand (5000) feet and they are exactly the same except that scale 29 is laid off from left to right whereas scale 25 is laid off from right to left. Suitably engaged with the slide 26 and adjustable longitudinally thereof is a runner 30 marked "width." Fastened to the face plate in parallelism with the guide rail 23 but appropriately spaced below the latter is another guide rail 31 on which is mounted an adjustable slide 32. Slide 32 is provided with an allowable error scale 33, corresponding to the scale 29, but which reads directly in range dimensions of the target. The fixed altitude error scale 34, to which the slide 32 is set by means of the arrow 35, corresponding to the scale 25 but is offset relative to the latter and reads in values of range probable errors (Rep). Adjustable on slide 32 is a runner 36 marked "length." Runner 30 is adapted to be set relative to the target deflection scale 29 in accordance with the width dimension of a given target and runner 36 is adapted to be set relative to the target range scale 33 in accordance with the range dimension of the target. In any required setting of the runners on their respective slides, the right hand edge of runner 30 and the left hand edge of runner 36 (Figure 1) should be aligned with or over the scale graduation corresponding to the given target dimension. Extending from the upper right hand corner of runner 30 and fixed rigidly thereto is a long narrow arm 37. A similar arm 38 extends from the upper left hand corner of the runner 36. These arms extend at right angles of forty-five (45) and one hundred and thirty-five (135) degrees respectively, as measured in an anti-clockwise direction from the upper longitudinal edges of the respective slides. They cross each other at right angles and serve as coordinates establishing at their intersection a reference point 39 over the portion of the face plate on which are located the guide curves 22; the position of the point relative to the face plate being determined by the setting of the runners and changing as the spacing between the

runners is varied. The arms 37 and 38, as well as the top panels of the runners 30 and 36, preferably are of suitable transparent material so that the scales 29 and 33 and the guide curves 22 are not obscured.

Each arrangement of altitude error scale, slide, and runner corresponds essentially to an ordinary logarithmic slide rule with a reciprocal scale to facilitate division; the two divisions (Formulas 5 and 6) being carried out on the separate slide rules. When the slides are set to given Rep and Dep errors and the runners are set to given target dimensions, the positions of the arms relative to the face plate determine the values of the range and deflection vulnerability factors which may be translated directly into percentage values representing the probabilities of hitting the target in range and deflection. Arm 37 may be considered, therefore, as representing the deflection single shot probability (DSSP) and arm 38 as representing the range single shot probability (RSSP). For every setting of the slides and runners, the arms intersect and determine a point on the face plate to which is assigned a single percentage value which is the product of the separate probability values represented by the arms. This single percentage value represents the probability of hitting the target with a single shot (SSP). Points on the face plate of equi-probability, that is, having the same SSP value, are connected by a guide curve 22. Therefore, each one of the various guide curves 22 represents a constant value of single shot probability and the SSP value of each guide curve is found by the exposure of appropriate data through the diagonal window 14 as hereinafter explained.

The data to be exposed through the various windows of the face plate are provided on an endless tape 40 housed within the framework 7 between the bottom of the box 1 and the face plate 8 as shown in Figure 2. The tape is supported by and travels over a plurality of guide rolls or cylinders located within the framework and including a main cylinder 41 at the back of the framework, a pair of vertically spaced auxiliary cylinders 42 and 43 at the front of the framework, and a tape-tautening cylinder 44 immediately in front of the main cylinder. The main and auxiliary cylinders are journaled in side members of the framework 7 but the tape-tautening cylinder is supported by and journaled between a pair of upstanding members 45 and 46. These support members have their lower ends respectively pivoted, as at 47 to the bottom of the case for movement about a common axis extending transversely to the direction of travel of the tape and are resiliently connected at their respective upper ends, by springs 48 to the sides of the framework. The springs are tensioned to exert a pull on the support members constantly tending to displace the tape-tautening cylinder 44 in the direction and with a magnitude required to take up any slack in the tape. The tape is held tightly to the main cylinder by lock rolls 49 on shaft 50 and is moved when the main cylinder 41 is turned by means of the hand knob 51 on the extended right end of the cylinder stub shaft 52. Displacement of the tape laterally of the supporting cylinders is prevented, without binding, by cone-shaped guards 53 mounted on the cylinders adjacent the edges of the tape, as shown in Figures 2 and 12.

The data carried by the tape 40 comprises a plurality of curves and scales based on bombing probability calculations. These are arranged in separate groups or charts covering different given conditions throughout a range of broad or limited scope, as may be found expedient. In the instant case, four groups or charts of such curves and scales, are provided on the tape and are marked D, C, B and A, as shown collectively in Figures 3, 4 and 5. These charts correspond to representative chance levels for success of 99.5, 95, 85, and 70 percent, respectively. Each chart comprises a set of curves in which each curve indicates a number of bombs; a non-uniform scale in which each graduation indicates a number of bomb hits; and a series of similar markings indicating the particular percentage degree of assurance of success upon which the curves and scales of the particular chart are based. Chart A comprises the set of bomb-indicating curves **54**, the bomb hit scale **55**, and the percentage markings **56**. Chart B comprises the bomb-indicating curves **57**, bomb-hit scale **58**, and percentage markings **59**. Chart C comprises the bomb-indicating curves **60**, bomb-hit scale **61** and percentage markings **62**. Chart D comprises the bomb-indicating curves **63**, bomb-hit scale **64**, and percentage markings **65**. These charts are arranged one behind another on and in the lengthwise direction of the tape in the natural sequence of their respective indicated percentage values. A set of curves **66** for evaluating the guide curves **22**, and obtaining thereby the different values of single shot probability, is located on the tape between the first and last charts A and D and is coordinated with the marking SSP on the tape, as shown in Figure 3. The curves **54**, **57**, **60**, **63**, and **66** extend diagonally across the tape in the opposite sense to the diagonal window **14** of the face plate **8** and are positioned on the tape to be exposed through the window **14** at a given setting of the tape. The bomb-hit scales **55**, **58**, **61**, and **64**, and the SSP marking, are arranged in a column lengthwise of the tape and to the right of the curves in position to be exposed through the window **15**. The percentage markings **56**, **59**, **62**, and **65** are similarly arranged on the tape for exposure through the face plate window **16**.

The curves and scales of the respective charts A, B, C and D cover a comparatively large number of bombs and bomb-hits, ranging in the former from one to at least twenty thousand bombs (1–20,000) and in the latter from one to one hundred bomb hits (1–100). The values of the single shot probabilities represented by the curves **66** range from one-half percent to ninety-nine and one-half percent. The curves (bombs) of each chart are distinguishably marked to designate the number of bombs individually represented thereby and are coordinated with the corresponding non-uniform scale (for the bomb hits required) of the chart. This coordination is accomplished in the process of laying out the various charts as will be clear from the following explanation of the manner of laying out chart A. The tape is moved relative to the face plate and its position thereto for the solution of bomb requirements is determined by means of a scale, such as shown at **55**, on the tape and the hairline indicator **21** on the face plate: the scale can be non-uniform and arbitrary. The surface of the tape is viewed through the diagonal window at the upper end of the guide curves **22**. For every combination of guide curve (or SSP) and position of the tape (or graduation of scale **55**) there corresponds a point on the surface of the tape which is directly at or below the upper end of the guide curve. To this point is assigned a numerical value which is a function of the SSP as represented by the guide curve, and the number of bomb hits as represented by the scale graduation determining the position of the tape; this numerical value represents the number of bombs to be dropped to obtain the desired number of hits in accordance with the percentage degree of success on which the scale is based. On the surface of the tape, a curve **54** is empirically drawn where the numerical values are constant. By selection of several fixed values of number of bombs required, the various curves **54** are drawn. Each curve is marked at spaced points along its length with a value indicative of the number of bombs represented by the curve so that it can be evaluated.

The spacing of the graduations of the scale **55** governs the formation of the curves **54** and in the process of laying out the chart the spacing of the scale graduations is empirically varied until the curves **54** of the tape are approximately straight lines parallel to each other and at right angle to the long lower edge of the diagonal window **14** so as to achieve ease in reading the answer. When the tape moves relative to the face plate, the positions of the curves **54** along the lower edge of the diagonal window change and each change in position of the curves **54** gives rise to different evaluations of the guide curves **22** in terms of the number of bombs to be dropped for given conditions. When the tape is moved relatively to the face plate for evaluation of the guide curves **22** in terms of single shot probability (SSP), its position is determined by means of the SSP marking on the tape and the hairline indicator **21** on the face plate. Evaluation of the guide curves **22** in terms of single shot probability is given by the curves **66** on the tape. These curves **66** are drawn and coordinated with the SSP marking so as to be exposed at the diagonal window **14** substantially as straight line continuations of the guide curves **22** when the SSP marking is opposite the hairline indicator **21**. The value of SSP represented by each of the curves **66** is indicated at one end of the curve.

As an illustrative example of a problem confronting a bombardment commander, let it be assumed that the commander of a bombing unit is given an order to neutralize a certain objective—a factory, for instance. His problem is to determine the number of bombs to be dropped on this target to attain a reasonable chance of destroying or neutralizing the same without dropping more than a necessary number of bombs. In order to do this, he must know, among other things, the size of the target; the accuracy of his bombing unit; the minimum altitude of bombing that may be considered in operating against this particular target (often very high because of enemy antiaircraft fire), and the number of actual hits necessary to reduce the target. Since there is, also, an element of chance that every aimed bomb will miss the target and that the mission will be unsuccessful and will not carry out the required number of hits, he must determine what percentage chance of success of accomplishing the mission is a reasonable chance in view of the urgency of the situation or other tactical considerations. The highest chance of success is set usually at 99.5% (i. e. only 5 raids out of 1000 will fail) since absolute certainty of success would require an impossible number (theoretically infinite) of bombs to be dropped.

The minimum chance of success is set usually at 70% (i. e. 7 out of 10 raids would get the required number of hits) because experience indicates that this is the lowest value usually acceptable on and justifying a bombing mission against targets which, though important, offer no immediate menace and the destruction of which is not urgent. The target dimensions, size of bombs, required number of bomb hits, and other specific information of his targets required by the bombardment commander are obtained from an "objective folder" which is a file or booklet of information concerning the targets and collected by observation aviation and the various intelligence agencies; such information being compiled and arranged for the use of the commander in planning a bombing mission. The decisions as to the minimum altitude from which to bomb and the percentage degree of success to be attained are tactical and are made in accordance with the judgment of the commander. The accuracy of his bombing unit for the conditions given are obtained from table 6. The number of bombs to be dropped ordinarily is computed directly from or by interpolation of bombardment tables or curves. Such computation is avoided by the use of the present invention in solving the problem as will be apparent from the succeeding explanation of its use and operation.

For some conditions of bombing it may be desirable to know the number of individually sighted and released bombs which should be dropped on a given target to give the required degree of assurance of at least one hit. In such a case, it is necessary first to determine the single shot probability which is applicable to the given factors of the problem. For example, assume the values of the given factors to be: target dimensions—500 feet by 100 feet; altitude—15,000 feet; required percentage degree of obtaining at least one hit—70%. It is required to find (a) the single shot probability (SSP) and (b) the number of bombs to be dropped. The particular setting of the instrument which solves this problem is shown in Figure 1 and is obtained by the following procedure: The runner **30** is set over **100** on the deflection dimension scale **29** and runner **36** is set over 500 on the range dimension scale **33**, the longer of the two given target dimensions being taken as the length. From the table **6**, the probable errors in range (Rep) and in deflection (Dep) corresponding to the given altitude of 15,000 feet are found to be 130 feet and 168 feet respectively. The slides **26** and **32**, with the runners **30** and **36** set thereon, as just described, are positioned so that the index arrow **28** is centered over **168** on the Dep scale **25** and the index arrow **35** is centered over 130 on the Rep scale **34**. The knob **51** is turned to move the tape until the marking SSP (single shot probability) on the tape is centered beneath the hairline **21** of the window **15**. As a result of this movement of the tape and the arrangement of the scales and curves thereon, the curves **66** for the different values of single shot probability (SSP) are exposed through the diagonal window **14** but no data will show in the percentage window **16**.

From this setting of the instrument, the percentage chance of a single bomb hitting the target is found by noting the position of the reference point **39** relative to the guide curves **22**, particularly with reference to its distance or spacing from the nearest guide curve within the upper angle of the crossed arms **37** and **38**, and at the same distance following the curve, by eye, to the bottom edge of the diagonal window **14**.

The reference point **39** represents the product of the range single single shot probability (RSSP) and the deflection single shot probability (DSSP) and the value of this product (which gives the percentage chance of hitting the target with a single bomb, abbreviated SSP) is obtained from curves **66** by following the guide curve **22** nearest to the reference point. The answer is found to be a single shot probability (SSP) of 0.13 percent. Having thus determined the percentage chance or probability of hitting the target with a single bomb in one trial, the same is used as a basis for further determining the number of trials necessary (bombs dropped) to secure a desired percent chance, from 1% to 100%, of hitting the target with at least one bomb. In current practice, tables based on the desired degree of certainty may be entered with the known or calculated value of single shot probability to secure opposite it the required number of bombs to be dropped to attain the result sought. With the herein described instrument, however, it is required only to turn the knob **51** until the number 1 of scale **55** on chart A of the tape is centered in window **15** with the required percentage number (70%) showing in window **16**. The movement of the tape occasioned by the turning of the knob results in the displacement of the SSP curves **66** from the diagonal window and the substitution therefor of the bomb curves **54** of chart A. The number of bombs to be dropped with the required percentage degree of chance of getting at least one hit, based on the single shot probability of 0.13 percent, would be read off the bomb curves in the diagonal window by following the procedure previously explained and described in connection with reading the SSP.

The values of Rep and Dep are theoretically needed in planning attacks against most targets, especially rectangular ones, as long as the range and deflection errors are unequal. However, determination of single shot probability is quicker and easier using Cep values and such use is justified when range and deflection errors are substantially equal. Now, if the values of Rep and Dep are expressed in terms of circular probable error (Cep) in accordance with the Formula 4, then Rep and Dep can be represented by a single value and the evaluation of the formulae by mechanical means is simplified. Reverting to Formula 4 and assuming Rep and Dep to be equal, it is obvious that Rep equals Cep divided by 1.746. Also that Dep equals Cep divided by 1.746. The constant 1.746 is a conversion factor derived as an integral part of relationship between range, deflection, and circular probable error by mathematical calculations. Hence, Formulas 5 and 6 may be restated in the following forms:

$$\text{(7)} \qquad RVF=\frac{\frac{1}{2}RDT}{Rep}=\frac{\frac{1}{2}RDT}{Cep\div 1.746}$$

$$\text{(8)} \qquad DVF=\frac{\frac{1}{2}DDT}{Dep}=\frac{\frac{1}{2}DDT}{Cep\div 1.746}$$

It is an empirical fact that the value obtained, by dividing the Cep for a given altitude by 1.746, lies between the true values of Rep and Dep for the same altitude and that this "average" value can be used to represent both the range probable error and the deflection probable error. The range probable error, as represented by this "average" value, will be larger than the true Rep but the represented deflection probable error, on the other hand, will be less than the true Dep. The two discrepancies therefore compensate each other and, as a result, the value of single shot probability determined by using this "average" value is substantially the same as the value of single shot probability determined by using the true values of Rep and Dep. This may be shown in connection with the problem illustrated in Figure 1. As therein depicted, the Dep slide 26 is set to 168 on the Dep scale 25 and the Rep slide 33 is set to 130 on the Rep scale 34. As shown in table 6, the corresponding Cep is 266. If the value of the single shot probability were to be determined by using only the Cep, the settings of the Dep slide and the Rep slide on their respective scales would have to be identical, that is, have a common value (Dep=Rep). This common value is obtained by dividing 266 by 1.746 (Formulas 7 and 8) and is found to be 152. This common or "average" value (152) is larger than 130 (Rep) but less than 168 (Dep). If the range and deflection slides of the instrument were set to 152 instead of to 130 and 168 respectively, the guide curve 22, on which the reference point 39 would fall in this setting, would be the same curve upon which it was positioned in the setting shown in Figure 1. As seen, this curve has an SSP value of 0.13 percent.

Formulas 7 and 8 are preferred over Formulas 5 and 6 because in the former the denominators are equal and are expressed in terms of circular probable error. Also, the numerator of Formula 7 is greater than that of Formula 8. Hence, the two divisions can be carried out simultaneously on one ordinary reciprocal slide rule with a single setting for the denominators and the use of two runners or indicators on one slide to give separate readings for the numerators. It is upon the empirical fact herein explained, and the advantages flowing therefrom, that the preferred form of the invention, shown in Figures 7 to 11, inclusive, is based as hereinbefore stated. Since Formulas 7 and 8 require only values of Cep and not Rep or Dep values, a single table converting altitude into Cep values is all that is needed when using the instrument, in its preferred form, to determine the range and deflection vulnerability factors. A specimen table of altitude versus circular probable error values, intended for use with the instrument, is shown in Figure 11. Only a few representative values of circular probable error corresponding to given altitudes are shown but it is to be understood that all blank spaces are to be filled in for convenient reference by the bombardment commander; the inserted values depending of course on the rated accuracy or bombing ability of his unit for the indicated altitudes.

As is apparent from a comparison of Figures 1 and 7 of the drawings, both forms of the instrument are substantially alike in respect to their various parts and general constructional features; the preferred form being distinctive in respect to the number and arrangement of slide rule parts. Referring to Figure 9, the face plate 8 is provided with a single scale 67 in which the Rep and Dep for a given range of altitudes are represented, in feet, logarithmically and by "average" values (Cep—1.746 Formulas 7 and 8). For convenience the scale reads directly in terms of Cep errors corresponding to the "average" values. This permits the instrument to be set directly to the Cep values given in the table 68, shown in Figure 11. Scale 67 is, therefore, designated the altitude error or Cep scale and it constitutes the fixed part of a slide rule; the movable part of which, as shown in Figure 10, is a slide 69 dove-tailed with and slidably adjustable on the guide rail 70, which is fastened to the face plate inwardly of and in parallelism with the Cep scale 67. An extension 71 on the slide normally overlies the Cep scale and is provided with a window 72 having a hairline 73 for guidance in setting the slide to a given Cep value on the scale 67. The slide is provided on its upper surface with a scale 75, in feet, of allowable errors in range and deflection expressed logarithmically. For convenience, scale 75 reads directly in dimensions of the target which are twice the allowable error in range or deflection and is thereinafter designated the target dimension scale. The Cep scale 67 and the target dimension scale 75 are exactly the same except that the former is laid off from right to left and the latter from left to right. Each scale covers a range from twenty-five (25) to five thousand (5000) feet. Suitably engaged with the slide 69 for independent adjustment longitudinally thereof are two runners 76 and 77 marked "width" and "length" respectively. The former is adapted to be set relative to the target dimension scale 75 in accordance with the given width dimension of a target and the latter in accordance with the given length dimension; the inner vertical edge of each runner being used as the setting-guide or index. These runners are similar in construction to the runners 30 and 36 of Figure 1 and in like manner the arms 37′ and 38′ cross each other and serves as coordinates establishing at their intersection a reference point 39′ over the portion of the face plate bearing the guide curves 22′. The arrangement of scale 67, slide 69, and runners 76 and 77 corresponds essentially to an ordinary slide rule with a reciprocal scale to facilitate division and the operation thereof is the same as in the form of instrument first described: a chief feature of distinction being that in the preferred form of instrument the two divisions (Formulas 7 and 8) are carried out simultaneously on the same slide, made possible because of the equality of denominators.

For example, assume the values of the given factors of a problem to be solved are as follows: target dimensions—1000 feet by 200 feet; altitude 20,300 feet; number of bomb hits required—40; chance of successful raid—70%. It is required to find the number of bombs to be dropped. The setting of the instrument which solves the problem is shown in Figure 7 and is obtained in the following manner. Runners 76 and 77 are set over 200 and 1000 respectively on the target dimension scale 75; the longer dimension being taken as the length. Slide 69 is then positioned so that the hairline 73 of the window 72 is centered over 400 on the Cep scale 67; this number representing the Cep corresponding to the given altitude as taken from table 68. Tape 40 is then moved relative to the face plate 8′ by turning the knob 51′ until the number 40 is centered under the hairline 21′ of window 15′ with the number 70% showing at window 16′. The number of bombs to be dropped is found by following the guide curve 22′ nearest to the reference point 39′ as in previous examples. The answer, 215 bombs, is read off the set of curves 54 (chart A), appearing in the diagonal window 14′, by interpolation. When the guide curves 22′ are to be evaluated in terms of single short probability, the knob 51′ is turned until the marking SSP on the tape is centered beneath the hairline 21′ of window 15′, at which time the curves 66 will be exposed through the diagonal window.

From the foregoing description, the many advantages of the instrument are apparent. The device is compact and durable without involving complicated structure and the calculations there included cover a broad scope of conditions. The numbers set in are all visible and easily checked and only a few seconds are required to work out a given problem. The instrument is advantageous not only for everyday use in the field but also as a valuable adjunct to training and as a gauge of proficiency. The use of the instrument, by visibly presenting results as the measure of the bombing accuracy of a particular bombing team or unit, emphasizes and drives home the importance of improving the accuracy so that a small bombing force can do the work of a large force.

It is obvious, also, that the invention is not restricted to the exact construction and use hereinbefore set forth but is adapted for general use as a computer. It is understood, therefore, that omissions, substitutions and alterations in the form and details of the instrument may be made within the scope of the appended claims and without departing from the spirit of the invention.

Having thus described the invention, I claim:

1. A computer comprising a pair of superposed relatively movable members, one of said members having thereon an index mark and also a row of value-representing characters, the latter extending transversely with respect to the direction of relative movement of the members, and the other of said members having two separate groups of value-indicating characters arranged thereon so that during relative movement of the members the characters of one group align successively with the said index mark while the characters of the other group register with the said row of value-representing characters, the characters of the said one group being arranged in a single column extending in parallelism with the direction of relative movement of the members and the characters of the said other group being arranged in several approximately straight lines parallel to each other and obliquely disposed with respect to the direction of relative movement of the members, each line including only characters of a constant value which is a function of the values of a given value-representing character on the index-carrying member and a selected value-indicating character of the column on the other member when the said selected character is aligned with the said index mark.

2. A computer having in combination a pair of superposed relatively movable members, one member having a series of value-indicating characters and a set of evaluated curves and the other member having a fixed mark and a narrow elongated window extending transversely with respect to the direction of relative movement of the said members, said other member having markings representing a scale of numerical values along an edge of the said window, the said characters and curves of the one member being arranged relative to the said mark and window so that during relative movement of the members characters successively register with the said mark while at the same time the curves travel past the window as approximately straight lines parallel to but obliquely disposed with respect to the direction of relative movement of the members whereby the point of intersection of each line with the window scale markings is continuously displaced along the said markings, each line representing a constant value which is a function of a given numerical value of the particular window scale marking intersected thereby and a given value of the value-indicating character in registry with the said mark in a predetermined relative position of the said members.

3. A computer comprising a member having a set of curves, a slide rule mounted on the member and comprising two scale-bearing units disposed for relative sliding movement against each other in parallelism with and adjacent the axis of abscissas of the curves, one of said scale-bearing units being fixed against movement in parallelism with the said axis and the other scale-bearing unit being free to be so moved, a pair of runners on the said other scale-bearing unit, and an index member carried by each runner and extending angularly therefrom and over the curves and across the index member of the other runner to establish at their intersection over the curves a reference point.

4. A computer comprising a body having a scale and a series of evaluated curves, a slider movable relative to the body and carrying a scale, and a pair of runners on the body and slidably and separately settable to given positions relative to the scale on the slider, each runner having an arm extending angularly therefrom and over the said curves, said arms crossing each other to establish at their intersection over the curves a reference point, the evaluation of which is dependent upon and varies with its position over the curves as determined by the relative settings of the scales and runners.

5. A computer comprising a body having a scale and a series of curves, a slider movable relative to the body and carrying a scale, a pair of runners on the body and slidably and separately settable to given positions relative to the scale on the slider, each runner having an arm extending angularly therefrom and over the said curves, said arms crossing each other to establish at their intersection over the curves a reference point, the evaluation of which is dependent upon and varies with its position over the curves as determined by the relative settings of the scales and runners, a member mounted on the body and slidably movable to various predetermined positions relative to the said curves, said member having a plurality of value-indicating characters arranged thereon to give different evaluations of the curves in the various positions of the member, and cooperative indicia on the said body and member for setting the latter to any predetermined position.

6. A computer comprising a set of curves, a pair of logarithmic scales arranged in parallelism with the axis of abscissas of the curves for sliding movement against each other, one of the scales being fixed relatively to the curves and having values which are reciprocals of the values on the other scale and said other scale being movable relatively to the curves, a pair of slidable runners on the movable scale, separate arms fixed respectively to the runners and extending over the curves, said arms crossing each other and serving as coordinates establishing at their intersection a reference point having a value dependent upon its position over the curves, and means associated with each curve for indicating the value represented thereby.

7. A computer comprising a member having a set of curves representing various values of single shot probability, a scale bearing member fixedly

associated with the said curves and graduated to provide a scale of values in terms of circular probable errors extending in parallelism with the axis of abscissas of the curves, a movable scale-bearing member slidable longitudinally of the fixed scale-bearing member and graduated to provide a scale of allowable error values, the values of one scale being the reciprocals of the values of the other scale, means on the slidable scale-bearing member for setting it to a given graduation of the fixed scale-bearing member, a pair of runners on the slidable scale-bearing member, a vulnerability factor-representing element carried by each runner and extending angularly therefrom over the said curves in crossed relation with the corresponding element of the other runner, said elements serving as coordinates establishing at their intersection a reference point having a value of single shot probability dependent upon its position over the curves, and means associated with each curve for indicating the value represented thereby.

8. A computer comprising a support, a chart mounted in the support for sliding movement relative thereto and having value lines extending diagonally of its direction of movement, a slide rule mounted on the support and extending transversely of the direction of the movement of the chart, said slide rule having a stationary scale fixed to the support and a movable scale reading against and slidable longitudinally of the fixed scale, runners on the movable scale, separate index members respectively carried by the runners and extending angularly over the value lines in relatively crossed relation to serve as coordinates establishing at their intersection a reference point having a determinable value dependent upon its position with respect to the value lines.

9. A computer comprising a member having a series of points and marked to provide a scale remote from the said points and fixed relatively thereto, said member also having guide curves extending from the points and between the points and the fixed scale, a scale bearing slide movable lengthwise of the fixed scale, a pair of runners on the slide and having setting guides to be selectively aligned with the graduations of the slide scale, an index member carried by each runner and extending angularly therefrom over the guide curves and across the corresponding member of the companion runner to establish at their intersection a reference point having a value dependent upon its position with respect to the series of points as determined by its position to the nearest guide curve, and means associated with the said member and operatively positioned in relation to the said points for indicating the value represented by each point.

10. A bombing probability computer comprising a member having a set of curves, means for indicating the values of the curves in terms of single shot probability values, a set of indicia on said member and representing a scale of probable error values, a body slidable on said member and along the scale of probable error values, said body carrying a scale of allowable error values, the values of both of said scales being expressed logarithmically and the values of one of the scales being the reciprocals of the values of the other scale, index means on the slidable body for registry with the values of the probable error scale, a pair of runners carried by the slidable body and slidably settable thereon with respect to the values of the allowable error scale, a vulnerability factor-representing member fixedly secured to each runner and extending angularly over the curves in crossed relation with the corresponding member of the other runner to establish at their intersection a reference point having a value of single shot probability determinable from its position over the curves either directly or by interpolation between curves.

11. A bombing probability computer comprising a member having a set of equi-probability curves and a set of indicia representing a scale of probable error values, the probable error scale being remote from the said curves, a movable body on said member adjacent to and slidable along the probable error scale, said body carrying a scale of allowable error values, the values of both of said scales being expressed logarithmically and the values of one scale being the reciprocals of the values of the other scale, a pair of runners carried by said movable body and settable thereon with respect to the values of the allowable error scale, a member carried by each runner and extending angularly over the curves in crossed relation with the corresponding member of the other runner to establish at their intersection a reference point having a determinable value dependent upon its position relative to the said curves and upon the values assigned to the curves, and a movable member adjacent the said curves and having separate sets of indicated values to be alternately positioned with respect to the curves for assigning different values thereto.

12. A computer comprising a set of evaluated curves, a scale-bearing member disposed over the curves and having a pair of logarithmic scales extending in parallelism with the axis of abscissas of the curves and slidably movable against each other, said scale-bearing member and the said set of curves being relatively movable in a direction parallel to the axis of ordinates of the curves but one of said scales being fixed against movement relative to the curves in a direction parallel to the axis of abscissas and having values which are the reciprocals of the values on the other scale, a pair of slidable runners on the said other scale, separate arms fixed respectively to the runners and extending over the curves, said arms crossing each other and serving as coordinates establishing at their intersection a reference point having a value dependent upon its position over the curves, and means associated with each curve for indicating the value represented thereby.

13. A computer comprising a face plate having a diagonal edge and a set of indicia representing a fixed scale remote from and opposite the diagonal edge, said face plate also having a series of guide curves extending from the said diagonal edge to points adjacent and parallel with the fixed scale, a member movable past the said diagonal edge and carrying a set of value curves arranged thereon to appear at the said diagonal edge approximately as straight line continuations of the guide curves parallel to each other and to the said diagonal edge, a movable scale-bearing member operatively associated with the face plate and slidably against the fixed scale, a pair of runners on the movable scale-bearing member, a member carried by each runner and extending angularly therefrom and over the said guide curves in crossed relation with the corresponding member of the other runner, said runner-carried members establishing at their intersection a reference point having a value dependent upon its position relative to the value curves as determined by its distance from the nearest guide

curve, and means associated with each value curve for indicating the value represented thereby.

14. A bombing probability computer comprising a member having a set of bomb requirement curves based on a constant percentage degree of assurance of obtaining certain numbers of hits throughout a given range and for different values of single shot probability, a slide rule mounted in parallelism with the axis of abscissas of the curves and movable relative to and over the curves in parallelism with axis of ordinates of the curves, said rule including a unit fixed against movement laterally of the curves and graduated to provide a scale of probable error values and a unit slidably movable against the fixed unit, and graduated to provide a scale of allowable error values, the values on one of the scales being the reciprocals of the values on the other scale, a pair of runners on the slidably movable unit of the rule, each runner having an index member extending over the curves in crossed relation with the index member of the other runner to establish at their intersection a reference point having a value dependent upon its position relative to the curves and means associated with each curve for indicating the value represented thereby.

15. A bombing probability computer comprising a member having a set of equi-probability curves and a set of indicia representing a scale of probable error values fixed relative to the said curves, a movable body on said member adjacent to and slidable against the fixed scale, said body carrying a scale of allowable error values, the values of the fixed and movable scales being expressed logarithmically and the values of one scale being the reciprocals of the values of the other scale, a pair of runners carried by the said body and settable thereon with respect to the values of the allowable error scale, a member carried by each runner and extending angularly over the curves in crossed relation with the corresponding member of the other runner to establish at their intersection a reference point having a determinable value dependent upon its position relative to the said curves and upon the values assigned to the curves, and a movable member adjacent the said curves and having separate sets of value curves to be alternately positioned with respect to the set of equi-probability curves for assigning different values thereto, the value curves of one set representing different values of single shot probability and value curves of the other set representing the varying number of bombs required to provide a given percentage degree of assurance of securing a given number of hits, and means associated with each value curve for indicating the value represented thereby.

16. A computer comprising a body; two slide rules on the body, each rule comprising a scale-bearing unit fixed relatively to the body and a scale-bearing unit slidably movable along the fixed scale-bearing unit and a runner mounted on the said slidably movable scale-bearing unit and having an angularly extending arm; said rules being relatively arranged on the body so that the said arms extend crosswise of each other to establish at their intersection a reference point and the said runners being slidably movable along their respective mounting scales to vary the position of the reference point, each position of the reference point having a determinable value; a series of curves on the said body to be traversed by the said arms, each curve connecting points on the body corresponding to different positions of the reference point which have the same determinable value; a curve-evaluating member mounted on the said body and movable in a direction crosswise to the said curves to various predetermined positions relative to the body, said member having a plurality of value-indicating characters arranged thereon to be aligned selectively with the curves by and during the positioning of the curve-evaluating member whereby to give different evaluations of the curves in the various predetermined positions of the curve-evaluating member; and cooperative indicia on the said body and curve-evaluating member for setting the latter to any predetermined position.

17. A bombing probability computer comprising a body having a scale of probability errors fixed on the body and a scale of allowable errors movable on the body, the latter scale being slidably settable along the fixed scale to a given value of probable error, a pair of indicators on the body slidably and separately settable to given values of allowable errors and extending crosswise of each other to establish at their intersection a reference point the position of which relative to the body varies in accordance with the relative settings of the scales and indicators, each indicator representing in terms of probability value the corresponding vulnerability factor which is a function of the given values of probable and allowable errors and each position of the reference point having a determinable value which is a function of the probabilities represented by the said indicators, and a series of curves on the body to be traversed by the said indicators, each curve connecting points on the body corresponding to different positions of the reference point which have the same determinable value.

18. A computer comprising a body having a series of guide curves thereon representing different values of single shot probability, indicator-means on the body and movable into indicating position relative to the said guide curves, a member associated with the body and movable into various predetermined positions relative to the latter for disposing different selected points on the member in line with the guide curves for every different combination of guide curves and position of member, each position of the member representing a value in terms of number of bomb hits desired with a given percentage degree of success and each selected point on the member representing a determinable value in terms of number of bombs which is a function of the values represented by a given combination of guide curve and position of member, a series of evaluated curves on the member and connecting selected points thereon having the same value, said evaluated curves being arranged on the member to be displaced laterally across the guide curves by and during the positioning of the member to give different evaluations of the guide curves in the various positions of the member, and cooperative means on the body and on the member for determining the setting of the latter to a desired position.

19. A bombing probability computer comprising a body having a series of curves representing different values of SSP, a set of indicia fixed on the body and representing a scale of probability errors, a member slidably settable along the scale of probability errors to a given value of probable error, said member carrying a scale of allow-

able errors, two indicators separately slidable and settable to given values of allowable errors, said indicators extending across the SSP curves and crossing each other at every relative setting of the scales and indicators to chosen values of probable and allowable errors for establishing at their intersection over the SSP curves a datum point, an evaluating member having a series of evaluated curves representing different amounts of bombs, said evaluating member being settable into various predetermined positions relative to the body for disposing each of the said evaluated curves in line with a different SSP curve for every position of the evaluating member, and cooperative indicia on the body and evaluating member for determining the setting of the latter to each of its various predetermined positions.

20. A bombing probability computer comprising a member having a plurality of charts thereon, each chart including a set of value curves representing the varying number of bombs required to provide a given percentage degree of assurance of securing a given number of hits—a set of indicia representing a non-uniform scale of bomb hits coordinated with the curves—and a series of indicators of the percentage degree of assurance on which the bomb hit scale and value curves are based, a face plate over the member and movable relative thereto, said face plate having a long window for exposing portions of the value curves diagonally with respect to the direction of relative movement of the member and face plate and having other windows exposing units of the scale and indicator series respectively, a set of indicia representing a scale of probable error values in which the range and deflection probable errors are represented by an average value, said scale-representing indicia being fixed to the face plate remote from the long window and reading directly in terms of Cep errors corresponding to the average values, guide curves of equi-probability on the face plate and extending from the probable error scale to the long window, an indexed slide associated with the face plate and slidable longitudinally over the said probable error scale to a position corresponding to a given value of circular probable error, a set of indicia on the slide representing a scale of allowable errors reading in dimensions of target which are twice the allowable error in range and deflection, a pair of runners on the slide and separately settable with respect to the scale-representing indicia on the slide to given values of range and deflection dimensions respectively of a target, an arm carried by each runner and extending angularly over the guide curves in crossed relation with the corresponding arm of the other runner, said crossed arms serving as coordinates establishing at their intersection a reference point having a value in number of bombs dependent upon its position relative to the value curves as determined by its distance from the nearest guide curve.

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