July 31, 1956 G. T. PELSOR ET AL 2,756,930

COMPUTING DEVICE

Filed Jan. 6, 1955 3 Sheets-Sheet 1

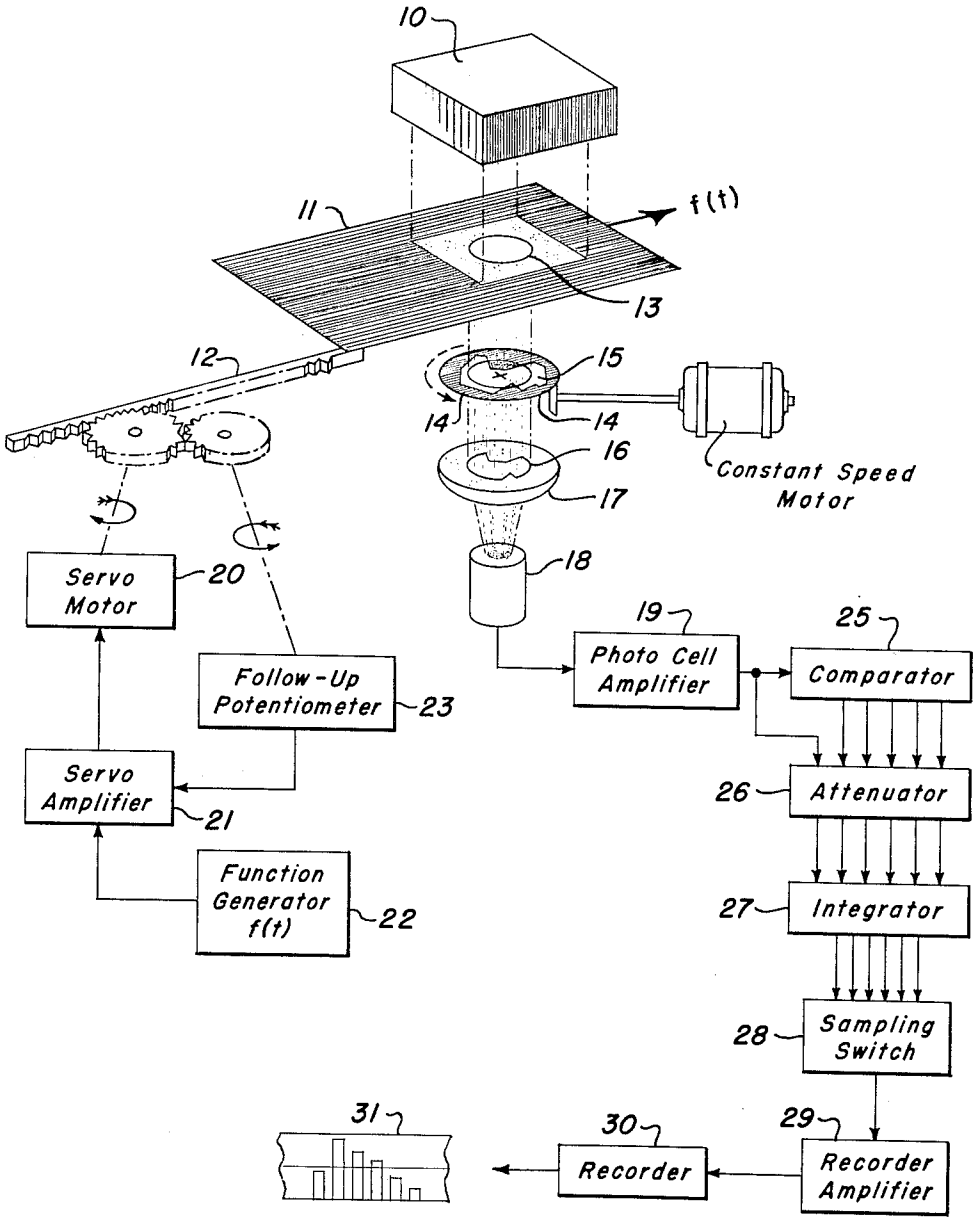


Fig. 1

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3 Sheets-Sheet 2

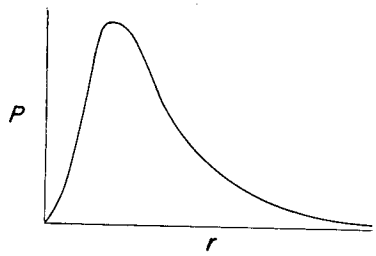


Fig. 2a

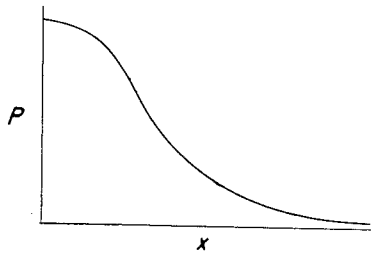


Fig. 2b

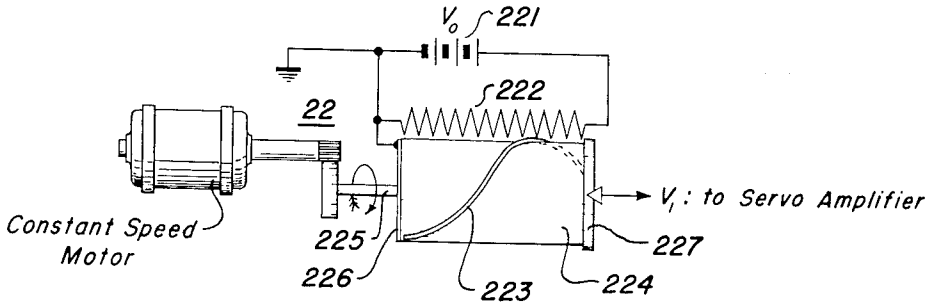


Fig. 3

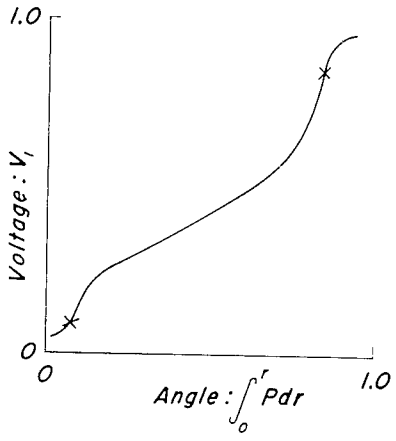


Fig. 4a

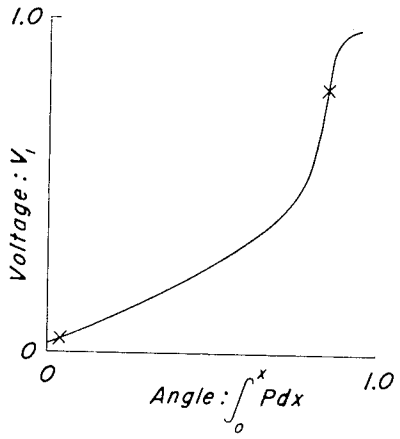


Fig. 4b

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COMPUTING DEVICE

Filed Jan. 6, 1955 3 Sheets-Sheet 3

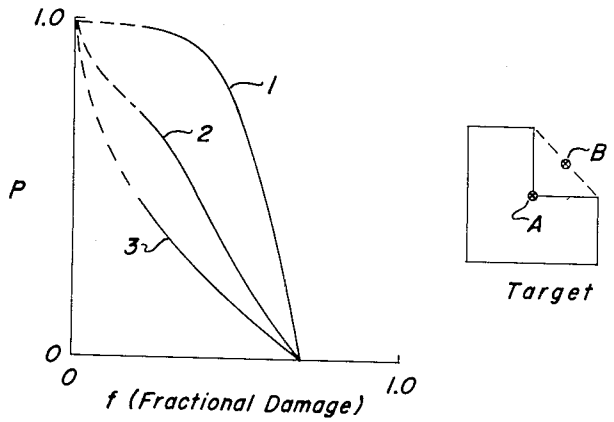


Fig. 5

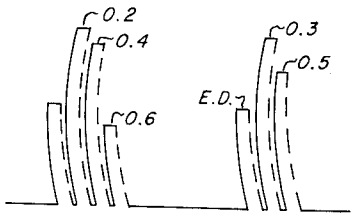


Fig. 6a

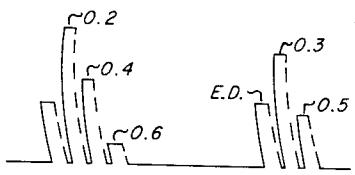


Fig. 6b

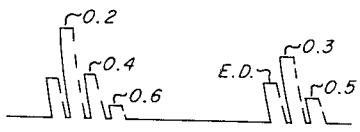


Fig. 6c

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2,756,930

COMPUTING DEVICE

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Application January 6, 1955, Serial No. 480,308

4 Claims. (Cl. 235—61)

This invention relates to a novel form of electromechanical computer, a device especially designed to accomplish automatically the estimate of damage to a target to be expected from a missile thereon directed or a bomb bursting thereabove. Such damage may be computed from theoretical considerations involving plausible assumptions as to damage capability of the weapon and the probable error in its delivery, but such computations are laborious and time consuming unless restricted to targets of simple geometry. The computing device herein described replaces the tedious computation to obtain rapidly and to a close approximation the computed result, namely, the expected percentage damage to a target, and that without limitation of target shape. Obviously, it is impossible to check the result, however computed, by comparison with field experiments, but studies of the kind are valuable in forming conclusions as to the type of missile or bomb most appropriate for attacking a known target.

A general object of the invention is therefore to facilitate the choice of the best weapon for attacking a target.

Specifically, an object of the invention is to provide a system of apparatus adapted to the computation of the damage to a given target to be expected from any weapon involving delivery error.

The apparatus includes, besides means for estimating the expected percentage damage to the target, means for estimating the probability of doing to the target at least a specified fractional damage. In attack upon a body of troops, partial damage may be considered enough to put to rout the entire body, while against warehouses and arsenals complete damage may be intended.

Another object of the invention therefore is to provide means for estimating the likelihood of effecting target damage at least as great as a chosen percentage of total destruction.

Two types of error distributions are considered: that of the missile, either self-guided or otherwise directed toward the target, and that of the bomb dropped to explode above the target. The curves of error probability with respect to the target point aimed at are different for the two weapons, and the computer reveals different probabilities of over-all, or of a chosen fractional, damage to a given target.

Thus another object of the invention is to facilitate the choice of weapon and delivery system most appropriate to use against a known target.

It will appear in the later description that any desired probability function may be dealt with by the present computer, but it is thought sufficient to discuss the cases of the linear error in delivery of a missile directed at the target and falling short or overshooting the same, and of the circular error in allowing a bomb to burst at a point other than directly above a chosen part of the target. In each case, the area of possible damage by the weapon is considered circular and as a further simplifying approximation it will be assumed that target areas within this circle are completely destroyed while areas outside are uninjured. Further, it is assumed that the military importance is the same for all equal areas of an actual target. From the description below, the reader will perceive how these limitations may be removed without departing from the teaching of the present invention.

The computer serves as an area integrator, that is, for evaluating such expressions as $\iint f(r)\,dx\,dy$ or even

$$\iint f(x,y)\,dx\,dy$$

The particular error distributions discussed herein represent particular forms of the function f, but the computer may also be used for integrating other functions.

It is found from theoretical analyses not needing to be here detailed that either type of error probability, i. e. the probabilities of delivery errors of assigned magnitudes, may be computed and graphically shown by a curve of which the abscissae are error values and the ordinates are "probability densities" of the errors of the corresponding abscissae. Otherwise stated, the probability of an error between e and $e+\Delta e$ is the product $P_e\Delta e$, when P_e is the ordinate at abscissa e.

In the cases of the missile and of the bomb, the probability density curves are different for the reason that the errors in missile delivery are regarded chiefly as errors in range and therefore linear, while the errors in point of bomb burst are distributed equally in all directions from the desired point and are therefore circular. This consideration leads to the designation of linear and circular error probabilities as LEP and CEP, respectively.

The total probability of damage to the target is the integrated damage at the various error values to be taken into account, weighted by the probabilities of occurrence of these errors. Since for each Δe the probability of damage may be considered proportional to the corresponding $P_e\Delta e$, the P_e curve may be regarded as a weighting curve, and this weighting may be applied as a time-of-dwell curve, any ordinate of which when multiplied by Δe represents the time during which indications of damage over the corresponding Δe interval are summed. A feature of the invention is therefore the provision of a method whereby a mathematical weighting curve is effectively expressed as a time function of the abscissae.

The apparatus of the invention includes a number of conventional electrical circuits such as voltage comparators and integrators, summing amplifiers and servomotors, etc., which are not specifically described; reference may be made to the relevant volumes of the Radiation Laboratory Series of the Massachusetts Institute of Technology, Cambridge, Massachusetts, published by the McGraw-Hill Book Company of New York. Optical and photoelectric elements are conventional and, with the electrical elements, are assembled in a novel organization to attain the objects above recited.

This organization and the mode of attaining these objects will be understood from the following description of a preferred embodiment of the invention read with reference to the accompanying drawings, in which:

Fig. 1 is a block schematic diagram of the computer;

Figs. 2*a* and 2*b* illustrate respectively the curves of the probability density for the case of a bomb dropped upon the target and that of a missile launched toward the target;

Fig. 3 is a simplified representation of a function generator used in the system of Fig. 1;

Figs. 4*a* and 4*b* are graphs of the output voltages provided by the function generators corresponding to the curves of Figs. 2*a* and 2*b*, respectively;

Fig. 5 is a plot of the probabilities of doing various fractional damages to an L-shaped target outlined in the figure for one and for another aiming point and with different values of CEP; and

Figs. 6*a*, 6*b* and 6*c* are representative of the charts produced by the recorder of Fig. 1 for curves 1, 2 and 3, respectively, of Fig. 5.

In the following description emphasis will be placed upon the dropped bomb evaluation with incidental reference to the operation in the case of a guided missile. The underlying principle is the same although the operations differ in the two cases.

Referring now to Fig. 1, light source **10** illuminates a traveling mask **11** driven (from left to right in the figure) through traveling rack **12**, provided beneath and affixed to mask **11**. Mask **11** is opaque except where it is cut out to let light pass through damage circle **13**. In choosing a circle to represent the extent of area expected to be damaged the approximation is made of complete damage for all target areas exposed within the projection of the circle and no damage outside the circular exposure. This approximation is assumed for the sake of simplicity; it may be removed by providing a transparency radially decreasing outward from the perimeter of the circle shown in the figure. This may be accomplished by known means, for example, a photographic mask with radially graduated density decreasing from zero in the center to a maximum outside the circle, or, for another example, a rotating opaque mask of appropriate form.

By known means the light intensity from source **10** is made uniform over the entire area of interest. The light passing through circle **13** falls next upon target mask **14**, which is a disc opaque except for a cutout **15** representing to scale the shape and size of the target. The scale is the same as that of damage circle **13**. At the center of mask **14** the cross indicates the aiming point of the attack.

Light from source **10**, limited first to the damage circle **13**, is further restricted by target cutout **15** and illuminates area **16** on the surface of lens **17**, by which it is concentrated to fall upon a photocell **18**. The output of cell **18** is amplified by amplifier **19** to a level suitable for use by the computing and recording portion of the apparatus.

Mask **11** is caused to travel (from left to right in the figure) across target cutout **15** by gearing which drives rack **12** to traverse the distance from the cross to the limit desired. This drive of rack **12** is effected by servomotor **20**. The operation of motor **20** is responsive to amplifier **21**, which receives as input voltage the difference between two voltages: one is that from function generator **22**; the other is from linear potentiometer **23**, on which the brush position corresponds to the position of mask **11** as it travels from left to right. Limit stops are advantageously provided near the ends of the travel of mask **11** over a supporting structure (not shown), which also carries, at a level below mask **11**, target mask **14** at a fixed level.

It has been mentioned above that the probability of damage over any part of the target is directly related to the time spent by the damage circle over that target part; therefore, it is convenient here to describe the curves of probability density of Figs. 2*a* and 2*b*.

It will be readily understood, from the earlier discussion of the representation of error probability by time-of-dwell of the damage circle over an area of the target, that circle **13** travels rapidly across the target where the probability-density is low and more slowly where that density is great. The different probability-density curves for the circular and for the linear case may be computed from theoretical considerations and have the forms shown on Figs. 2*a* and 2*b* for the respective cases. In Fig. 2*a*, *r* is the radius outward from the cross shown in target cutout **15**, Fig. 1, to which the center of the damage circle has traveled, while P is the probability-density of actual ground zero at various values of *r*. Similarly, *x* in Fig. 2*b* is the distance from the cross (intended ground zero) to the point at which the missile may land on the target, and P is the probability-density of that landing.

The cumulative probability in either case is represented by the integral of the corresponding curve. Mathematically this may be stated in the case of normal distributions as:

For the circular case,

$$\text{cumulative probability}=\frac{t}{T}=1-\epsilon^{-\frac{V^2}{2\sigma^2}} \qquad (1)$$

For the linear case,

$$\text{cumulative probability}=\frac{t}{T}=\frac{1}{\sigma\sqrt{2\pi}}\int_0^V \epsilon^{-\frac{V^2}{2\sigma^2}}dV \qquad (2)$$

In the above expressions,

T is the total time of travel of target mask **11** across the field of target **15**;

t is the time elapsed since the beginning of travel of mask **11** to some particular position above the target;

V is the voltage provided at that particular position by function generator **22** controlling the speed of mask **11**;

ϵ is the base of natural logarithms; and

σ is the standard deviation of the burst or impact horizontally relative to the desired aim point.

These expressions may be better understood from the descriptions of Figs. 2*a* and 2*b*, 3 and 4*a* and 4*b*.

Referring now to Figs. 2*a* and 2*b*, which depict the variation in probability density of burst or hit respectively with horizontal distance from the intended point of the target, it is seen that for the circular case (Fig. 2*a*), the probability density P of burst directly above the aim point is zero and rapidly increases as *r* (the radial distance of the actual burst from that intended) increases from zero to the point where $r=\sigma$ and thereafter falls more gradually to zero again at large values of *r*. For the linear case where *x* is the distance of the actual hit from the aim point, the probability density (Fig. 2*b*) is a maximum when $x=0$ and decreases thereafter in either direction according to a Gaussian curve.

The integrals of the curves of Figs. 2*a* and 2*b* with respect to *r* in the first case and to *x* in the second are to be provided as voltages from function generator **22** as inputs to servoamplifier **21**. The instantaneous variations in the respective integral voltages follow the ordinates of the curves in Figs. 2*a* and 2*b* respectively, causing servomotor **20** to drive traveling rack **12** rapidly or slowly when P is small or large respectively.

The voltages above alluded to are derived from a functional potentiometer shown schematically in Fig. 3. This instrument is suitably one manufactured by the Reeves Instrument Corporation of New York, N. Y. In Fig. 3, battery **221** supplies a constant voltage V_0 to linear resistance card **222**. A formed wire **223** embedded in a drum **224** of non-conducting material makes contact with consecutive points of card **222** as the drum is rotated at a constant angular speed by means schematically shown. The sense of drum rotation is indicated by the curved arrow encircling shaft **225**. A gear at the end of this shaft indicates symbolically the means for driving drum **224**. At the ends of drum **224** are affixed conducting plates **226** and **227**, connected respectively to the grounded end of card **222** and to wire **223**. As drum **224** turns, plate **226** continues to make contact with the grounded end of card **222** while a wiper in contact with plate **227** continues to deliver to the servoamplifier a voltage V_1 varying with the point of contact between wire **223** and card **222**.

The form of wire **223** may be varied as suits the function to be derived and is so varied for the circular and the linear cases above discussed. The extreme ends near zero and near the top of card **222** are used only to enable start and stop of mask **11** without jar. Switches, not shown, are provided to enable the photoamplifier to activate integrator **27** only between the limits indicated by crosses in Figs. 4*a* and 4*b*.

Referring now to the last mentioned figures, the former exhibits voltage V_1 as a function of the angle through

which drum **224** has turned for the case of circular error while the latter exhibits the same voltage-angle relation for the linear case. The curves of Figs. 4*a* and 4*b* are (with axes interchanged) the integrals of those of Figs. 2*a* and 2*b*, respectively. In neither figure does the voltage start from zero at zero angle of drum rotation. This is harmless because of the excluding stops which, as previously explained, permit enablement and disablement of the computing circuits.

Since the abscissae of Figs. 4*a* and 4*b* are proportional to time and V_1 is proportional to distance moved by mask **11**, the slope of the curve is proportional to the speed with which the mask is moved.

Equations 1 and 2 are dimensionally correct since σ is a length and V is proportional to the distance from the ground connection that wire **223** makes contact with resistance card **222**. In rotating drum **224** at constant angular velocity it comes about that for any angular position of the drum the rotation to that position of the drum is proportional to the probability of burst integrated to the corresponding position of mask **11** or the like integration of curves of Fig. 2*a* or 2*b*. In other words, cumulative probability increases linearly with time.

This will be understood to be in accordance with the earlier stated requirement that the travel of mask **11** shall be slow when P is large and fast when P is small. It will be seen that when the linear speed of mask **11** varies inversely with P, each unit of time in the rotation of drum **224** corresponds to the same increment of probability, the area $P\Delta e$ under the corresponding segment of the curve being the same for each time unit. The variation of σ from one type of missile to another is taken care of by appropriately changing the voltage V_0.

The foregoing discussion has related to the drive of rack **12** without reference to target cutout **15**. The curves of 2*a* and 2*b* are illustrative only while those of Figs. 4*a* and 4*b* substantially represent the voltage angle curves actually realized for particular forms given to wire **223** of Fig. 3 in correspondence with the probability density functions computed for a specific problem. The scales of these curves are in each case correspondent to the accuracy of delivery of the attacking object whether a bursting bomb or a guided missile. Where the circular or linear probability (i. e. CEP or LEP) is least, rack **12**, in order to cover the probability function, need move the least distance from where the center of aperture **13** stands vertically above the cross indicated in cutout **15**, and the total movement of rack **12** is appropriately limited, conversely, when the CEP or LEP is greatest. The variation in these errors is known beforehand for different bombs or missiles, and suitable change in V_0 made to enforce the desired travel of mask **11**.

When the entire probability function (except for a negligible tail) has been traversed there is substantial certainty that a bomb burst or a missile impact has come about somewhere in the course of travel of rack **12**; and the curve of Fig. 2*a* or of Fig. 2*b*, integrated to a particular value of r or x, denotes the probability that such an event has taken place within the travel to that abscissa.

The damage to the target is dependent on the portion of the target lying within circle **13** projected on cutout **15** at the moment of burst or impact. It is thus proportional to the area of target exposed at that instant. In Fig. 1 this area is obtained by measurement of light from source **10** to photocell **18** through circle **13** and cut out **15** in tandem.

The increment of probability of burst between errors e and $e+\Delta e$ has been designated as $P\Delta e$, where P is the probability density at the abscissa e; this in the cases of Figs. 2*a* and 2*b* is $P\Delta r$ and $P\Delta x$, respectively. Since damage circle **13** has been taken to represent an area within which total damage is wrought upon a target large enough to extend in all directions beyond the circle, the increment of probable damage done as circle **13** travels

from r to $r+\Delta r$, say, is seen to be proportional to $P\Delta rA$, where A is that part of the target area exposed in this motion and is measured as the voltage v supplied by photocell **18** to amplifier **19**.

The output voltage of amplifier **19** may be integrated over the T (for example, $T=20$) seconds run to obtain the expected damage to the target; and this will be total destruction if circle **13** is large enough to cover target cutout **15** in all positions of circle **13**, effectively the same as omitting mask **11** entirely.

A run is made omitting mask **11** and the output voltage of amplifier **19** is integrated for the T seconds by integrator **27** (Fig. 1), a device such as is described in the M. I. T. Radiation Laboratory Series, volume 21, page 79. In the figure, integrator **27** receives the voltage to be integrated by way of attenuator **26**, which may be set to pass all or any fraction of the voltage from amplifier **19**. With the attenuator set to zero attenuation, the photoamplification is so adjusted that now the output of integrator **27** is 50 volts, for example, and this voltage is taken to represent total destruction of the target. The integrator output voltage increases proportionally to that of amplifier **19**.

Additional integrator circuits, shown in Fig. 1 as five in number, for example, are used to obtain the probabilities of fractional damages to the target. As an illustration, one may estimate an expected overall damage of 50% while a fractional damage of 40% is nearly certain. In other words, the integrator supplied directly from amplifier **19** may have an output of 25 volts, corresponding to 50% damage, while an integrator supplied from a comparator which permits the integrator to function whenever the output from amplifier **19** reaches 20 volts will sum the time such a comparator is itself enabled. This may be 90% of the time, and the associated integrator will produce 45 volts. In the figure, numeral **25** indicates the five comparators, each of which opens a gate to the corresponding integrator when a preset voltage is reached by the output of amplifier **19**. These comparators are similar to those described in the M. I. T. Radiation Laboratory Series, volume 19, page 349. Each integrator has a time constant circuit set to deliver 50 volts at the end of a run if its comparator has been on all the time, proportionately less if the comparator gate has been closed part of the time.

The system outlined in Fig. 1 provides for deriving from integrator **27** a voltage corresponding to expected damage in per cent of 50 volts and five other voltages, the last named representing the times over which the comparators allowed voltages from their individual integrators of 10, 20, 30, 40 and 49 volts respectively, representing 20, 40, 60, 80 and 98% damage to the target.

The six output voltages from integrator **27** are by a rotary-driven sampling switch **28** successively applied to recorder amplifier **29**. This amplifier actuates a recorder **30** of known type, which in turn operates to record on tape **31** the magnitude of the several output voltages.

It has been earlier pointed out that the errors in ground zero for a bomb burst are circularly distributed about the chosen aim point while the like errors for a missle are substantially in a line. Since it is practically difficult to drive mask **11** in a circular path of increasing radius, an equivalent is used, namely, to rotate the target cutout **15** about the desired ground zero (indicated by a cross) at about 300 revolutions a minute while the motion of mask **11** carries the damage circle **13** through its extreme travel in 20 seconds. This rotation is indicated by the curved broken arrow shown adjacent element **14**.

For the linear case where the errors are distributed in a line, fore and aft the desired aim point, it is convenient to make a run from that point to the right, then turn the target cutout half way around about the point and make a second run, also to the right, the mask traveling as before. Then, adding the records, one obtains an estimate of total damage for the linear case.

If damage probabilities intermediate those given are desired, appropriate substraction of voltages from the output of amplifier **19** between that amplifier and comparator **25** without resetting the integrators, will permit such to be recorded; for example, subtracting 5 volts at this point will permit the records of tape **31** to correspond to probabilities of 30, 50, 70 and approximately 90% damage as well as expected damage.

In the circular case a modification of the described procedure for estimating expected damage allows for errors in burst height of the bomb. From other studies a curve of probability of burst errors above and below the intended height is obtained and successive runs are made with different diameters of damage circle **13**. Estimating the variations in such diameter for various burst heights, one may provide by an iris or other convenient means the appropriate changes in the damage circle. Let us assume that a number N of such diameters will be used, corresponding to the like number of heights distributed at and about the intended burst. Then the same number of runs will give N estimates, which, averaged with proper weight, compose an estimate of expected damage with allowance for burst height errors. In the linear case allowance for these height errors may be accompanied by a shift in aiming point to account for trajectory inclination.

Fig. 5 illustrates the application of the computer to the case of bombing an area of L shape indicated to the right in the figure. Aiming points A and B are considered, and for aim point A two valves of CEP are chosen.

Curves **1**, **2** and **3** to the left in Fig. 5 represent the observations of fractional damage probability. Actual results are plotted. At abscissas less than 20% the curves are extrapolated. Curve **1**, aim point A, relates to a CEP half the "effect radius" (damage circle **13**); curve **2**, aim point A, CEP approximately the same as the effect radius; curve **3**, aim point B, CEP as in curve **2**, the effect radius being the same for all three curves. The expected damage is: curve **1**, 55%; curve **2**, 34%; curve **3**, 22%.

Figs. 6*a*, 6*b* and 6*c* show the graph records on tape **31** for curves **1**, **2** and **3** respectively. Each of these figures shows the probable expected damage E. D. and five probabilities of fractional damage from 20% to 60% in the respective cases. In actual use of the computer the accuracy of the result has been found to be within 2% of that mathematically computed.

We claim:

1. A system of apparatus for estimating the damage to a known target to be produced by a missle of known destructive effect comprising a first mask having a circular aperture of area representing the effect, a second mask having an aperture representing the area and contour of the target, the masks being mounted in substantially parallel planes and representing to the same scale the effect and the target respectively, a light source directing light through the apertures to the extent of their alignment, a photosensitive element adapted to receive the light transmitted and to generate a voltage proportional thereto in any alignment of the apertures, means for traversing during a prescribed time interval the first mask from an initial alignment relative to the second mask in accordance with a time function representative of the probability of successive alignments and at a rate containuously varying inversely with said probability, means for continuously amplifying and integrating over the time interval the generated voltage and means for indicating the magnitude of the integrated voltage.

2. A system of apparatus as in claim 1 including means for evaluating the likelihood of damage to the target at least equaling a specified fraction of its total destruction, the included means comprising means for deriving from the generated voltage a fractional voltage, means responsive to the fractional voltage on its attainment of a magnitude correspondent to the specified fraction and means for indicating the fraction of the prescribed interval that the fractional voltage has at least the correspondent magnitude.

3. Means for evaluating the fractional destruction of a target by a weapon capable of causing destruction over a known area comprising a light source, a light-sensitive electrical element adapted to receive light from the source, a first mask having an aperture representative of the area, a second mask having an aperture representative of the target, said masks being superposed in substantially parallel planes intermediate the source and the element and having their apertures in a prescribed initial alignment, means for traversing the first mask relatively to the second mask in accordance with a prescribed function of time, means for rotating the second mask about an axis normal to its plane during the traverse of the first mask, means for continuously deriving from the element a voltage proportional to the light received through the apertures in tandem, means for integrating the derived voltage with respect to time over a prescribed interval and means for indicating the magnitude of the integrated voltage.

4. Destruction evaluating means as in claim 3 including in addition, means responsive to the derived voltage when equal at least to a preset magnitude to derive a second voltage of said magitude, means for integrating the second voltage with respect to time over the prescribed interval and means for indicating the magnitude of the integrated second voltage.

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