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METHODS OF COMPUTATION

FOR

PILOT BALLOON ASCENTS.

BY

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METHODS OF COMPUTATION FOR PILOT BALLOON ASCENTS.

By J. S. Dines, M.A.

In the early days of observations with pilot balloons, it used to be said and not without reason that the number of different methods of working up the results was equal to the number of individual observers. The very large development of this mode of determining upper wind currents which occurred during the late war caused certain methods to be standardised in the different armies, but nevertheless the number of separate methods in use continued to be large. In the present note an attempt has been made to collect particulars of the different means of computation of which a description has been published, and to put them together in a form convenient for reference. In most instances sufficient detail is given for the method to be followed by any worker familiar with the subject, but this was not found practicable in all cases if the paper were to be kept within a reasonable length, and therefore in a few instances the chief features only have been briefly described and a reference given to some publication where a full account may be found. Emphasis must be laid upon the fact that the figures which are shown in the paper are in most cases purely diagrammatic, they must not be regarded as scale reproductions of the graphs which would actually be employed in carrying out the computation. It is not claimed that all methods which have ever been worked out are referred to in the paper; the number of such methods is too great and there must be many of which no published account has appeared. On the other hand the different means of working set out below probably cover the whole field fairly fully, and should enable any worker to see whether he can materially improve his own method by adopting the devices which have been found serviceable by others.

Of the two methods of working with pilot balloons, the single theodolite and double theodolite, the former has received far more attention, and the different ways of working up the results with this method will first be considered.

PART I.—SINGLE THEODOLITE ASCENTS.

The most straightforward method and that demanding the least knowledge from an unpractised operator is the simple graphical, in which all the calculations are carried out by graphical means. As an example of this the method adopted by the French Military Meteorological Service will be described. For full details see "Notice sur le Fonctionnement des Postes de Sondages Aerologiques, Paris 1918," published by the Ministère de la Guerre.

In cases where a single theodolite is employed and angular measurements are not made on a tail of known length attached to the balloon, a uniform rate of ascent is assumed so that the height h after any number of minutes from the start is assumed known. The horizontal distance D of the balloon from the

(27852- 12) Wt. 42796—S.O.P. 580 600 7/20 H. St. G. 3 A 2 starting point is then deduced by means of the formula $D=h\cot\alpha$ where α is the angular elevation of the balloon. (*Note.*—The letters D, h and α will be used with the same significance

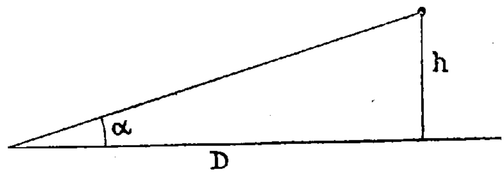

Fig. 1.

throughout this paper.) The horizontal distance of the balloon at the time of each reading being thus obtained and the corresponding azimuth determined from the theodolite the horizontal track may be plotted from minute to minute. The distance traversed between two consecutive readings gives the mean wind velocity for that interval and the direction of the track the wind direction.

Method I. 1.—In the method adopted by the French Military Meteorological Service the value of $h\cot\alpha$ is obtained by means of a protractor working over squared paper. On this paper horizontal lines are ruled, which represent the height of the balloon at each successive minute, *see* Fig. 2. The protractor

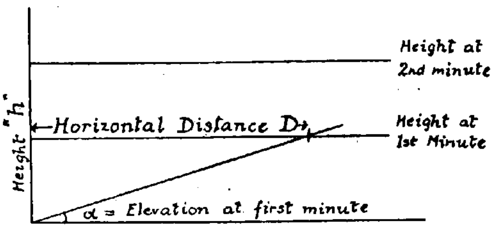

Fig. 2.

being set for each reading at an angle equal to the elevation of the balloon, the horizontal distance D is taken directly from the point of intersection of the protractor with the appropriate horizontal line. The track is then plotted on another piece of squared paper on which radial lines corresponding with each azimuth reading have already been ruled. The use of squared paper in this way would seem to be particularly convenient when it is desired to obtain by graphical means component wind velocities to E. and to N. instead of resultant velocity and direction.

Method I. 2.—The French Service have modified the above scheme for purposes of rapid calculation in the following way. The horizontal distance is obtained from a book of tables setting out the value of $D=h\cot\alpha$ for values of h ranging from 0 to 3,000 m. by 100 m. steps and by 500 m. steps above 3,000 m. Angular elevation α is given for each $\frac{1}{10}$th of a "grade." The employment of "grades" would render these tables unsuitable for use with the British type of theodolite, which is divided in degrees. The use of the tables is facilitated by giving the balloons such a lift that they rise at either 100 or 150 metres per minute. The distance D being obtained from the tables the track of the balloon is plotted on radially-ruled paper. Wind velocities in m/s are read from the plotted track directly by means of a special scale.

Method I. 3.—The two methods outlined above probably represent the simplest means which can be adopted for the computation where a single theodolite is employed. The graphical method has been further developed by several different workers with a view to reducing the time taken in obtaining the results. One of the best of these developments is that worked out by the R. Servizio Aerologico in Italy. The object aimed at was the development of a system by means of which the resultant velocity could be obtained with a minimum of time and labour by workers without previous scientific training. A standard rate of ascent of 150 metres per minute is employed for the balloons and, as in Method I. 2, a book of tables is used for $D = h\cot\alpha$. In this book a page is devoted to each minute reading, that is to each consecutive value of h, and on each page the value of $h\cot\alpha$ is given for all values of α. Values of α are set out in degrees, so that the tables could be used in connection with British instruments. Thus it will be seen that one page has to be turned over for each minute reading from beginning to end of the ascent. For plotting the track a drawing board is employed on which is set out a circular scale of degrees. For each ascent a sheet of tracing paper is pinned on the board and a ruler pivoted at the centre of the scale is used for laying off the distance $h\cot\alpha$ along the corresponding azimuth. The divisions on this ruler are numbered corresponding with five different scales marked A, B, C, D, E, respectively for use with different strengths of wind and lengths of track. For reading velocities from the minute runs five different scales are necessary to correspond with the linear scales A—E above. These scales are combined in a single ruler of triangular cross-section, which on its six edges has inscribed (1) a cm. scale and (2)—(6) scales giving velocities directly to correspond with A—E above. These five scales are marked with the letters A, B, C, D, E, respectively, to minimise the risk of error. Wind directions are read off by placing the triangular scale along the track and swivelling the pivoted ruler round the centre till it lies parallel to the scale when wind direction is obtained from the outer degree scale. The details of this method appear to have been worked out very carefully with a view to facility of use, and it seems to mark the limit of convenience which can be obtained with graphical methods and with a simple straighforward type of appliance. The above particulars have been supplied to me by Major A. H. R. Goldie, R.E.

Method I. 4.—A purely graphical method of computation which appears to be of much merit was used in the Military Meteorological Service of the United States during the war. It is described and illustrated in the United States "Monthly Weather Review" for April, 1919, p. 222. The equation

$D = h \cot \alpha$ is solved by means of a radial arm moving over squared paper, the arm being set at the appropriate angular altitude against a graduated arc on the paper. The diagram (Fig. 4) shows the scheme in outline.

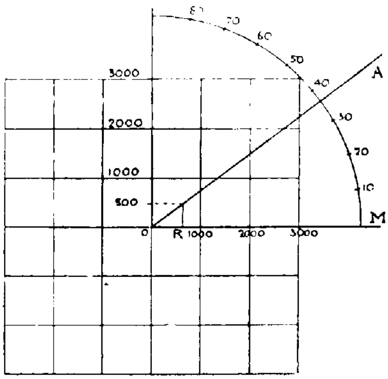

Fig. 4.

If at the end of the first minute the height of the balloon is 500 feet and the altitude 37°, the arm is set at 37°, and the horizontal "500" line is followed across to the point where it cuts the arm. If the vertical line is followed down from this point to the point R, the distance OR indicates the horizontal distance D of the balloon from the theodolite. Thus far the method follows ordinary lines (see Method I. 1). The novel feature consists in placing a circular disc of transparent celluloid above the squared paper but beneath the arm, the disc being pivoted at the same point O as the arm. This celluloid disc has a degree scale running from 0—360° engraved upon its circumference. The disc is rotated till the fixed line OM on the paper reads against the degree scale engraved upon the edge of the disc an angle equal to the azimuth of the balloon. The point R on the squared paper is then marked by a pencil upon the roughened surface of the celluloid and shows with reference to the celluloid the projection of the balloon's position both in distance and azimuth. For the second reading the radial arm is reset to the appropriate altitude, the disc rotated to the new azimuth and the next point marked upon it. Thus the whole track is pencilled on the celluloid disc. Wind velocities may be measured in the ordinary manner by means of a suitable scale from the successive distances travelled in each minute, while to determine the wind direction in each time interval the celluloid is rotated till the appropriate part of the balloon track comes parallel to the reference line MO. The wind direction is then read immediately against the point M from the degree scale engraved on the edge of the disc.

By this means the two graphical processes involved in the solution are combined in a very ingenious manner and the use of a celluloid sheet in place of paper for plotting the track probably proves of considerable advantage in field work. The method is due to E. R. Ryder, of the United States Signal Corps.

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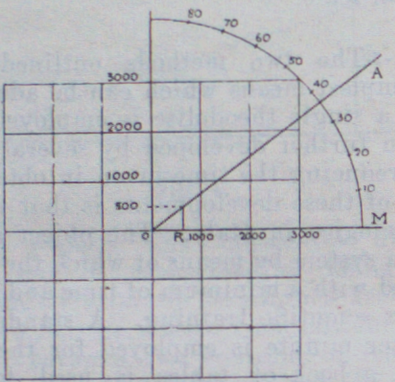

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Method I. 5.—A method possessing original features has been suggested by W. Hartree, of H.M.S. "Excellent," Portsmouth, and employed by R. E. Watson, for some time Assistant in Charge of Falmouth Observatory. In main outline this is similar to that described under Method I. 2, but the book of tables for h cot α is replaced by a set of polar curves running spirally outward from the origin of polar co-ordinates. One polar curve is required for each height step and D can be read off directly from the graph when α is known. In ordinary notation the family of curves is given by $r = h\cot\theta$, a curve being given for each value of h (height) which is required. If a protractor pivoted at

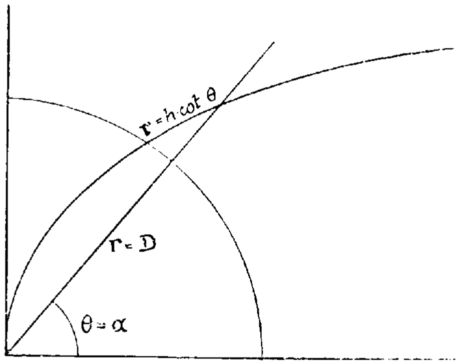

Fig. 3.

the origin be set at the elevation α of the balloon the length of the radius vector to the appropriate curve gives the required distance D. D being thus determined the rest of the computation is carried out on squared or radially ruled paper in the ordinary manner. It appears to the writer doubtful whether this method could compare in general convenience with the use of tables for D, especially in the case of field work.

Method I. 6—Another method of computing $D = h\cot\alpha$ which has much to recommend it is with the aid of a slide rule either of the ordinary pattern or of the special type (see p. 156) supplied by the Meteorological Office for pilot balloon observations. This method is so simple that but little knowledge of the use of a slide rule is required for its employment.

The combination of graphical means and slide rule mentioned above naturally leads on to a consideration of the purely slide rule methods in which all graphical work is dispensed with. These will next be considered.

Method I. 7.—To facilitate computation by slide rule it is customary to provide specially ruled forms with an appropriate column for the figures deduced in each step of the calculation. Thus in forms issued by the Meteorological Office and used for some years past columns are provided under the headings "Time," "Azimuth," "Angular Altitude," "h" (height), "$h\cot\alpha$" (=distance), "D_E," "D_N" (component distances to E and N), "V_{W-E}," "V_{S-N}" (component wind velocities), ϕ (wind direction 0-360°), and V (wind velocity). Details of

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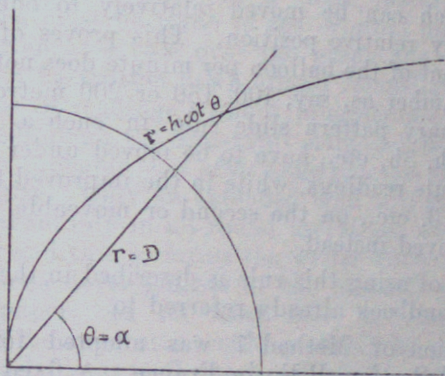

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The method of using this rule is described in the section of the Computer's Handbook already referred to.

A modification of Method 7 was adopted for use in the Meteorological Section, R.E., in France. A fixed rate of ascent of 500 feet per minute was employed so that the heights at the ends of successive minutes were the same in all ascents and were printed on the forms used; the computation was also simplified as the values of h were multiples of 500. A further improvement was introduced by the construction of a table in place of a graph or slide rule for obtaining resultant velocity from components. With skilled operators it was found possible not only to keep the calculation of the wind velocity and direction "up to date" from minute to minute as the balloon was followed, but also to calculate the necessary "ballistic" winds for the use of the Artillery. The complete information obtainable from the ascent was ready for despatch immediately on the termination of the ascent. To do this two operators proved sufficient, one at the theodolite and one using the slide rule. For field work in those cases where intelligent operators are available this method is probably the most serviceable that can be employed. The absence of the somewhat large sheets of paper which must necessarily be used in any graphical method to give the required accuracy is a distinct advantage for use out of doors.

Method I. 8.—A slight modification of Method 7 which has been employed by some workers consists in using $h/60$ for h in the computation. In Method 7 where h is entered in metres, in order to obtain the component velocity from successive increments of the component distance it is necessary to divide by 60 to obtain values in metres per second instead of in metres per minute. By entering $h/60$ for h on the forms this necessity is obviated and thus a little time is saved. A separate table can be used showing the height of the balloon at each successive minute from the start which will serve in the absence of the figures on the working sheet. As it is a very general practice to employ one or perhaps two standard rates of rising for all ascents the provision of such a table presents no difficulty.

Method I. 9.—A very ingenious method of calculation of wind from pilot balloon ascents was described by P. Bolton in the Quarterly Journal of the Royal Meteorological Society (Vol. 44 p. 31, 1918). This is best classified under the slide rule methods, though the slide rule is replaced by a graph ruled with logarithmic scales in a special manner. The method is too complicated in principle to admit of a brief description and for details reference must be made to the original paper. By suitable manipulation of a rule over the graph the wind direction and velocity can be written down almost immediately from each consecutive pair of readings without intermediate steps in the calculation. Although the apparatus employed is rather complicated it appears probable that after some practice it could be used with great facility. Only an extended trial will show whether it can compare favourably in all round usefulness with other established methods and this so far as the writer knows it has not yet received. Various developments of the method are also mentioned in the paper. In its most fully developed form the primary cost of the apparatus would probably be somewhat high. No data are available as to the accuracy of this method.

PART II.—DOUBLE THEODOLITE ASCENTS.

As already stated, work with two theodolites at the ends of a base has received little attention compared with that devoted to the single theodolite method, and the means of computation are consequently, in general, less well developed. The simplicity and speed of working with one theodolite caused it to be almost universally adopted in this country and on the different fronts during the late war. As with a single theodolite, both graphical and slide rule methods have been employed for two-theodolite work.

Method II. 1.—Among purely graphical methods attention may be directed to one described and illustrated recently in the United States Monthly Weather Review. In this a sheet of paper ruled with both squared and radial ruling is mounted upon the plotting board. The centre of this ruling marks one theodolite station. At the position on the board which represents the second station a radial arm is pivoted working against a fixed protractor. Under this arm, but above the ruled paper, is a circular disc of roughened but transparent celluloid, mounted in a similar manner to that described in Method I. 4 for single-theodolite work. It can be rotated about the same pivot as the radial arm. For plotting the balloon track the celluloid remains fixed and the successive points are marked upon it at the intersection of the rotating radial arm and the appropriate radial line on the chart, the two angles being taken from the azimuth readings of the two theodolites at successive minutes. Wind directions are read off from the track by rotating the celluloid disc in the manner described under Method I. 4, and wind velocities are read by means of a suitable scale in the usual manner. The height of the balloon at the end of successive minutes is obtained quite simply by solving the equation $h = D \tan \alpha$ (where D and α are known) graphically by means of the rotating radial arm working above the squared paper. For details of this method, reference may be made to the **Monthly Weather Review** for April, 1919, pp. 222-3.

Method II. 2.—A modification which provides a ready means of obtaining the height of the balloon by solving the equation $h = D\tan\alpha$ graphically in a simple manner is outlined in the "Journal of the United States Artillery," Vol. 51, No. 1 (July, 1919), p. 15. The track is plotted by two radial arms $O_1 P$ and $O_2 P$ working from two origins O_1 and O_2 in a straightforward manner. One of these radial arms $O_2 P$ has a perpendicular arm P C arranged to slide along it while remaining perpendicular, *see* Fig. 5. An additional radial arm $O_2 Q$ can be rotated about O_2 and set at the altitude angle α with $O_2 P$.

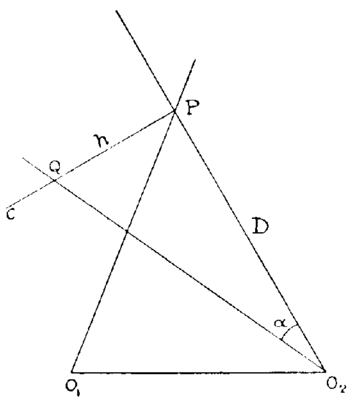

Fig. 5.

Since $O_2 P = D$ and $\angle P O_2 Q = \alpha$ the distance P Q which is read off on a scale engraved upon P C is equal to h, the height of the balloon above the station O_2. A protractor fixed to $O_2 P$ and turning with it allows $O_2 Q$ to be set at the correct angle with $O_2 P$ without difficulty.

Method II. 3.—A well-thought-out example of the mainly graphical method is that adopted by Captain E. M. Wedderburn, R.E., at Shoeburyness. It possesses many points of similarity with that described above (II. 1). The following account is taken from the Meteorological Office Circular No. 30. "The method is a combination of graphical and slide rule methods. On a large drawing board there are fixed two of the radial charts supplied by the Meteorological Office, joined so as to have lines radiating to the left as well as to the right. The common centre of these charts represents the home station. A paper protractor (obtained by cutting up a radial chart) is arranged so that its centre is at a distance from the centre of the radial charts equal to the length of the base between the theodolite stations on a scale of 2 cm. to 600 feet; the bearing of the centre of the protractor is the bearing of the distant from the home station. The whole is covered with a sheet of tracing paper on which the path of the balloon is plotted. The tracing paper is renewed when necessary, but the radial charts seldom require renewal. Two Chesterman steel tapes are pivoted, one at the centre of the radial chart and the other at the centre of the protractor. The home theodolite is set with azimuth N$=180^\circ$ and the distant theodolite with zero$=$bearing of the home station. The steel tapes are set according to the simultaneous readings of the azimuths of the balloon, and their intersection on the plotting table gives the projection of the balloon. Successive positions at intervals of one minute are plotted in this way. The wind speed is obtained directly in feet per second by measuring the distance between successive points. As the scale is 2 cm. to 600 feet the speed in feet per second is measured on the scale of 2 cm. to 10 ft/s. The wind direction is obtained by setting a rolling parallel ruler along the line joining the two successive points; the ruler is then rolled until it coincides with one of the lines of the radial charts. This gives the wind direction directly. The distances from the intersections on the charts to the origins are read off on the steel tapes, 2 cm. being taken as the unit. These give $h\cot\alpha/600$ for each station where h is the height in feet above the station from which the elevation of the balloon is α. From this the height above each station is computed by slide rule. A pilot balloon slide rule is used, 1 on the inner slide is set against 6 on the main slide. The tangent cursor is set to the complement of the angle of elevation and the inner slide is then set so that the horizontal distance of the balloon from either station, as measured on the plotting board, falls under the cursor. Height in feet is then read against the end of the sine-scale.

The ends of the base and the office where the computing is done are connected by telephone. The telephone installation is arranged so that any observer who is using the telephone can speak to and hear either of the other two. This is the case whichever base is being used. Five observers are required, they are allocated as follows:—

Two at the station from which the balloon is being released (the home station).
One at the other station (the distant station).
Two in the office computing.

At the home station, one of the observers follows the balloon. The other, who is at the telephone, gives the needful time-signals and transmits the observations of his own station to the office; the observer at the distant station transmits his own observations on hearing the time-signals given by the home observer. To prevent any confusion, the routine adopted is for the distant observer to send his reading through first and for the home station to send theirs immediately afterwards.

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In the office there are two computers. The one who is wearing the telephone receives the observations and notes them on the special form at the same time giving them verbally to the second computer who plots them on his radial chart and reads off the values $h\cot\alpha/600$, wind speed and direction. He gives these to the first computer who enters them on the form and, by means of the slide rule, calculates the height of the balloon above each station. The necessary computing is done before the reading for the next minute becomes due. Thus the whole work is done during the balloon ascent, and the results are obtained just as rapidly as with single-theodolite observations.

Telephone connections are available at each angle of a triangle which is nearly equilateral, with sides which are about 4,000 feet long. The base used may be any one of the sides of this triangle and the particular side to be used is that which will be most nearly at right angles to the path of the balloon."

It will be seen that with a sufficient staff and suitable telephone connections it is possible to obtain the resultant velocity and direction as rapidly by means of the double-theodolite method as with the single-theodolite and at the same time the large source of uncertainty as to the rate of ascent which is inherent in the latter is eliminated.

Method II. 4.—As in the case of the single-theodolite the purely slide-rule method of computation offers advantages in simplicity of apparatus and absence of the large sheets necessary for graphical means. A straightforward method of working by slide rule is described in the Computer's Handbook (M.O. 223) Section II., Sub-section I. Special forms to facilitate the work have been issued by the Meteorological Office. The amount of computation is necessarily considerably greater than in the case of single-theodolite ascents and with a single computer the time taken would probably be not less than double that required for the simpler method.

Method II. 5.—A modification of P. Bolton's method for single-theodolite ascents which has already been mentioned (I. 9) is adapted for use with two theodolites. An account of the process will be found in the same paper.

Method II. 6.—An original plan for following balloons is put forward in the Beiträge zur Physik der freien Atmosphäre for March 15, 1916, by O. Tetens of Lindenberg Observatory. It is intended to overcome certain drawbacks found in the normal method, the chief of which is the trouble experienced in keeping the balloon in the field of view when it is nearly overhead. The method requires specially constructed theodolites which resemble the normal balloon pattern turned on its side, so that the main axis of the instrument becomes horizontal. When using two theodolites at the ends of a horizontal base the axes of the two instruments lie in the same line, *i.e.*, along the base. The primary circle of each instrument then measures the angle between the horizontal and the plane containing the two posts of

In the office there are two computers. The one who is wearing the telephone receives the observations and notes them on the special form at the same time giving them verbally to the second computer who plots them on his radial chart and reads off the values $h\cot\alpha/600$, wind speed and direction. He gives these to the first computer who enters them on the form and, by means of the slide rule, calculates the height of the balloon above each station. The necessary computing is done before the reading for the next minute becomes due. Thus the whole work is done during the balloon ascent, and the results are obtained just as rapidly as with single-theodolite observations.

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PART III.—OBSERVATIONS OF A BALLOON TAIL.

In this method of observation a tail of known length is hung below the balloon and the angle which it subtends at the théodolite is measured at frequent intervals by a micrometer eyepiece. From this reading and the angular altitude of the balloon, the height can be calculated. Ideally the method gives the advantages of two theodolites without much more labour than in the single-theodolite method, but in practice certain difficulties arise.

A good deal of attention was devoted to this method about 10 years ago by Captain C. H. Ley, R.E., who published two papers in the Quarterly Journal of the Royal Meteorological Society, describing the mode of working and setting out the results obtained. (Vol. 34, 1908, p. 27; Vol. 37, 1911, p. 33.) The method has been tried by many workers and has been developed somewhat of late years.

Method III. 1.—The work of computation for h from the micrometer readings on the tail and the altitude α can be carried out readily with a slide rule. The equation to be solved is of the form $h = k\,\dfrac{\sin 2\alpha}{m}$ where m is the reading of the micrometer and k is a constant depending upon the length of the balloon tail and the scale of the micrometer. A description of the slide-rule method will be found in the Computer's Handbook, Section II., Sub-section I. (continuation).

Method III. 2.—For solving the above equation in "h" graphically instead of by slide rule, a means of great simplicity has been introduced by J. H. Field of the Indian Meteorological observation and the balloon. These two readings should be identical and a check on the simultaneity of the observations from each station is thus obtained, according to the claims of the author. A graphical method of computation is set out. The method can also be adopted for single-theodolite work. There appear to be considerable disadvantages in the system. The type of computation is inherently more complicated than that associated with the normal system. Further development might partially overcome this drawback, but it seems unlikely that it could be entirely removed. One of the great advantages of the normal balloon type theodolite is that the eye-piece always remains at the same height with its axis horizontal. This feature would appear to be sacrificed in the proposed new type. It seems to the present writer very doubtful whether the advantages claimed for this modified method of working would in any degree compensate for the drawbacks introduced.

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Department. In this method a diagram is prepared by setting out points along the axis of x marked ($\alpha =$) 5°, 6°, &c., to 45°, the position of the points being such that x is proportional to sin 2α.

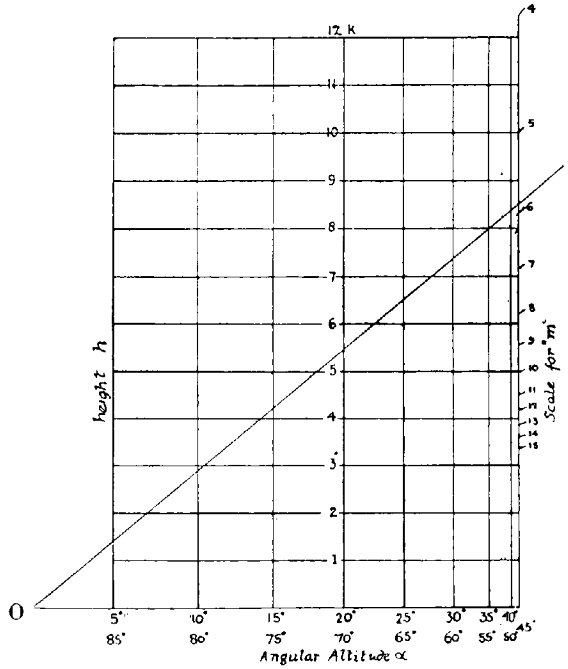

Fig. 6.

Thus for the point marked 10°, x is proportional to sin (2 × 10°), for the point marked 20°, to sin (2 × 20°), and so on. Vertical ruling is drawn through each of these points corresponding with the different values of α. Ordinates on the diagram represent heights h, on a linear scale. The equation $h = \frac{k}{m}$ sin 2α plotted upon the diagram thus represents a straight line through the origin O, the slope of the line depending upon the particular value of m in the equation.

To determine h for a known value of α and m, a cotton is stretched across the diagram from the origin at the slope appropriate to the value of m, thus forming the line $h = \frac{k}{m}$ sin 2α, and the height is read off immediately from the point of intersection of the cotton with the ordinate through the corresponding value of α. The slope of the cotton across the diagram is set by means of a scale for m running up the right-hand side of the graph. For the use of this diagram it is necessary to adhere to one standard length of balloon tail, for which the diagram has been prepared.

Method III. 3.—Another graphical means of solving the equation $h = k \frac{\sin 2\alpha}{m}$ is due to F. J. W. Whipple. This method has the advantage that the horizontal distance of the balloon is obtained in the same operation as h the height. In this method a graph is employed having a series of semi-circles which touch one another at the common point O and stand upon the same line O A which forms a diameter to each.

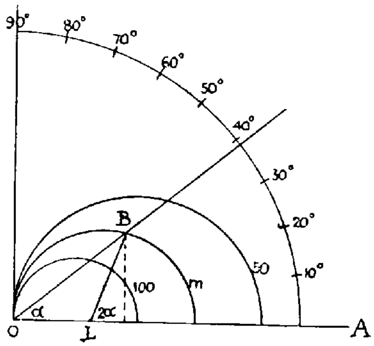

Fig. 7.

Altitude angles from 0° to 90° are set out on a divided quadrant centred at O. The whole is drawn upon squared paper, the ruling of which runs parallel and perpendicular to O A. Each circle corresponds with a given reading of the micrometer eye-piece and its radius is proportional to $\frac{1}{m}$ the appropriate value of m being marked against it. The principle of the method is based upon the fact that the angle subtended by an arc at the centre of a circle is twice that subtended at the circumference, so that if the angle B O A in the figure $= \alpha$ the angle B L A will equal 2α (L is the centre of the circle m). The mode of use will be made clear by an example. If the micrometer reading of the balloon tail be m and the altitude α, a radial ruler is set along the line O B through the α point on the protractor scale and the point B noted where the ruler cuts the circle marked m. The radius of the circle is, as noted above, proportional to $\frac{1}{m}$ or $= \frac{k}{m}$ on any suitable scale; so that B L $= \frac{k}{m}$ and the ordinate from B to O A $=$ B L $\sin 2\alpha = \frac{k}{m} \sin 2\alpha = h$. Thus the height of the balloon above the ground is given by the ordinate of B and obviously the horizontal distance is given by the corresponding abscissa. As in Method III. 2 above a given graph can only be employed with one length of balloon tail. The graph is easily prepared and easy to use, but it appears that interpolation for values of m between those for which semi-circles are drawn might be a little troublesome.

I am indebted to Mr. R. A. Watson Watt of South Farnborough for bringing the preceding two methods to my notice

APPENDIX.

Reference may appropriately be made here to two methods which have been developed during the past few years for determining winds up to considerable heights on occasions when the presence of much cloud renders the use of pilot balloons impracticable. The first is due to Captain A. V. Hill and consists in sending up an anti-aircraft shell to burst at the height at which an observation is required. The drift of the smoke cloud from the burst is watched in a specially designed mirror or pair of mirrors. These mirrors have their reflecting surfaces horizontal and take the place of the theodolites used in pilot balloon observations. If two are employed at the ends of a base line the height of the burst can be determined as well as the subsequent drift, while if one only is used the height must be calculated from the fuse setting of the shell. In taking a reading the eye is placed against a fixed eye-piece above the mirror and the motion of the drift as reflected in the mirror marked with a pen upon the glass. The necessary calculation to determine the wind velocity is very simple and easily performed. In this method it is necessary to fire a separate shell for each height at which it is desired to determine the wind current. In practice it has been found that the method can be used to advantage on many occasions when pilot balloon observations are out of the question on account of the presence of much cloud. The shell can be fired and the smoke drift observed through a small and temporary break in an otherwise persistent cloud sheet. In a further development for use on entirely overcast days a succession of shells is fired at definite short intervals of time and the distances apart of the smoke-clouds and the direction in which the line lies are determined from an aeroplane flying above the spot. The wind is thus measured.

The second method, also to a large extent independent of atmospheric conditions, consists in sending up small balloons loaded with bombs which burst after a certain time, the position of the burst being determined by sound-ranging from the ground. The average rate and direction of travel of the balloon up to the level of the burst is thus obtained. By arranging for several bombs to burst at different heights the average wind current in each intermediate layer of air can be determined. (*See* Comptes Rendus 167, 1918, pp. 769-772.)