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THE MEASUREMENT OF UPPER WIND VELOCITIES BY OBSERVATIONS OF ARTIFICIAL CLOUDS

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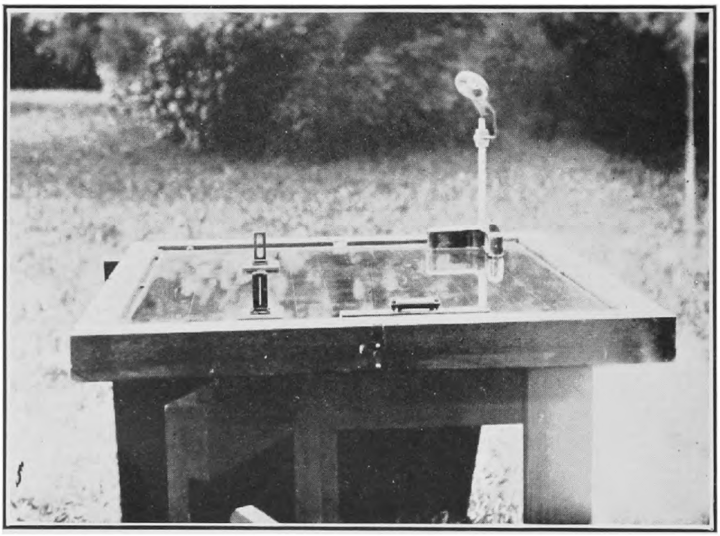

The Hill Mirror

THE MEASUREMENT OF UPPER WIND VELOCITIES BY OBSERVATIONS OF ARTIFICIAL CLOUDS

By C. D. Stewart, B.Sc.

Observations of the motion of clouds have formed part of the regular work of meteorological observatories for many years. Measurement has been made by means of nephoscopes, of which there are two main types; the first, of which the Besson Comb nephoscope may be said to be representative, has an elevated scale on which the motion of the cloud is observed directly; the second, the best-known example of which is probably the Fineman nephoscope, having a suitable scale engraved on a mirror in which the cloud is observed. In the absence of precise knowledge as to the heights of clouds the information obtainable from these observations is limited to the ratio of the linear velocity of the cloud to its height above ground. Although in this way valuable knowledge is gained about the general circulation of the atmosphere, the observations are manifestly unsuited to the measurement of actual linear velocities, and, in fact, have never been intended to serve that purpose. More recently, however, the principle of the mirror nephoscope has been utilised in a method for obtaining the velocities of both natural and artificial clouds.

By employing two horizontal mirrors, suitably mounted, the height of a cloud can be obtained and hence its velocity, but in actual practice the method has been mainly confined to observations of artificial clouds, which, as they are formed at a known height, require only one mirror for the complete determination of their motion, and, moreover, have the advantage, as compared with natural clouds, that they can be formed and observed at whatever heights may be desired. The method was originally practised with clouds formed by the bursting of shells at specified heights and successful observations have recently been made on clouds liberated from aeroplanes.

The present paper gives a brief account of the theory of the method of determining upper wind velocities from observations of clouds in a mirror, followed by practical instructions for the use of the Hill mirror both for double-mirror and single-mirror observations, and a short description, with the necessary practical details, of the new method in which the smoke cloud is discharged from an aeroplane.

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I.—Theory of the Method.

Suppose the image B of a portion of cloud at A to be observed in the horizontal mirror PQRS (Fig. 1).

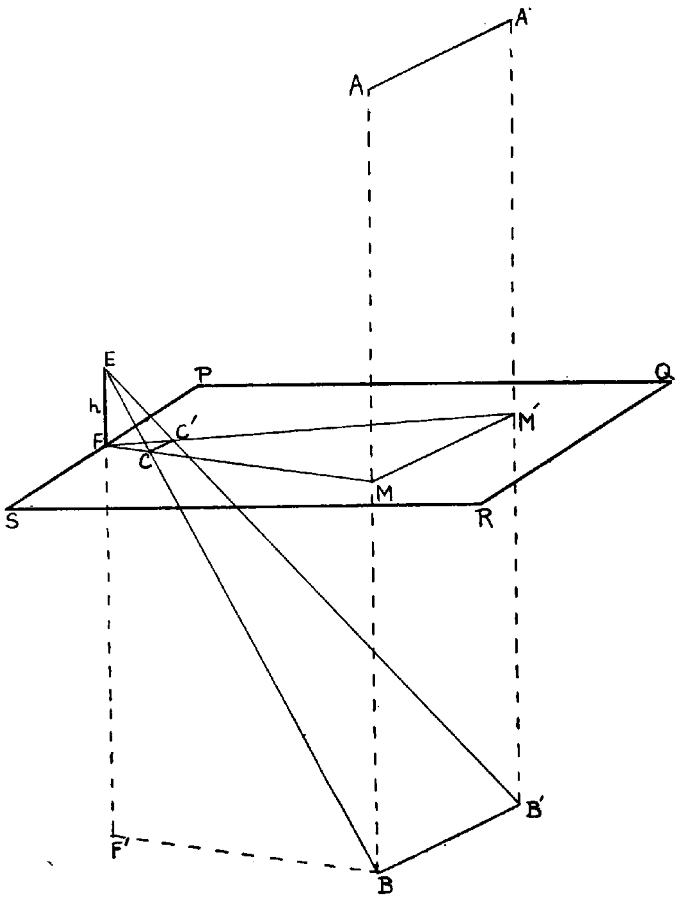

FIG. 1.

The line AB joining the cloud and its image cuts the surface of the mirror at M. After a certain interval of time, suppose the portion of cloud to have moved to A′ along the horizontal path AA′. The image will appear to have moved along BB′ to B′. It is evident that:

$$AM = BM$$
$$A'M' = B'M'$$
$$AA' = BB' = MM'$$

If now the image is observed through an eyepiece at E, vertically above a point F in the edge of the mirror, the line EB will cut the surface of the mirror in a point C: this point can be fixed by interposing some small obstacle on the mirror, such as a pen point. Similarly the point C′ where the line EB′ cuts the mirror can be found, and, if desired, the path of the cloud image can be traced out on the mirror as the line CC′.

It is now seen that EBB′ and ECC′ are two triangles in the same plane. Moreover, since the mirror is a horizontal plane and the line of motion of the cloud AA′ is supposed to be horizontal, BB′ will also be horizontal. It follows, therefore, that CC′ and BB′ are parallel and that ECC′ and EBB′ are similar triangles. We thus see that:

$$\frac{BB'}{CC'}=\frac{BE}{CE}$$

Imagine the line EF to be extended downwards to cut the horizontal plane containing BB′ in F′. Then EF′B and EFC are triangles in the same plane, and FC and F′B, both being horizontal, are parallel. These are therefore two similar triangles so that

$$\frac{F'E}{FE}=\frac{BE}{CE}.$$

It follows then that

$$\frac{F'E}{FE}=\frac{BB'}{CC'}.$$

Now FF′ = MB = AM. AM is the height of the cloud above the mirror surface; if we denote this height by H and the height FE of the eyepiece above the mirror surface by h, we have

$$\frac{BB'}{CC'}=\frac{H+h}{h}$$

$$\text{or } BB'=\left(1+\frac{H}{h}\right)\cdot CC'$$

As the ratio H/h is large compared with unity this may be written sufficiently accurately as

$$BB'=\frac{H}{h}\ CC' \qquad - \quad - \quad - \quad (1)$$

If, then, we can draw a trace of the motion of the cloud on the surface of the mirror, as viewed from a fixed eyepiece, we can, if we know the height of the cloud, calculate the distance through which it has moved during the observation. Further, if the time during which the cloud has been observed has also been measured it is a matter of simple division to obtain the velocity.

It is to be observed also, referring again to Fig. 1, that CC′ being parallel to BB′, is therefore parallel also to AA′ and will give the direction of drift of the cloud, provided that some fixed line on the mirror has its azimuth determined.

II.—Instructions for the Use of the Hill Mirror.

The Instrument.—This instrument consists of a horizontal glass mirror mounted in a wooden frame. When in use it is supported on three flat-topped levelling screws which are fixed to a wooden base in such a way that they form an equilateral triangle with 21-inch sides. In the centre of the underside of the mirror frame is a bearing into which fits a spindle standing vertically from the wooden base, providing an axis about which the mirror can readily be turned in a horizontal plane as required.

The mirror itself is of silvered glass some 70 centimetres square. On its surface is marked permanently a 50cm. square with each side divided into 5cm. segments by lines which divide up the large square into 5cm. square sections. The photograph shows the mirror with the accessories necessary for the observation of cloud motion. The eye-piece is fitted to a heavy metal base and consists of a flat metal fitting bent inwards at an angle of 45 degrees near the top and having screwed into it a circular plate with an aperture 2 millimetres in diameter at its centre. The under side of the circular plate is painted white. The centre of the aperture is ordinarily 30cm. above the surface of the mirror, but the fitting is fixed to the base by two nuts which permit of a possible variation in the height of the eyepiece of about one inch.

The instrument is provided with a spirit level and with sights for the direction adjustment. The foresight consists of a small metal frame with a vertical wire across the centre and the backsight of an upright metal plate with a vertical slit. The manner of using the sights will be clear from the photograph of the apparatus.

Adjusting the Mirror for Use.—In use the mirror is set so that one set of lines runs in a standard direction, usually from north to south. It is necessary, first, if there is no convenient mark to the north, south, east or west of the observing station, to erect some suitable object, as, for example, a stout rod, in one or other of these directions at a distance of one or two hundred yards. For this purpose a magnetic compass may be used. The sights are placed one at each end of a centre line of the mirror, and it is necessary, of course, that the centres of the slit and the wire in the respective sights shall be vertically over the line. This is secured by looking through the sight and adjusting it until the line on the mirror appears to run up the centre of the slit or along the wire, according to which sight is being tested. The mirror is now swung round the centre bearing until the rod or other direction mark is covered by the wire when viewed through the slit. It is not necessary, of course, to choose north as the standard direction, but correction of the angles measured by the mirror is thereby avoided so that directions can be read off directly from the traces obtained. In the case of its being more convenient to set the mirror on some mark, away from north, whose azimuth is known, each direction angle observed will require to have added to it the angle the reference lines of the mirror make with the north direction.

The writer has found it more convenient in practice to make the direction setting before levelling the mirror. When the mirror is properly levelled it rests on the flat tops of the levelling screws and owing to its considerable weight the friction between it and the screw tops is such as to make the swinging of the mirror for azimuth adjustment a matter of some difficulty and, in fact, unless the base is specially fixed in some way, the level already obtained is likely to be deranged. The mirror is supported quite firmly on the centre bearing if the screws are lowered until they no longer carry the weight, and then turns quite easily for the direction adjustment.

Levelling is carried out with the three screws in the ordinary way. The level is laid on the face of the mirror so as to be parallel to the line joining two of the screws (A and B, Fig. 2). The level is altered by turning these two screws in opposite directions by equal amounts so that while one end of the mirror is raised the other is depressed by a like amount. The point M, midway between A and B, is neither raised nor lowered: the point C over the third screw, also has its level unchanged, so that the motion of the mirror is a rotation about the line CM, and since one line perpendicular to CM has been adjusted to be horizontal, namely, the line AB, a rotation of the mirror about AB bringing CM to a horizontal position will secure that the mirror as a whole lies in a horizontal plane. This is effected by placing the level along the line CM and levelling by the use of the screw at C only. It is necessary to check the first level after finishing the second one as a slight departure of the level from the line AB is possible, owing to the screws below the mirror not being visible.

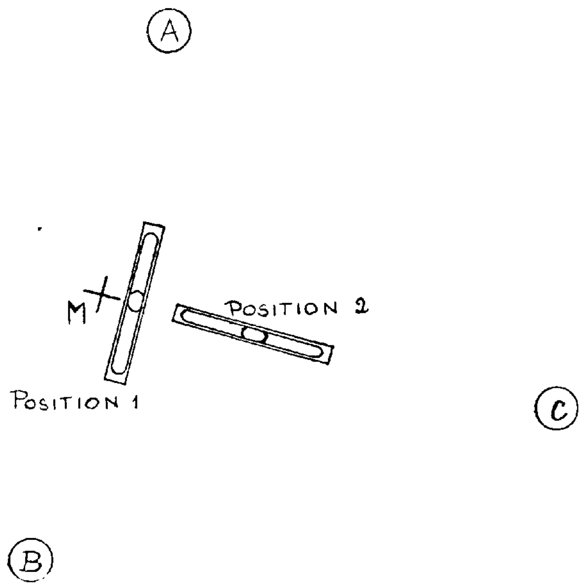

FIG. 2.

Observations with two Mirrors.—The mirror, being level and having its orientation fixed, is ready for observations. As originally used for natural clouds two mirrors were required for the measurement of velocity as it was necessary in this case to determine the height of the cloud. The mirrors were fixed at the ends of a long base-line PQ (Fig. 3) of length b.

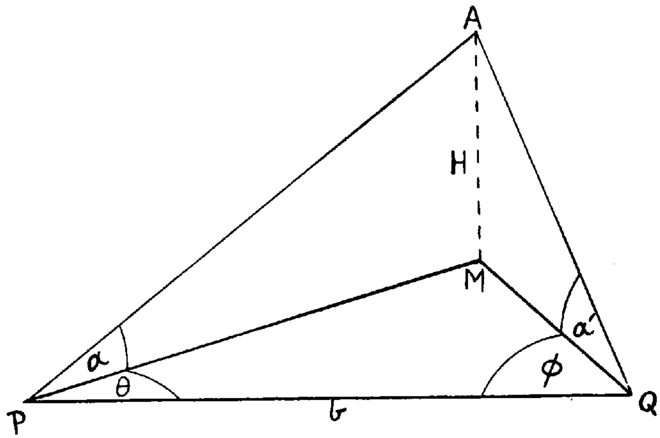

FIG. 3.

Suppose A to be the position of the cloud of height H at the beginning or end of the observation and M a point on the ground vertically below C. Then PM and QM give the directions of the cloud as viewed from P and Q respectively. θ and ϕ are the angles that PQ and QM make with the base-line PQ, a and a' being the angles of elevation of the cloud at the two stations. Then we have

$$\begin{aligned} H &= \text{PM} \tan a \text{ or QM} \tan a' \\ &= b \frac{\sin \phi}{\sin (\theta + \phi)} \tan a \text{ or } b \frac{\sin \theta}{\sin (\theta + \phi)} \tan a' \end{aligned}$$

We require to know, therefore, the angles a, θ and ϕ in order to determine the height H. A measurement of a' will give a second value of H which is useful as a check on the first one.

In order to be able to obtain these angles easily it is convenient to observe from one of the corners of the fifty-centimetre square on the mirror. The eyepiece fitting is therefore placed so that on looking downwards through the aperture the corner of the square and the image of the aperture in the mirror are seen in line. This secures that the eyepiece aperture is vertically over the corner.

A portion of cloud having been selected for observation, a stylographic pen is held to the surface of the mirror so that through the eyepiece the point of the pen and the portion of cloud are seen in line; as the cloud moves the pen is moved with it so as to keep its point and the cloud in line as seen through the eyepiece. At the beginning and end of an arranged interval, position marks are made with the pen on the glass, giving the observed motion of the cloud.

If a line is now ruled from the observation corner of the mirror at P to one of these marks we evidently have a part of the line PM (Fig. 3). Direct measurement with a protractor gives now the angle between PM and the north and south lines of the mirror. The angle between these north and south lines and the base line PQ can be measured without difficulty with a prismatic compass so that we get the angle θ, either by calculation or by drawing on the mirror a line to represent PQ and making the appropriate angle with the north lines, the angle θ being then measured directly from this line. The same process at the other mirror gives the angle ϕ.

The method of obtaining the elevation will be clear from Fig. 4. The angle of elevation of the cloud A from the point C, marked by the pen on the glass, is evidently equal to the angle between the mirror and the line ECB, along which the cloud image is viewed from the eyepiece E. The tangent of this angle is EF/CF; EF is the height of the eyepiece, an instrumental constant, while CF is the distance from the pen mark at C to the corner of the fifty-centimetre square.

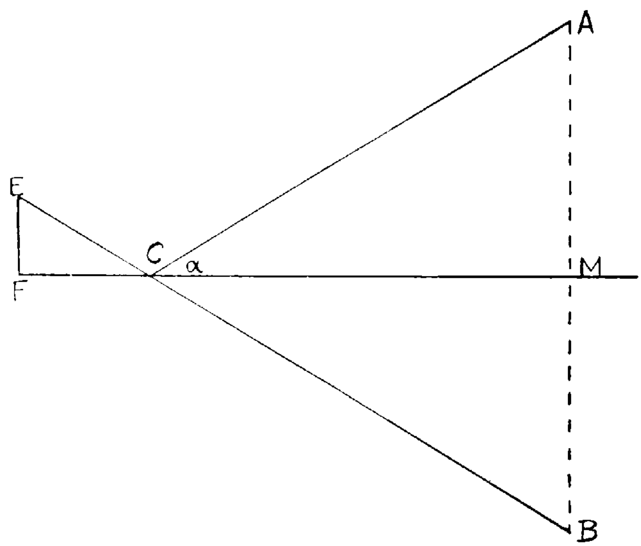

FIG. 4.

If the trace obtained by following the cloud in the mirror is of length m, the actual distance moved by the cloud during the observation is, from (1), mH/h. The velocity of the cloud, if the interval of time during which it was followed is t, is then given by :—

$$u = \frac{mH}{t\,h} \quad - \quad - \quad - \quad - \; (2)$$

It is necessary, of course, to have a reasonably long base-line, and consequently telephonic communication between the two mirrors is essential in order to ensure that the same cloud is being observed in each mirror and that the observations at each station are made at the same time.

Observations with a Single Mirror.—The use of a second mirror in the observation as described above is only necessary when the height of the cloud has to be determined. In observations of artificial clouds the use of the second mirror is avoided by having the cloud formed at a known height. The actual process of observation in the mirror differs in no way from that just described, but as there is no height to be measured there is no necessity for measuring the angle of elevation of the cloud. Consequently it is no longer necessary to fix the eyepiece in any particular position. A shell having been burst at the height for which the wind is required, the observer places the eyepiece in the most convenient position for following the resulting cloud. When he has the cloud image in the mirror covered by the pen point he marks the position on the glass, at the same time giving a signal to an assistant who thereupon starts a stop-watch. The assistant follows the time and warns the observer shortly before the end of the observation period and again exactly when the period is completed, when the observer again marks the position of the cloud on the mirror. An alternative method of marking is to use small heavy pellets for the beginning and end of the cloud path, but, as compared with the use of a pen, there is the danger that the pellets may be moved while the length of the path is being measured. Also, if the pen is used a permanent copy can be readily taken on tracing paper of the path of the cloud, together with the nearest direction lines on the mirror. The direction of the wind is read off directly by means of a protractor.

As in the observation with two mirrors the distance x travelled by the smoke is obtained from m, the length of the trace on the mirror, by the equation :—

$$x = \frac{mH}{h},$$

H and h being, as before, the heights of the cloud and eyepiece respectively. The eyepiece is usually fixed at a distance of 30 centimetres above the mirror while the height of the cloud will commonly be expressed in thousands of feet. Now 30cm. $= 30/(2{\cdot}54 \times 12) = 0{\cdot}985$ feet, so that with the data given in thousands of feet we have :—

$$x = \frac{1000\,mH}{0{\cdot}985} \quad \cdot \quad \cdot \quad \cdot \quad (3)$$

x appearing in the same units as m. If the time of observation is one minute and m is measured in centimetres, x gives the velocity in centimetres per minute; the velocity in metres per second is thus given by :—

$$\frac{x}{60 \times 100} \text{ or } 0 \cdot 17\, mH.$$

Similarly we find that for the velocity in other units each centimetre of trace on the mirror represents :

$\cdot 56\ mH$ feet per second, or
$\cdot 38\ mH$ miles per hour.

If the trace is measured in inches, it follows that each inch of trace represents :

$\cdot 43\ mH$ metres per second,
$1 \cdot 41\ mH$ feet per second,
$\cdot 96\ mH$ miles per hour.

From these formulæ the following table has been calculated for convenience in computing wind velocity from the length of trace on the mirror.

TABLE I.—WIND VELOCITIES FROM A MIRROR OBSERVATION OF ONE MINUTE WITH EYEPIECE 30 CM. ABOVE MIRROR.

Height of cloud	Wind velocity per cm. of trace on mirror			Wind velocity per inch of trace on mirror		
feet	m./sec.	ft./sec.	mi./hr.	m./sec.	ft./sec.	mi./hr.
1,000	0·2	0·6	0·4	0·4	1·4	1·0
2,000	0·3	1·1	0·8	0·9	2·8	1·9
3,000	0·5	1·7	1·1	1·3	4·2	2·9
4,000	0·7	2·2	1·5	1·7	5·6	3·8
5,000	0·9	2·8	1·9	2·2	7·1	4·8
6,000	1·0	3·4	2·3	2·6	8·5	5·8
7,000	1·2	3·9	2·7	3·0	9·9	6·7
8,000	1·4	4·5	3·0	3·4	11·3	7·7
9,000	1·5	5·0	3·4	3·9	12·7	8·6
10,000	1·7	5·6	3·8	4·3	14·1	9·6
11,000	1·9	6·2	4·2	4·7	15·5	10·6
12,000	2·0	6·7	4·6	5·2	16·9	11·5
13,000	2·2	7·3	4·9	5·6	18·3	12·5
14,000	2·4	7·8	5·3	6·0	19·7	13·4
15,000	2·6	8·4	5·7	6·5	21·2	14·4
16,000	2·7	9·0	6·1	6·9	22·6	15·4
17,000	2·9	9·5	6·5	7·3	24·0	16·3
18,000	3·1	10·1	6.8	7·7	25·4	17·3
19,000	3·2	10·6	7·2	8·2	26·8	18·2
20,000	3·4	11·2	7·6	8·6	28·2	19·2

For an observation of half a minute the factors given in the table must be doubled; for an observation of two minutes they must be halved.

Examples.—(i) Suppose the shell to be burst at 8,000 feet, and one minute's observation on the mirror to give a line from A to B (Fig. 5). The length of AB is 3·8 cm. and from the table we find that each cm. with a cloud at 8,000 feet represents 1·4 metres per second or 3·0 miles per hour. The velocity is thus $1 \cdot 4 \times 3 \cdot 8 = 5 \cdot 3$ metres per second or $3 \cdot 0 \times 3 \cdot 8 = 11 \cdot 4$ miles per hour. If, on the other hand, we measure in inches we find that the line AB is 1·5 inches in length; from the right-hand side of the table we have for each inch of trace 3·4 metres per second or 7·7 miles per hour. The velocity, therefore, is $3 \cdot 4 \times 1 \cdot 5 = 5 \cdot 1$ metres per second or $7 \cdot 7 \times 1 \cdot 5 = 11 \cdot 6$ miles per hour. As the trace is from A to B the direction as measured with a protractor from the line LM is 43° west of south, or 223° from north measured in a clockwise direction, since LM is one of the permanent lines of the mirror and is set in a north-south direction.

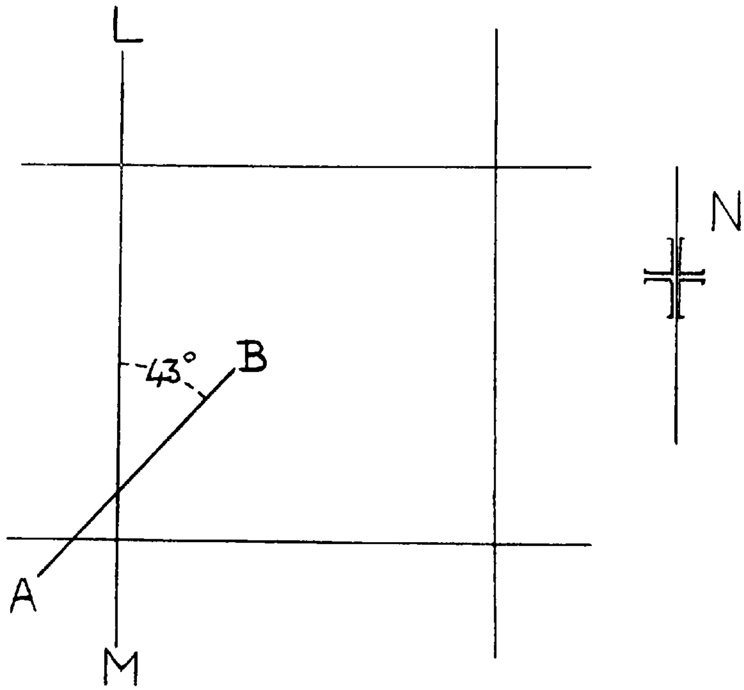

FIG. 5.

(ii) A shell burst at 15,000 feet gives a trace of 4·2cm. on the mirror for an observation of two minutes. From the table the factor is 5·7 for miles per hour, but as the trace took two minutes to obtain we divide the factor by 2, obtaining 2·85. This gives a velocity of $2 \cdot 85 \times 4 \cdot 2 = 12 \cdot 0$ miles per hour.

(iii) A shell burst at 4,000 feet gives a trace of 3·7 inches in half a minute. The factor to give miles per hour for this height is 3·8, but as the trace was obtained in half a minute we double the factor, getting 7·6. The velocity required is thus found to be $7 \cdot 6 \times 3 \cdot 7 = 28 \cdot 1$ miles per hour.

Whether half a minute, one minute or two minutes is the time for which the cloud is to be followed is determined solely, of course, by the consideration that a reasonable length of trace on the mirror is desirable, both for length and angle measurements.

III.—Observations of Smoke Clouds discharged from an Aeroplane.

The Smoke Bombs used.—In times of peace the use of shell bursts must be restricted to a very small number of places where the shooting can take place without danger to life or property : it becomes necessary, therefore, either to abandon the method, except in such places, or to devise some alternative method of producing smoke at a specified height. From 1919 to 1921 the method fell into disuse, but in November, 1921, Lieutenant-Colonel E. Gold suggested that bursts of smoke emitted from an aeroplane would probably give good clouds for observation and, an opportunity presenting itself a little later for a trial of the method, the writer was asked to carry out some experiments. After one or two trials it was found that good results were to be obtained in this way. It is not permissible, of course, to discharge smoke from an aeroplane by any device which involves fire or explosion. A special bomb had, therefore, to be devised and the one which was finally used was of a very simple type. A tin canister with a lid which jams in, such as the tins in which Lyle's Golden Syrup or some kinds of paint or enamel are sold, had one wire soldered through the middle of the base and another through the centre of the lid. The base wire was fastened to the under-carriage of the aeroplane while the lid wire was fastened within easy reach of the passenger. The tin was filled with stannic chloride, a liquid which in contact with the air makes a dense white cloud if broken up quickly. When the aeroplane had reached the required height the passenger pulled the lid off the canister by means of the wire; the liquid was ejected from the tin with considerable violence owing to the speed of the aeroplane. The result was a large white cloud which lasted for upwards of a quarter of an hour and which was admirably suited for observation in the mirror.

The tins used held about one pound of stannic chloride. At 6,000 feet one tin was opened and at 10,000 feet two tins were used together. It had been intended to open a four-pound tin at 15,000 feet but the clouding over of the sky prevented this trial being carried out. The results at the lower heights, however, were such as to suggest that at 10,000 feet a single one-pound tin would have been more than sufficient and even at 15,000 feet would have given a cloud that could probably have been followed quite easily in the mirror. In any case not more than two tins should be necessary. It seems that a tin of about half-a-pound capacity would do well for heights of 5,000 feet or thereabouts, so that an aeroplane in an ascent could probably carry sufficient tins for clouds at several different heights for a set of observations. In the experiments described it was intended to observe at three heights on the one ascent, though it appeared afterwards that sufficient stannic chloride had been carried to give observations at six different levels up to 15,000 feet.

It seems probable that in cloudy weather observations could be made through gaps in the clouds even more easily by this method than by shell bursts since the pilot would always discharge the cloud when in sight of the aerodrome. It may be noted here that if there is a large concrete platform, such as the large compass marking to be found on most aerodromes, the mirror should be mounted on it. The pilot can then see more readily if he is in sight of the observers and should, when there is any option, release his cloud as nearly as possible over the platform; the observations are then made more easily and can be continued for a longer period on the same cloud. If there is no such prominent marking it would be well to provide some temporary one near to the mirror for the reasons indicated.

The Determination of the Height of the Aeroplane.—The question of the height actually attained by the aeroplane is of great importance since the results are obtained by assuming the height to be known with sufficient accuracy. The pilot will read his height from an altimeter, but this instrument does not, as a rule, register accurately, being calibrated for special temperature conditions which are rarely, if ever, met with in an actual ascent. A full discussion of this problem is beyond the scope of the present work but the reader will find a more complete account in a publication of the Meteorological Office*. It will be sufficient here to indicate briefly the principles on which approximate corrections to the altimeter readings may be obtained.

The formula connecting barometric pressure and height is

$$h_1 - h_0 = CT(\log p_0 - \log p_1)$$

where h_0 and h_1 are the heights of two points in a vertical line, p_0 and p_1 the barometric pressures at these points, T the absolute temperature of the column of air between them and C a constant which is $221 \cdot 1$ when, as in the present case, the heights are to be measured in feet. T, of course, varies with height, but it is

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* M.O. Publication 228. *The Estimation of Height from Readings of an Altimeter.*

permissible for the present purpose to regard it as the arithmetic mean of the temperatures at the two points under consideration.

When the formula is applied to the calibration of an altimeter h_0 refers to ground level and is therefore zero. The formula then becomes

$$h = CT(\log p_0 - \log p),$$

p_0 being the barometric reading at the ground; and for any particular height the reading of the altimeter will be correct only if the mean temperature during the ascent is the same as the mean temperature adopted for the column of air up to that height in the calibration of the altimeter, a condition which will usually not be fulfilled.

If we suppose, first, that this condition is fulfilled, then, as previously stated,

$$h = 221 \cdot 1\ T(\log p_0 - \log p) \qquad - - - \quad (4).$$

If, however, as is usually the case, the mean temperature during the ascent is some other temperature T', the actual height will be h' where,

$$h' = 221 \cdot 1\ T'(\log p_0 - \log p).$$

The height registered on the altimeter will be h, since this depends only on p_0 and p, and we are necessarily supposing these the same in the two cases. An error is thus involved which is given by

$$h - h' = 221 \cdot 1\ (T - T')\ (\log p_0 - \log p) \qquad (5).$$

A knowledge of the value of T used in calibration for any particular value of h enables us to calculate the appropriate value for that height of $(\log p_0 - \log p)$ from formula (4), and hence, by substitution in formula (5), the correction $h - h'$ which must be applied to a reading of this height on the altimeter for a given mean temperature.

Tables II (A) and II (B), overleaf, give corrections computed in this way for different temperatures at aircraft level, assuming that the temperature increases 1·5° a. (2·7° F.) for each 1,000 feet decrease in height. The assumption is not always quite correct, of course, but in a case such as the present it is necessary to make some little sacrifice in accuracy for the sake of feasibility in working and except in rare instances the error involved is relatively small. Table II(A) is intended for use with what has been the usual type of altimeter, calibrated for a constant temperature of 50° F., while Table II (B) applies to the more recent type of altimeter, graduated for a temperature of 15° C. (62° F.) at the ground and a uniform decrease of 6·5° C. per kilometre of height, or, approximately, 3·6° F. per 1,000 feet.

TABLE II.—ADDITIONAL HEIGHT TO BE ATTAINED (BY ALTIMETER) FOR GIVEN TEMPERATURE.

(*See p.* 197.)

Altimeter Reading	Temperature on Aeroplane (Degrees Fahrenheit)											
	−25°	−20°	−15°	−10°	−5°	0°	5°	10°	15°	20°	25°	30°
Feet	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
	(A)—*Altimeter calibrated for constant temperature of* 50° *F.*											
1,000	150	140	130	120	110	100	90	80	70	60	50	—
2,000	290	270	240	220	200	180	170	150	130	110	—	—
3,000	430	400	370	340	300	270	240	210	180	150	—	—
4,000	550	510	470	440	400	360	320	280	240	200	—	—
5,000	680	630	580	530	490	440	390	340	290	—	—	—
6,000	810	740	680	620	560	500	440	390	330	—	—	—
7,000	920	850	780	710	640	570	500	440	370	—	—	—
8,000	1,040	960	880	800	720	640	560	470	—	—	—	—
9,000	1,140	1,050	960	880	790	700	610	510	—	—	—	—
10,000	1,250	1,150	1,050	950	840	740	640	540	—	—	—	—
11,000	1,350	1,230	1,120	1,010	900	790	680	570	—	—	—	—
12,000	1,450	1,320	1,190	1,070	950	830	710	600	—	—	—	—
13,000	1,540	1,400	1,270	1,140	1,000	870	740	—	—	—	—	—
14,000	1,620	1,470	1,330	1,190	1,040	900	760	—	—	—	—	—
15,000	1,700	1,550	1,400	1,250	1,090	940	780	—	—	—	—	—
16,000	1,770	1,600	1,440	1,280	1,110	950	—	—	—	—	—	—
17,000	1,840	1,660	1,490	1,320	1,150	970	—	—	—	—	—	—
18,000	1,910	1,720	1,540	1,360	1,180	1000	—	—	—	—	—	—
19,000	1,970	1,770	1,570	1,380	1,200	1010	—	—	—	—	—	—
20,000	2,030	1,820	1,610	1,400	1,200	—	—	—	—	—	—	—
	(B)—*Altimeter calibrated for* 15° *C. at ground and vertical lapse rate of* −6·5° *C. per kilometre.*											
1,000	160	150	140	130	120	110	100	90	80	70	60	50
2,000	300	280	260	240	220	200	180	170	150	130	110	—
3,000	440	410	380	350	320	290	260	230	200	170	140	—
4,000	560	520	480	440	400	360	320	280	240	210	—	—
5,000	670	620	570	520	480	430	380	330	280	—	—	—
6,000	770	710	650	590	540	480	420	360	300	—	—	—
7,000	860	790	720	650	580	510	440	380	—	—	—	—
8,000	940	860	780	700	620	540	460	380	—	—	—	—
9,000	1,000	910	820	730	650	550	450	—	—	—	—	—
10,000	1,050	950	850	750	650	550	—	—	—	—	—	—
11,000	1,090	980	870	760	650	540	—	—	—	—	—	—
12,000	1,120	1,000	880	760	640	—	—	—	—	—	—	—
13,000	1,140	1,010	870	740	—	—	—	—	—	—	—	—
14,000	1,140	1,000	850	710	—	—	—	—	—	—	—	—
15,000	1,130	980	820	—	—	—	—	—	—	—	—	—
16,000	1,110	950	780	—	—	—	—	—	—	—	—	—
17,000	1,080	900	—	—	—	—	—	—	—	—	—	−850
18,000	1,030	840	—	—	—	—	—	—	—	—	—	−1,010
19,000	970	—	—	—	—	—	—	—	—	—	−990	−1,200
20,000	—	—	—	—	—	—	—	—	—	—	−1,190	−1,390

The table is used in the following manner. The aeroplane must be provided with an aeroplane spirit thermometer mounted on one of the outside struts, where it can be read by the pilot. When the specified height is recorded on the altimeter the pilot reads the thermometer, when reference to the table will tell him how many feet he still requires to ascend. For example, if the wind at 10,000 feet is required he ascends until his altimeter reads this height; if the thermometer now reads 5° he requires to continue to climb until the altimeter registers 10,640 feet if it is of the older type which is accurate at 50° F. If the altimeter is of the more recent type the height shown is sufficiently accurate at this height and temperature so that no further gain in height is necessary.

NOTE

The original experiments were carried out at an aerodrome of the Royal Air Force, and it was found that officers of the squadron were able to learn to use the method after a very brief course of instruction and practice.

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