M.O. 354
(formerly Form 2086)

FOR OFFICIAL USE ONLY

AIR MINISTRY

METEOROLOGICAL OFFICE
(NAVAL DIVISION)

UPPER AIR OBSERVATIONS OVER THE SEA

(Revised 1932)

PART I—UPPER WINDS
PART II—UPPER AIR TEMPERATURES

WITH AN APPENDIX ON THE FRONTAL THEORY AND AIR NAVIGATION

LONDON:
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PART I—UPPER WINDS

THE OBSERVATION OF UPPER WINDS BY THE PILOT-BALLOON METHOD.

§ 1.—PRINCIPLES OF METHOD.

General.—One of the most practicable methods of finding the wind in different layers above the surface of the earth is the pilot-balloon method. A rubber balloon, measuring some three or four feet in diameter, is inflated with hydrogen to a known size and after being released its elevation and azimuth are usually read at intervals of one minute. The method has been used on land for many years, a theodolite being employed for the measurement of the elevation and azimuth of the balloon. At sea, owing to the motion of the ship, a theodolite of normal pattern cannot be employed and considerably greater difficulty is experienced in making the observations. A special type of theodolite, mounted in gimbals, may however be used, and various other methods have been developed during the past few years, during which considerable attention has been given to the matter; these are described below.

In addition to knowing the elevation and azimuth of the balloon, it is necessary, before its movement over the surface of the earth can be traced, to determine its height at the time of each observation. The following methods of obtaining the height are in common use :—

(1) by assuming a constant rate of ascent;
(2) by heightfinder, or similar instrument;
(3) by observation of the angle subtended at the point of observation by a tail of known length hanging below the balloon, and
(4) by simultaneous observations from the ends of a base line.

In method (4) the base line must be at least ½ mile in length and the method is, therefore, inapplicable at sea, while method (3), which involves a tail hanging beneath the balloon has not, so far, been found convenient for use afloat (brief particulars of the method are given below). Reliance has, therefore, been placed on methods (1) and (2), and that in most common use, owing to its simplicity, is method (1) in which the balloon is filled to give a known lift and its rate of ascent is then assumed to be constant and of a known value. The height being then known at the end of each minute, the horizontal distance of the balloon from the observer is found from the reading of elevation and its position over the surface of the sea can be determined from the azimuth angle. If the ship is stationary, the position of the balloon can, in this way, be plotted from minute to minute and the speed with which it has moved, i.e., the speed of the air current in which it is travelling, can be readily calculated. If the ship is moving a correction has to be applied to eliminate the effect of this motion.

Rate of Ascent.—The rate of ascent of a balloon is governed by the free lift, which is the force driving the balloon upwards, and the resistance to its motion imposed by the air. With the method of filling now used, in which the balloon is inflated until it just *floats* with a certain weight attached, the free lift is equal to the weight removed from the balloon after inflation has been completed. Thus, if the balloon is filled with the standard filler (weighing 238 gm.), the free lift given to the balloon by removal of the filler is 238 gm. If after removal of the filler a 100 gm. weight is attached to the balloon, the net weight that has been removed will be (238–100) gm. and therefore the free lift will be 138 gm. If L be the free lift of a balloon, W the weight of the rubber balloon and of any equipment which may be attached to it, and v the rate of ascent, it can be shown that v is given by the following formula :—

$$v = \frac{q\,L^{\frac{1}{2}}}{(L + W)^{\frac{1}{3}}}$$

where q is a constant. The value of the constant q varies somewhat with different sizes of balloon, but for balloons measuring 150 inches in circumference when inflated, the size in most common use in the Navy, it is 310 when L and W are measured in grams and v is given in feet per minute. This has been found from a large number of ascents made at Shoeburyness and followed by two theodolites at the ends of a base line. For balloons less than 100 inches in circumference when fully inflated (*see* § 2) q may be taken as 276.

It is not always possible to adjust the free lift of a balloon with great accuracy, particularly if the balloon has to be filled with hydrogen in a position exposed to the wind; the following table, which shows the variation in v for different values of L is, therefore, of interest :—

Free lift L =	200	220	238	260	280 gm.
Rate of ascent v =	671	686	700	716	730 ft./min.

In calculating this table, the balloon is assumed to weigh 80 gm., the mean weight of 150-inch balloons. The free lift normally used is 238 gm., which gives a rate of ascent of 700 ft./min. The table shows that a variation of 4 per cent. in the free lift produces a change of 1 per cent. in the rate of ascent.

It is found in practice that balloons, even if they are filled to the same free lift, do not always ascend at the same rate, the variations being due to the presence of upward and downward currents in the atmosphere. If the balloon is caught in one of these currents, it will rise at a greater or lesser rate than if it were rising in still air. Unless one of the methods for measuring the height of the balloon indicated above is adopted, it is not possible to say whether the balloon has been caught in one of these up or down currents and inaccuracies may accordingly be introduced into the results obtained. While it is very desirable that the height should be measured whenever possible, the inaccuracies referred to are not, as a rule, of sufficient magnitude to spoil seriously the usefulness of the results obtained. Upward and downward currents in the atmosphere are generally due to the effect of solar heating, pockets of air being warmed and then rising, owing to their added buoyancy. Cumulus clouds are generally an indication of such rising currents, so that the results obtained when a known rate of ascent is assumed will be of less accuracy on days when cumulus clouds are present than when the clouds show stratification in the atmosphere. The assumption of a uniform rate of ascent will, further, be more accurate in night ascents, when there is no solar heating, than on sunny days.

When determinations are made of the height of the balloon, it will certainly be found that in individual cases, the rate of ascent differs markedly from that given by the formula. It may even be found that the mean rate of ascent obtained from a series of such ascents also differs somewhat from that given by the formula. It would be undesirable in such a case for the individual ship to adopt a revised mean rate of ascent, for use in future ascents in which the height is not directly observed. When a sufficient number of accurate observations have been obtained over the sea, it may be necessary to reconsider the value of q, but for the present the value 310 (i.e. a rate of ascent of 700 ft./min.) should be used for all daytime ascents with 150-inch balloons, in which the height is not directly observed. When the height of the balloon is observed, the average rate of ascent of the balloon should be determined from the observations and this rate of ascent should be used in the calculations of this particular ascent.

§ 2.—Balloons.

Sizes, Weights and Rates of Ascent.—Balloons are made in four sizes, the circumference when inflated being 48, 70, 90 and 150 inches, and the average weights $9\frac{1}{2}$, 20, 30 and 80 gm., respectively.

Since a variation of 12 per cent. in the weight of the balloon alters the rate of ascent by only 1 per cent., some variation in the weights of balloons can be allowed without detriment to the accuracy of the results. Thus, individual 150-inch balloons may weigh anything between 70 gm. and 90 gm. without any appreciable difference in their rates of ascent.

The 48-inch balloons are used mainly on land for determining the height of low cloud, the balloons being filled to ascend at a known rate and the time observed until they enter the cloud. The 70 and 90-inch sizes are commonly used on land for obtaining upper winds, but it has been found that at sea the larger size, 150-inch, is most suitable for general use. The reason for this is that it is much more difficult to follow a balloon at sea than on land and a balloon of the larger size can be kept in view for a longer period. Further, owing to the fact that it rises at a greater rate than a smaller balloon, it ascends to a greater height in a given time. There is, therefore, a double advantage in using the

larger size of balloon. The average rates of ascent of the four sizes of balloon when inflated to their normal diameters are as follows :—

48-inch	70-inch	90-inch	150-inch
400 ft./min.	500 ft./min.	500 ft./min.	700 ft./min.

At the present time balloons of two sizes (150-inch and 90-inch) are supplied to H.M. ships. The 150-inch balloon, with a rate of ascent of 700 ft./min. in day ascents and the same or a slightly reduced rate in night ascents (*see* § 5) is generally used ; the 90-inch is intended for use in those day ascents for which a smaller rate of ascent is required. In the day time the *higher rate of ascent* (i.e., the 150-inch balloon) will be required, for example, on occasions :—

(*a*) of normal conditions in clear weather ;

(*b*) of strong winds, in order to gain the maximum height possible before the balloon is lost to view owing to its great (horizontal) distance away ;

(*c*) when the ship is steaming up wind at high speed or in fresh winds.

The *lower rate of ascent* (i.e., 90-inch balloon) on the other hand will be required—

(*d*) in misty weather, with light or average winds (a balloon can usually be kept in sight to a greater height in misty weather if moving away slowly than if moving away rapidly) ;

(*e*) when the sky is covered with detached clouds (the slower rate of ascent increases the chances of keeping the balloon in sight in the cloud gaps and this may enable the wind above the clouds to be determined) ;

(*f*) when the upper wind conditions are suspected to be variable (the variations can be more easily observed with the slower rate of ascent).

Colours.—Balloons are made in three colours, white or untinted, dark blue and dark red. The use of the several colours is, to some extent, a matter of individual preference, but white balloons are usually found to be best in cloudless weather, as the sun's rays are reflected by the balloon, which consequently appears as a bright point in the sky. Blue balloons are more opaque than red and appear black when viewed from a distance. They show up well against white skies, while red balloons are usually more suitable on days of broken cloud when the background varies between blue sky and cloud.

Storage.—The method of storing balloons is a matter which demands considerable attention, as the thin rubber of which they are made is liable to deteriorate rapidly, especially if exposed to light, heat or air. The best results have been found to be obtained by packing the balloons in air-tight tins after dusting them inside and out with a mixture of French chalk and ammonium carbonate in the proportion 20 parts of French chalk to 1 part of ammonium carbonate by weight. The balloons should be stored away from any artificial source of heat and in tropical regions should be placed in cold storage when possible. After removing them from cold storage the balloons should be heated gradually to soften the rubber. Many observers adopt the practice of carrying the balloon in the trouser-pocket for 15 or 20 minutes before use, the heat of the body warming the rubber. It is in general a good plan if a balloon is found to have hardened to warm and soften it by rubbing it between the hands or placing it in warm water, care being taken in the latter case that water does not enter the balloon.

Pinholes.—If the balloon is examined when inflated, it may be found that pinholes have developed, resulting in a gradual loss of gas and therefore a reduction in the rate of ascent. It is usually possible to patch such holes by sticking a piece of gummed paper over them (when the balloon is fully inflated), and it is advisable also to patch similarly any thin portions of the balloon which may be observed as they are liable to develop into pinholes. A careful examination of the balloon before release will often ensure that time is not wasted in following a balloon that bursts before sufficient observations have been obtained.

§ 3.—Hydrogen.

Hydrogen for filling balloons is supplied in cylinders of 100 or 200 cu. ft. capacity. The cylinders are usually filled to a pressure of 120 atmospheres, but this pressure is reduced for use in tropical climates to about 100 atmospheres. A 100 cu. ft. cylinder will fill about six 150-inch balloons (owing to the fact that the present balloons are only nominally 150 inches in circumference when fully inflated). The cylinders supplied to ships are covered with coir matting marked "Admiralty," and a steel cap is fitted to protect the valve. This cap should always be in position when the cylinder is not in use. The history of each cylinder, i.e., the latest date of testing and annealing is stamped on the end of the cylinder. The cylinders are tested by water pressure to twice the normal pressure at intervals not exceeding two years.

Cylinders should be stowed on the upper deck or above, in a cool dry place, in racks clear of the heat from the funnels and other sources of artificial heat and protected from the rays of the sun. No smoking should be allowed in their vicinity at any time. If the cylinders show signs of deterioration, such as corrosion or lamination to such an extent that it is considered dangerous, they should be emptied. In actual practice, it is found that the neck of the cylinder is the weakest part, and particular care should be taken to avoid damaging this when handling the cylinder.

Generally, the instructions contained in the "Engineering Manual" regarding gas flasks, are to be observed, so far as they are applicable.

§ 4.—Filling and Release of Balloons.

Pilot-Balloon Shelters.—Owing to the difficulty of filling balloons in a strong wind, it is desirable that a permanent roofed-in pilot-balloon shelter should be provided in ships carrying aircraft, in order that the windfinding from the ship may be carried out as rapidly as possible. This difficulty is particularly marked when a night ascent is undertaken and a candle lantern has to be attached below the balloon, owing to the liability of the candle to be blown out. Without a suitable shelter it is difficult to adjust the free lift accurately and there is also a danger of both balloon and filler accidentally being allowed to escape. If a shelter be provided, it is possible to fill a balloon in the evening and keep it in the shelter until it is required for the ascent made just before the dawn reconnaissance. (When this procedure is adopted, the balloon should be slightly overfilled and the free lift finally adjusted just before release.) Such shelters have been provided in certain carriers; although in some other carriers it has been found possible to fill the balloon on the lower deck and then when ready for release, to take it up by the lift to the upper deck.

The shelter should be large enough to hold a hydrogen cylinder and an inflated balloon with the two men who would normally be engaged in filling it. As it is awkward to carry inflated balloons from one place to another, the shelter in which the balloon is filled should be as close as possible to the position from which the balloon would normally be released. The choice of the latter position is governed by the conditions that the balloon when released should rise clear of the superstructure, etc. (especially in night ascents), and that the view of the balloon from the position of observation (for example, the position of the H.A. director) should not be likely to be obscured by any portion of the superstructure during the ascent.

Apparatus for Filling.—The apparatus required for filling the balloon consists of the hydrogen cylinder with key, a left-hand fine adjustment valve, a length of rubber tube and the balloon filler. Two types of balloon filler are supplied to H.M. ships. One is designed for use with 150-inch balloons alone and consists of a needle valve (operated by a plunger) upon which is screwed a solid brass weight; the total weight of this filler is 238 gm. The second type is supplied to ships carrying aircraft and is designed for use with both 150-inch and 90-inch balloons. The brass weight in this case is made in two concentric portions, the outer one of which may be screwed off. The weight of the complete filler is 238 gm., and when used with a 150-inch balloon it gives a rate of ascent of 700 ft./min. When the outer annular portion is screwed off the weight is reduced to 71·5 gm. and gives a rate of ascent of 500 ft./min. with a 90-in. balloon. Other fillers of different sizes are used on land for 48-inch and 70-inch balloons, but these are not supplied to H.M. ships. The use of fillers has completely replaced the use of the Gendle balloon balance; the former are easier to use, more robust and give results which are at the least just as accurate as those which would be obtained if a balance were used.

Method of Filling.—In order to fill a balloon, the cap should first be unscrewed from the hydrogen cylinder and the left-hand fine-adjustment valve screwed into the opening. The rubber tube is then connected to the left-hand fine-adjustment valve and to the end of the balloon filler through which the small plunger of the valve projects. The neck of the balloon is placed on the other end of the filler and if necessary tied on with soft string. The fine-adjustment valve being closed, the main valve of the hydrogen cylinder can be turned on by means of the lever key and all is then ready for filling the balloon by means of the fine-adjustment valve. If the rubber is in good condition, the filling can be proceeded with quickly, but if it shows any signs of having perished, it is better to proceed slowly, as this reduces the risk of bursting. Should the balloon burst while being filled, no harm will be done to the personnel engaged, provided that there is no naked light in the vicinity. This precaution is essential. The filling should be continued until the balloon just lifts the filler and the attached rubber tube, the main hydrogen valve then being closed and the rubber tube disconnected from the filler. Care is necessary at this point to hold the balloon firmly, or it may carry away the filler with it. Gas should be slowly liberated by use of the small valve in the bottom of the filler until the balloon and filler just float freely in the air. The valve is operated by pressing in the thin wire plunger projecting from the filler which permits a quantity of hydrogen to escape through the valve.

When the free lift has been adjusted in this manner, the neck can be tied with soft string and removed from the filler and the balloon is ready for the ascent. Alternatively, the neck of the balloon may be gripped firmly in the hand, to prevent the escape of more hydrogen, the filler removed and a knot tied in the neck of the balloon itself. During filling the balloon should be examined for weak patches, pinholes, etc., and these should be repaired in the manner described in § 2.

The balloon is now ready to be released. It may on some occasions be desirable and possible to turn the ship to steam down-wind while the balloon is being released (and perhaps during the ascent itself) in order to reduce the strength of the relative wind. Stop watches should be started at the instant of release of the balloon. The average rate of ascent of the latter will be either 700 ft./min. or 500 ft./min., according to whether it is a 150-inch or a 90-inch balloon. If a rate of ascent of 600 ft./min. is required, this can be obtained by attaching before release a weight of 104 gm. to a 150-inch balloon, after it has been inflated in the normal manner. The habitual use of several different rates of ascent is however to be deprecated as likely to lead to accidental errors in the calculations.

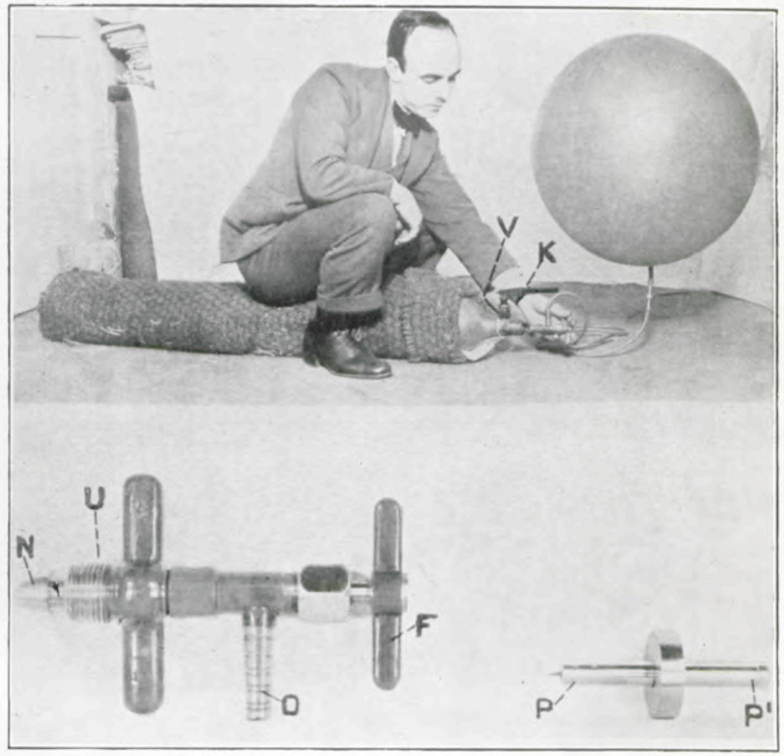


FIG. 1.

The Cylinder and Fittings.

N—the nozzle of the fine-adjustment valve.
U—Union, a left-handed screw for attaching the fine-adjustment valve to the cylinders.
O—Outlet for admitting hydrogen into the balloon.
F—Handle for operating the fine-adjustment valve. This is a right-handed screw

Screw U, Fig. 1, into the neck of the cylinder tightly, taking care that the nozzle N of the fine-adjustment valve and the union U are in contact. The cylinder is now ready for use.

In some cylinders the positions of V and K are reversed.

If, owing to poor visibility, difficulty in following the balloon is anticipated, two balloons may be used instead of one, giving a larger object to be sighted. The two balloons should be filled separately and attached to the opposite ends of a light line about $1\frac{1}{2}$ fathoms long, before release.

§ 5:—Methods of following the Balloon.

It has already been explained in § 1 that in order to calculate the upper wind currents, it is necessary to know the position of the balloon in elevation and azimuth at intervals of one minute from the start of the flight. In order that sufficiently accurate results may be obtained, the observer should aim at measuring elevation and bearing as accurately as possible, remembering, however, that it is generally a waste of time to measure one with great accuracy if the other can be measured only approximately. (The errors introduced by inaccuracies in the measurement of bearing and elevation are discussed in § 8). The height to which the balloon should or can be followed will depend upon the particular circumstances, but in general it is not necessary to follow it to more than 15,000 feet.

Method A. By Sextant and Compass.—The simplest method of following balloons is by the use of sextant and compass. The accuracy obtained by this method is not very high and, as the balloon has to be followed by the naked eye, no long flight is possible, but owing to the simplicity of the equipment required, it is the method most readily available for use. The elevation and bearing of the balloon are observed by means of a sextant and compass respectively, the readings of the latter being corrected to give true bearings. The instant the balloon is released the stop watch is started and the first observation for elevation and bearing is taken at the first half-minute, and then at one minute, and subsequently at every minute, the ship's head (true) being recorded at the same time. A warning to "stand by" should be given to the observers 5 or 10 seconds before each observation. The observations are noted on Form 2085, Table I, Columns 2 and 3. In obtaining the elevation, it is sometimes more convenient to hold the sextant reversed and reflect the horizon to the balloon rather than the balloon to the horizon, which is the usual way; the advantage being that the balloon becomes the direct image. It is also advantageous to keep the eye continuously on the balloon when it becomes faint, an assistant taking the elevation readings.

For obtaining the bearing, the ship's compass or a portable gyro-repeater can be used. This method of observing the bearing has two considerable disadvantages, one being that the balloon cannot be followed with the naked eye for any great distance and the other that it is difficult to observe the balloon at high elevations. If using the magnetic compass, the compass error must be applied before noting the readings on Form 2085. If a pointer can be rigged up over the compass to be kept pointed at the balloon, this will assist in obtaining the bearings.

Method B. By Sextant and Gun Director.—The weakest part of Method A is the determination of the bearing of the balloon by eye observation by compass. Considerably improved accuracy can be obtained if an open sight, swivelling about a horizontal axis, is mounted on a gun director. An arrangement adopted in H.M.S. *Daffodil* is shown in Fig. 2. A dummy telescope of hard wood is mounted in the director, a vertical brass rod, about ½ inch in diameter and 14 to 18 inches high being fixed in one end of the dummy telescope. A vertical slot is cut in the top of this rod and the open sight is mounted in the slot on a horizontal axis, a wing nut being provided to adjust the freedom of movement. The horizontal axis of the sight is positioned to cross the ship, so that the sight lies in a fore and aft plane. The length of the vertical rod should be chosen so that the open sight comes at a convenient height to the eye. The sight can then be trained on the balloon by means of slewing or training wheels and the bearing relative to the ship's head read off at the required times.

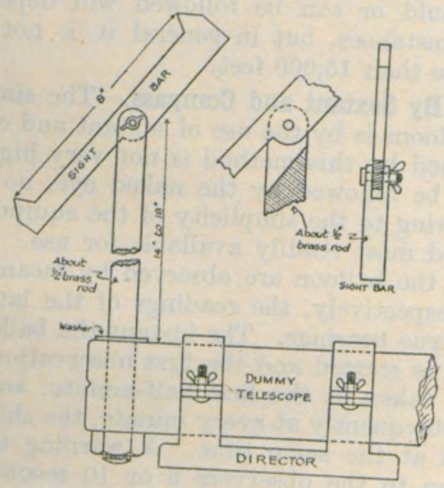


FIG 2.

By comparing the relative bearing with the ship's true course, the required true bearing of the balloon can be obtained. The method cannot be used unless the ship is on a fairly even keel, owing to the difficulty of keeping the sight pointed at the balloon.

Method C. By Sextant mounted in Searchlight Fitting.—In order to obviate the discomfort of holding the sextant in the hand for a long period, the method has been tried of mounting the sextant on an Evershed searchlight sight. The method has proved satisfactory on trial in H.M.A.S. *Canberra*, and enabled a balloon to be followed for 41 minutes on one occasion. The searchlight sight used was fitted for power training and elevating and the hand wheels controlling it could be turned with little effort. A small brass strip was fitted to the sextant handle and secured in position with a long screw substituted for the original screw of the handle, and with two small dowels, after careful

To face page 11.]

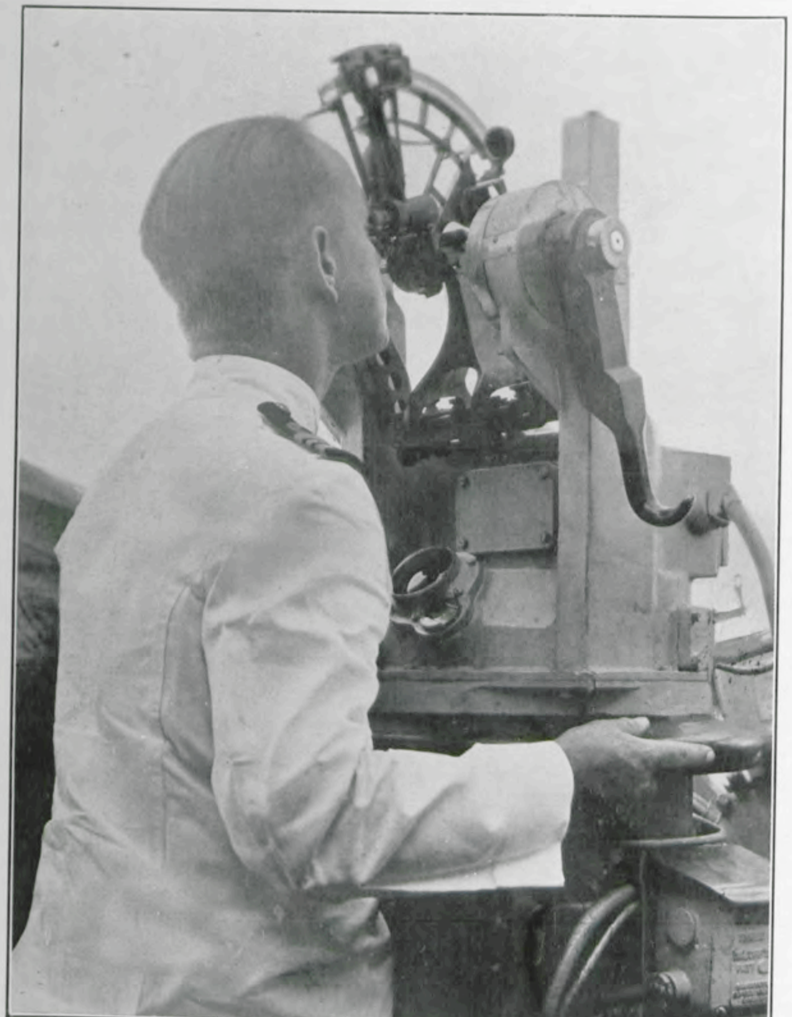


Fig. 3.

alignment test in the searchlight sight. The brass strip slides into the position designed for the open sight and the sextant is thus held clamped in position. Fig. 3 shows the sextant mounted on the searchlight sight. The sextant telescope is kept on the balloon by means of the elevation and training wheels, and the tangent screw is moved as necessary to keep the reflected horizon on the balloon. Very little strain is felt and the eye can be rested frequently without fear of losing the balloon. The best practice is to keep the index bar lightly clamped so that it can be moved to keep the horizon reflected on the balloon. When the warning "stand-by" is received from the time-keeper, the final adjustment is made with the tangent screw so that there is exact coincidence at the moment for reading off. Observations cannot be taken by this method when there is much motion on the ship, but when the ship is steady the method gives increased accuracy of reading, especially for bearing, over the simple sextant and compass method, with increased ease of observation and lack of strain.

Method D. By Director alone.—In ships fitted with H.A. directors, Evershed H.A. transmitters, etc., these can be used for obtaining both bearing and elevation at heights at which it is impossible to observe by sextant. If the balloon passes back over the ship, owing to a reversal of the wind direction at higher levels, it may be necessary to change over from one director to another in order to keep the balloon still in view. These methods can, of course, be used only when the ship is on a fairly even keel. In all cases when a director or similar instrument is used to follow a balloon, observations of elevation should be taken with the sextant for as long as possible ; the sextant angles should be used in the calculations for the lower levels.

The following is a description of the method of using the H.A.C.S. director adopted in H.M.S. *Courageous* :—

Personnel required.

At director	1 director layer.
	1 director trainer.
	1 recorder (with stop watch).
On Bridge	1 recorder (with stop watch).

Preliminary Preparations.—In H.M.S. *Courageous*, the port after director is always used unless aircraft are ranged on deck, in which case, the lee after director is used.

At about 15 minutes before the time chosen for the ascent, the operation of filling and balancing the balloon is commenced. This is done by the meteorological officer's assistant, who is also the recorder at the director.

The layer and trainer ship and adjust their telescopes, "free" the director, and train it on the beam. The layer then lays his telescope on the horizon and notes the elevation. The director is next trained to Red 180°, the layer acting as before. This is done in order to see whether any correction should be applied to the elevations read off the elevation dial, due to trim of the ship.

The Ascent.—When the balloon is ready and the ship is proceeding on a steady course, word is passed by telephone from the director to the Bridge to "stand-by." On the balloon being released, both recorders start their stop watches, the director is laid and trained on the balloon, and the director recorder, who releases the balloon, takes up a position in the director tower from which he can read both elevation dial and bearing racer.

At 10 seconds before each minute the director recorder orders "stand-by," and watches the elevation dial carefully in order to determine how much the elevation is altering due to roll of ship. From this he is able to judge the true elevation at the exact minute with fair accuracy.

At each exact minute after the release, the Bridge recorder reads the direction of the ship's head, to the nearest ½°, from the gyro compass.

Immediately the balloon has been observed for a sufficient time to enable the wind to be found to the height required, the records of elevation, relative bearing, and ship's head are taken to the meteorological office, where the upper winds are worked out by the method described below. (*See* p. 18.)

The procedure for a night ascent is similar, illumination being provided for the elevation dial and bearing racer.

Method E. By high-angle Gun.—The balloon is followed through the telescopic sight of a high-angle gun, the elevation and bearing being obtained from the elevation and training arcs, a five-second stand-by and stop being given at the end of each minute to enable these to be read. The azimuth is obtained by reference to the ship's head. The elevation readings may usefully be checked by simultaneous readings from a sextant if possible. The elevation arc of the high-angle gun can always be checked on the horizon, allowing for "dip." Opportunity should be taken of checking the accuracy of the training racer when in dock. One drawback of the use of the high-angle gun is that, owing to its fixed position, the balloon may pass out of the range of vision. It is, therefore, necessary to choose the gun which will be used for following the ascent, taking into account the probable direction in which the balloon will travel. Further, this method can only be used when the ship is on an even keel or the balloon cannot be kept in view through the telescope. It is particularly suitable for use in harbour, where there is no movement, and the absence of a sea horizon renders the use of a sextant difficult.

In strong winds, when the elevations to be measured are small, it has been found possible to use an ordinary 6-inch gun for following instead of the H.A. gun.

Method F. By U.B.3 or U.B.4 Heightfinder.—When utilising each of the previous methods of following balloons, it is necessary to assume a known rate of ascent of the balloon before the air movements can be calculated. The use of a heightfinder such as the U.B.3 or U.B.4 obviates this necessity as, although the height

of the balloon at the end of each minute cannot be determined accurately by the heightfinder, the mean rate of ascent can be determined (by plotting observed heights against time and smoothing the curve). The height of the balloon at each minute is then calculated from the rate so deduced. In practice, the U.B.4 has been found to be an excellent instrument for following balloons, and it can be used when there is moderate movement on the ship. In the latter case, however, it is particularly important that the readings obtained should be smoothed before commencing the calculations, to eliminate the errors in the individual readings introduced by the roll. This naturally increases the time taken in calculating the upper winds.

In H.M.S. *Hermes*, the U.B.3 heightfinder is used for balloon following, observations being taken also with the sounding sextant and gyro compass for as long as possible. A special balloon party of seven hands is detailed from each watch ; this party records the elevation, relative bearing, height of the balloon, as given by the U.B.3 heightfinder, and ship's head, every half-minute. By using half-minute intervals a more continuous record is obtained and errors due to rolling or pitching of the ship can more easily be detected. When the ship is rolling more than about 3° or pitching slightly, it has been found that the roll-corrector rating, however skilled, is unable to keep the roll-corrector always dead set, owing to the continuous movement of the heightfinder in elevation ; this renders the observations at low elevations particularly liable to error. The heights obtained, however, do give the mean rate of ascent and are sufficiently accurate to indicate any permanent change in this rate, due to leakage of hydrogen or some other cause.

The method of using the H.A.C.S. director with heightfinder suggested by *Courageous* is given below. Owing to the number of specially trained personnel required, however, this heightfinder method is not used in *Courageous*.

Personnel required.

On Bridge	1 recorder (with stop watch).
At director	1 director layer.
	1 director trainer.
	1 rangetaker.
	1 telephone operator.
	1 recorder (with stop watch).
In calculating position	1 height reader.
	1 roll corrector operator.
	1 telephone operator.
Total personnel required	9.

Preliminary Preparations.—All the preparations described (on page 11) for using the H.A.C.S. Director without heightfinder are necessary, with the addition that :—

(*a*) Power is required on the fire control system.

(*b*) Care must be taken that the lee after director and calculating positions are manned, as the rangefinder cannot be used across the deck when the angle of elevation is small.

(*c*) Elevation receivers, training receivers, and I/R hunters must be "lined up."

(*d*) The rangetaker must clear away and adjust the rangefinder.

The Ascent.—The procedure during the ascent is the same as described on page 12, with the addition that :—

(*a*) The rangetaker obtains a "cut" at each exact minute.

(*b*) The "stand-by" and "stop" must be repeated from the director to the calculating position.

(*c*) The height reader reads off and records the height at each minute.

Method G. By Shipboard Theodolite.—The design of a shipboard theodolite for use in H.M. ships for following balloons is under consideration ; when the type to be adopted has been decided upon, instructions for using the instrument will be promulgated to all concerned.

Note on the Tail Method of determining the Height of a Balloon.—Although trials of the use of the tail method at sea made some years ago did not give very encouraging results, it is considered that a brief description of the method (which is used regularly on land) may be useful and, as several new methods of following balloons have been developed since the original trials, it is possible that the tail method could successfully be used with one of these.

The principle of the method is to utilise the relation between the height of the balloon and the angle subtended at the observer's eye by a tail of known length attached to the balloon. If E = elevation of the balloon, h = its height, l = the length of the tail attached to it and a = the angle subtended by the tail at the observer's eye we have (*see* Fig. 4)—

$$a = \frac{l \cos E \sin E}{h} = \frac{l \sin 2E}{2h}$$

$$\text{Therefore } h = \frac{l \sin 2E}{2a}$$

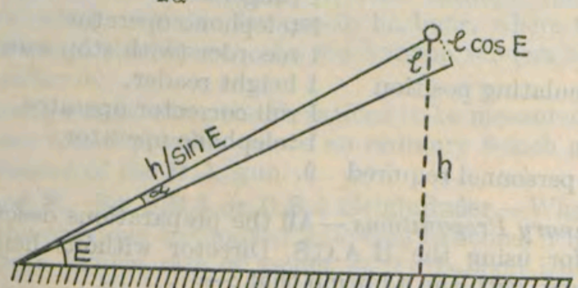


FIG. 4.

Thus, if a can be measured, we have a means of determining the height of the balloon. This can be done by using a graticule (with scale divisions every 0·01 inch, say) in the eyepiece of a suitable telescope, sextant or theodolite.

The tail consists of a length of thread with a piece of white, silver, red or black paper attached, usually bent and pasted to form a vertical hollow cylinder. The colour of the paper to be used will depend upon the cloud conditions ; the paper should be thin and about the size of a piece of foolscap. The tail is observed with the telescope and its apparent length, in terms of the graticule divisions, is determined at intervals, usually at the end of each minute. If the apparent length of the tail is m divisions and K divisions on the graticule, subtend an angle of 1 radian $a = m/K$.

$$\text{and } h = \frac{Kl \sin 2E}{2m}$$

K is a constant of the optical instrument and can be determined once and for all by fixing a foot rule vertically at a distance of 100 feet from the object glass of the instrument and determining its length in terms of graticule divisions. The angle subtended by the foot rule at the observer's eye is $\frac{1}{100}$ radians. If the rule appears to be x divisions long in the field of view, then $K = 100x$. Thus knowing K and l, we can determine the height of the balloon from the observation of E and the apparent length m of the tail in graticule divisions.

The tail is usually about 100 feet long, but for convenience in calculation, $\frac{lK}{2}$ should be, say, 10^5, and l should be chosen to give this or some similar simple factor with the fixed value of K. When l has been decided upon, fix two marks distance l apart and use them to measure off the tails instead of an ordinary measure.

It may be found that in the early stages of the ascent all the tail is not visible in the field of view, so that the apparent length cannot be obtained. This difficulty can be overcome by fixing a second sheet of paper one-quarter of the way down the tail, below the balloon. Measure the apparent length of this secondary tail, and multiply these lengths by four to obtain the apparent length of the long tail which is not completely within the field of view. As soon as the long tail has come completely into the field of view, observations should be made upon it instead of upon the secondary tail.

The apparent length of the tail should be estimated to tenths of a graticule division and the tail should be vertical when the observation is made. If the apparent length of the tail temporarily increases after the observation has been made, this indicates that the tail is swinging and the height calculated from the previous observation will be in excess of the true height of the balloon at that minute. Usually, however, the tail remains approximately vertical; in any case, the smoothing of the height-time curve should eliminate any occasional errors due to oscillation of the tail.

There is no necessity that observations of E and m should be made by the same instrument and better results will probably be obtained if one observer concentrates on measuring m, the values of E being obtained with those of A in the usual manner. There is no need either to take observations of m every minute; until practice has been gained m can be read at two or three-minute intervals, enabling the heights at two or three-minute intervals to be calculated. An ordinary slide rule or table can be used for calculation; a special slide rule is used at land stations enabling D_E and D_N to be calculated directly from A, E and m. It would, however, be generally preferable in using the method at sea to calculate h separately and plot it against time, enabling the observations to be smoothed out and accidental errors eliminated as far as possible before the values of h are used with A and E to give D_E and D_N.

The tail method ceases to give a reliable value for the height when the value of E exceeds 40° or when the height exceeds 10,000 feet.

§ 6.—Night Ascents.

When making night ascents it is necessary to show a small light below the balloon, in order that it may be visible in the sky. Illumination by searchlight has been tried, but the balloon is not visible for a sufficiently long time and the glare of the searchlight tends to blind the observer. Experimental ascents have been made from aircraft carriers using "long" lights and "short" lights, obtained from the gunner's store. The initial heaviness of these flares and the considerable decrease in weight as the flare burns, render them unsuitable as illuminants.

Lanterns.—The method of illumination in general use on land, which has also been tried with a fair degree of success at sea, is to hang a small lantern below the balloon. These lanterns are cylindrical in shape, about 3½ inches in diameter and 5 inches high, the top and bottom being cut out of cartridge paper and the cylindrical part made of tissue paper. Signal pad paper has also been found suitable. A hole 2 inches in diameter is cut in the top of the lantern to provide ventilation. A length of about 2 inches of Christmas candle is stuck down to the bottom of the lantern and provides the necessary illumination. A suspending loop of thin wire 6 inches long is provided. The illumination is improved somewhat if the tissue paper is soaked in thin oil, care being taken to drain off the surplus oil before the candle is lit. The lantern is hung from the balloon by about 2 fathoms of twine and the candle should not be lit until all is ready for the ascent, the balloon neck tied up and the hydrogen supply shut off. The naked light should not be brought close to the balloon at any stage. These lanterns are apt to blow out in a strong wind

and it has been found that a light cone, made of thin foolscap paper, with three holes in it, is efficacious in preventing this happening. The cone fits closely in the top of the lantern and enables the candle to remain alight in a wind of 15 knots.

Trials in H.M.S. *Eagle* have shown that it is possible to release a balloon with a lantern attached on any fair-weather night at sea, even when a comparatively strong wind is blowing, and to follow the movements of the balloon with H.A. gun sights up to heights sufficient for air reconnaissance purposes. The balloon can usually be followed for 10 to 15 minutes; on one occasion during the trials, when the surface wind was force 5, the balloon was followed for 18 minutes. It may be necessary to alter course for about 10 minutes in order to keep the lantern in view; this will, of course, depend upon the wind speed and direction, relative to the ship.

Owing to the difficulty of handling these thin paper lanterns in a strong wind, consideration has been given to other methods of illumination and trials are being made of electric torches and other similar appliances.

Rate of Ascent in Night Ascents.—The lamp or lantern hanging below the balloon will affect the rate of ascent unless additional lift is given. 150-inch balloons should always be used for night ascents and with a light lantern, such as the candle type, the balloon may be filled to lift two lanterns in addition to the normal filler, one lantern only, of course, being used in the ascent. With the lantern attached, the rate of ascent will then be the standard rate of 700 ft./min. With the heavier electric lamp there is a risk of bursting the balloon if this rule were followed and a compromise may be adopted by filling the balloon to lift the lamp together with the filler, detaching the filler after inflation. The rate of ascent of balloon and lamp will then be that shown in the following table :—

Weight of lamp attached. gm.	*Rate of ascent of 150-inch balloon and lamp.* ft./min.
0	700
25	683
50	667
75	653
100	640

Two balloons might be used to lift one lamp, each being filled to lift the filler and half the weight of the lamp, but it will be seen from the above table that not much is to be gained by doing so. If the lamp weighs 50 gm., the rate would only be increased from 667 ft./min. to 683 ft./min. For intermediate weights of lantern, the rate of ascent can be determined readily by interpolation.

Method of Release.—Some additional care is necessary in releasing balloons with lanterns attached. There is, in the first place, the risk that the connecting thread may foul some part of the ship, and further, the jerk of release may extinguish the light. If the relative wind over the ship is light, the thread can be eased out gently until the weight of the lantern is taken by the balloon and the whole then let go. In stronger winds, a simple way which has been found effective is for one person to grip the thread immediately above the lantern, holding the latter close to the deck, while a second person steadies the balloon itself, the thread between the lantern and balloon being taut. On release of the balloon, the person holding the thread quickly assumes an upright position and, in one sweeping motion, as if throwing an object into the air, releases the lantern above his head, with the thread still taut.

Method of Following.—For following balloons at night, the ordinary sextant cannot be used owing to lack of an horizon. A bubble sextant can be used instead, with a gyro repeater for bearings, but the most satisfactory method so far appears to be the H.A. gun or a director.

It is probable that the mirror theodolite eventually to be supplied to carriers will be fitted with an artificial horizon enabling it to be used to follow balloons at night.

It is suggested that the rate of ascent of night balloons could be checked by means of a heightfinder, using an astigmatiser to produce a line image of the light.

§ 7.—Methods of Computation of Wind Speed and Direction.

When the rate of ascent (usually 700 feet per minute), the bearing and the elevation of a balloon at minute intervals and the course and speed of the ship are known, there are three methods which can be employed to find the wind speed and direction. These are :—

(*a*) *Courageous* graphical method,
(*b*) slide-rule method,
(*c*) second graphical method.

There is not much to choose between methods (*a*) and (*b*) once some familiarity with the use of the pilot-balloon slide rule has been attained ; of the graphical methods, (*a*) would generally be preferred to (*c*), as being more compact.

(*a*) **"Courageous" graphical Method.**—The following is a description of the method employed in *Courageous* (1931) for obtaining the direction and speed of upper winds from observations of pilot balloons. In this method the results are obtained entirely by plotting, no calculation being necessary. A specially prepared "D4a" (Diagram to facilitate plotting, etc.) is convenient for this purpose, the scales used being :—

Distance ...	1 inch–2,000 feet.
Speed	1 inch–20 knots.

Preparation of diagram.—The right-hand compass rose on the "D4a" is prepared as follows (*see* Fig. 5) :—

In the north-east quadrant the degree graduations are marked anti-clockwise from 0° to 90° on the inside of the circle, 0° being the horizontal axis and 90° the vertical. This provides the scale for plotting angle of balloon elevation. The vertical axis of this elevation scale is then divided into distances of 700 feet (the rate of ascent of the balloon on the scale 1 inch to 2,000 feet) and height lines, parallel to the horizontal axis are drawn through these points. The height lines are numbered 1, 2, 3, 4, etc., from the centre of the diagram. Each line then corresponds to the height of the balloon at the time after release, in minutes, shown by the number of the line.

This is all the preparation necessary.

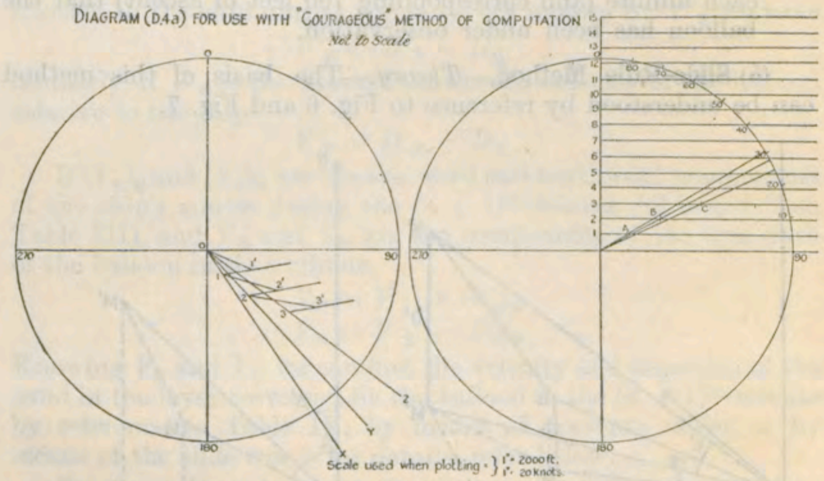


Fig. 5.

Method of use (*see* Fig. 5).—To find the wind direction and speed for the first and subsequent minutes (Surface—700 feet, 700 feet–1,400 feet, etc.), proceed as follows :—

Using the prepared elevation scale, lay off the elevation at 1 minute and mark the point at which the ruler cuts the 1-minute height line (A). Similarly, for each succeeding minute, the elevation for that minute is laid off, and the points at which the ruler cuts the appropriate height lines are marked (B, C, etc.). The distance between the vertical axis and the points so obtained, measured horizontally is, therefore, the plan range of the balloon at the end of each minute.

Next, from the centre of the left-hand compass rose on the "D4a," lay off the bearings of the balloon at each minute (X, Y, Z). These should be drawn in with light lines and numbered to avoid confusion. With dividers, measure the plan range found for each minute on the elevation scale and lay off this distance, from the centre, on the corresponding bearing lines on the compass rose. The points so obtained should be clearly marked 1, 2, 3, etc.

From each point (1, 2, 3, etc.) lay off the course and speed of the ship, the speed scale being 1 inch to 20 knots; these points to be marked 1′, 2′, 3′, etc. The wind direction and speed for each successive minute is then found by joining the centre to point 1′, point 1 to point 2′, point 2 to point 3′, etc., etc.

The wind direction during the first minute is from 0 to 1′, during the second minute from 1 to 2′.

The speed of the wind during each minute is represented by the length of the lines 0–1′, 1–2′, etc., on the scale 1 inch to 20 knots.

The wind direction and speed has now been obtained for each minute (and corresponding 700 feet of ascent) that the balloon has been under observation.

(*b*) **Slide-Rule Method.**—*Theory.*—The basis of this method can be understood by reference to Fig. 6 and Fig. 7.

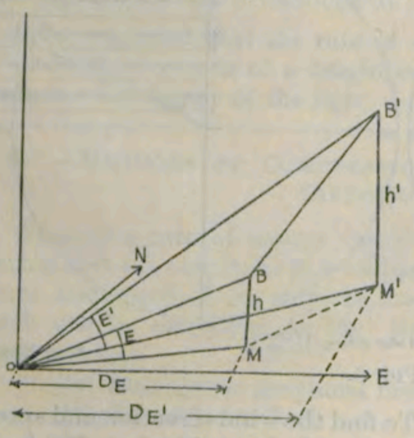


Fig. 6.

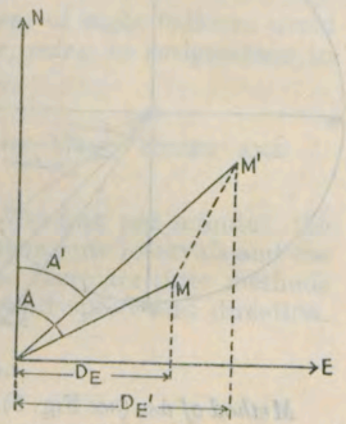


Fig. 7.

In Fig. 6—

B is the position of the balloon relative to the ship, O, at the end of the *n*th minute.

B′ is its position at the end of the $(n + 1)^{th}$ minute.

M and M′ are the projections of these points on the horizontal plane through the point of observation.

h and *h*′ are the heights, observed or calculated, of the balloon at these times.

E and *E*′ are the corresponding elevations.

In Fig. 7, which is the plan of Fig. 6, the symbols have the above meanings and, in addition, *A* and *A*′ indicate the azimuth readings.

Further, let

D_E denote the distance eastward of M from O at the end of the *n*th minute. (If M is to the westward of O then D_E is reckoned negative).

and D_N denote the distance northward of M from O. (If M is to the southward of O then D_N is reckoned negative.)

i.e. D_N and D_E are the S–N and W–E components of the displacement of B or M from O.

From Fig. 6 we have

$$OM = h \cot E$$
$$OM' = h' \cot E'$$

From Fig. 7 we have, further,

$$D_E = h \cot E \sin A\,;\quad D_N = h \cot E \cos A\,;$$
$$D_{E'} = h' \cot E' \sin A'\,;\quad D'_N = h' \cot E' \cos A'.$$

If we represent the average eastward velocity of the balloon relative to the ship during the $(n + 1)^{th}$ minute by V'_E we have

$$V'_E = D'_E - D_E$$

Similarly, if V'_N is the average northward velocity of the balloon relative to the ship

$$V'_N = D'_N - D_N$$

If $(V_S)_E$ and $(V_S)_N$ are the eastward and northward components of the ship's course during the $(n + 1)^{th}$ minute (obtained from Table III), and V_E and V_N are the components of the true path of the balloon in that minute,

$$V_E = V'_E + (V_S)_E$$
$$V_N = V'_N + (V_S)_N$$

Knowing V_E and V_N we can find the velocity and direction of the wind in the layer traversed by the balloon in the $(n + 1)^{th}$ minute by reference to Table IV, by means of traverse tables or by means of the slide rule; for details, refer below.

Practice.—In order to perform the calculations involved in the determination of V_E and V_N a special slide rule is provided. The pilot-balloon slide rule (Mark I) has a double slider, the two scales of which can be clamped in any position relative to each other. This double slide is particularly useful in calculating when a constant rate of ascent is assumed. The one (1) mark on the lower or time scale is set opposite the rate of ascent in hundreds of feet per minute (7) on the top scale. The two scales of the slider are then clamped in this position.

On the bottom of the stock of the slide rule is marked a tangent scale for elevation (*E*). On the top of the stock are marked cosine and sine scales for azimuth (*A*).

To calculate the magnitudes of D_E and D_N corresponding with any particular minute, say the third with the balloon in the north-east quadrant: (1) set the 3 of the time (or bottom) scale of the slider opposite the observed value of *E* on the elevation scale; (2) read off on the top scale of the slider the graduation corresponding with the azimuth reading (for the third minute) on the cosine scale. This gives D_N. (3) Read off the graduation corresponding with the azimuth angle on the sine scale. This gives D_E.

If the balloon is in the south-east quadrant read off D_N and D_E against the supplement (i.e., $180° - A$) of the azimuth on the cosine and sine scales. If it is in the south-west quadrant read off D_N and D_E against the angle $= A - 180°$ on the scales, and if it is in the north-west quadrant read off against the angle $= 360° - A$ on the scales.

These rules with regard to the azimuth angle appear rather confusing when expressed in words but they can easily be understood from a diagram showing the position of the balloon, and the observer performing the calculations is recommended to develop the habit of visualising this diagram in each particular case as the calculations are carried out. Note that D_N is always determined by means of the cosine scale, D_E by means of the sine scale.

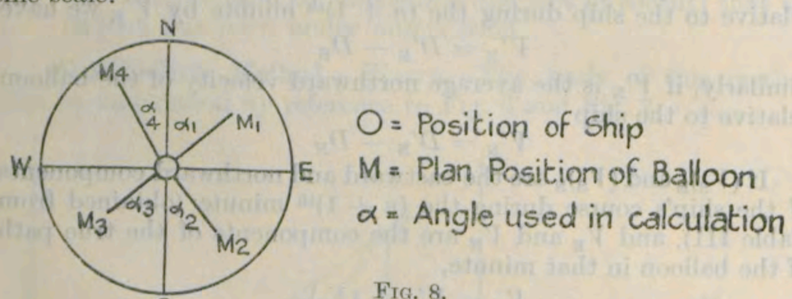


Fig. 8.

If the height of the balloon is actually observed at each minute interval, the two scales of the slider must be clamped together so as to correspond everywhere. Then if the observed value of h (in hundreds of feet) on the lower scale of the slider is set opposite the corresponding value of E on the elevation scale, the values of D_E and D_N are read off on the top scale of the slider.

It should be noted that in this second method of using the slide rule, if for example, the five on the bottom scale of the slide is used for five hundred feet, then the five on the upper scale of the slider (which should be opposite the five on the lower scale) also represents five hundred feet when used to give D_E and D_N.

The above calculation will give the magnitudes of D_E and D_N for successive minutes. In order to determine the signs of D_E and D_N the computer should note in which quadrant relative to the observer the balloon lay at that particular minute and then refer to this table.

Balloon in	D_E	D_N
N.E. quadrant	+	+
S.E. ,, ...	+	−
S.W. ,, ...	−	−
N.W. ,, ...	−	+

The table can be represented diagrammatically :

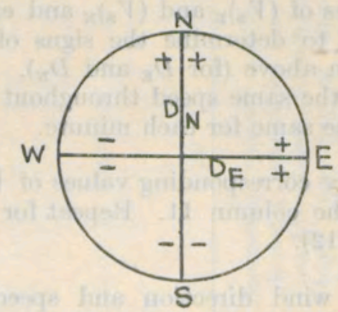


Fig. 9.

After a time the observer will acquire the habit of visualising this diagram as the calculation proceeds and will find it unnecessary to refer to the table. Note that D_N changes sign only when A passes through 90° or 270° ; D_E changes sign only when A passes through 180° and 360°. It is advisable to cast the eye down columns 5 and 6 when they have been completed, keeping this rule in mind.

Having determined the values of D_N and D_E at the end of each minute, and entered them in columns 5 and 6 of Form 2085, subtract algebraically from each D'_E the preceding value of D_E and enter the results (V'_E) in column 7. Repeat for the values of D_N and enter results (V'_N) in column 8.

When A differs from 180° or 360° by an amount *less than* 2°, the limitations of the slide rule prevent the calculation of D_E by the above method. In such cases, calculate D_N by means of the slide rule and use the formula $D_E = \frac{x}{60} D_N$ (where x = difference in degrees between A and 180° or 360°) for calculating D_E.

Similarly, when A differs from 90° or 270° by less than 2°, D_N cannot be calculated with the slide rule. In this case calculate D_E and use the formula $D_N = \frac{x'}{60} D_E$ where x' = difference in degrees between A and 90° or 270°. These formulae can be deduced from a diagram ; for instance, when A is nearly 180° we have

$$\frac{x}{360} = \frac{D_E}{2\pi\ D_N}$$

$$\therefore D_E = \frac{x}{60} D_N, \text{ (taking } \pi = 3 \text{ approximately).}$$

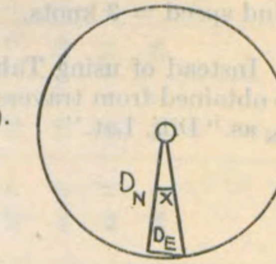


Fig. 10.

From the ship's course and speed obtain with the aid of Table III, the values of $(V_S)_E$ and $(V_S)_N$ and enter in columns 9 and 10. In order to determine the signs of $(V_S)_E$ and $(V_S)_N$ apply the rule given above (for D_E and D_N). If the ship steers the same course at the same speed throughout the ascent, $(V_S)_E$ and $(V_S)_N$ will be the same for each minute.

Add algebraically corresponding values of V'_E and $(V_S)_E$ and enter result V_E in the column 11. Repeat for V'_N and $(V_S)_N$ to obtain V_N (column 12).

To obtain the wind direction and speed from the wind components V_E and V_N, refer to Table IV.

From this table, take the larger component of the pair from the top horizontal row of figures (1 to 30) and run down the column below it. Also travel along the horizontal line of figures opposite the smaller component (on the diagonal or vertical line of figures). The figures in clarendon at the meeting place of the selected line and column give the wind speed, and the figures in italics an angle θ which is actually the angle between the true direction of travel of the balloon in the minute in question and that of the larger of the components, V_E and V_N of its path. θ is directly related to the wind direction ϕ, as shown in the following table. These relations can be readily seen by drawing diagrams, remembering that ϕ, the wind direction, is the direction *from* which the wind is coming.

V_E	V_N	If V_E greater than V_N	If V_E less than V_N
+	+	$\phi = 270 - \theta$	$\phi = 180 + \theta$
+	−	$\phi = 270 + \theta$	$\phi = 360 - \theta$
−	−	$\phi = 90 - \theta$	$\phi = \theta$
−	+	$\phi = 90 + \theta$	$\phi = 180 - \theta$

If $V_E = 0$, $\phi = 180°$ or $360°$, according to the sign of V_N, similarly if $V_N = 0$, $\phi = 90°$ or $270°$. When either V_E or V_N is zero, the wind speed in knots is numerically equal to the value of V_N or V_E in hundreds of feet per minute, i.e., if $V_N = 300$ ft./min. wind speed = 3 knots.

Instead of using Table IV, the wind speed and direction can be obtained from traverse tables, taking V_E as "Departure" and V_N as "Diff. Lat."

TABLE I.

Pilot-balloon ascent from H.M.S. *X*.
Position {Lat. 50° N. / Long. 1° W.

Date, 10.7.1926. Time, 10.00 G.M.T.

Course, 315°. Speed, 14 knots. Surface wind, 180° ; 18 knots.

Rate of ascent of balloon, 700 ft./min.

t	*A*° (Degrees true)	*E*°	*h*	Apparent. D_E	Apparent. D_N	Apparent. V_{WE}	Apparent. V_{SN}	Ship. V_{WE}	Ship. V_{SN}	True. V_{WE}	True. V_{SN}	Wind direction ϕ (Degrees true)	Wind speed V Kts.	Wind speed V m.p.h.	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
½			3·5												Depression centred south of Iceland, secondaries moving northward across British Isles, high over Bay of Biscay. Barometer falling slightly. Clouds : Cu. 4/10 ; A.St.6/10. Height of base of low cloud, 3,000 feet approximately. Temperature, 64° F. Relative humidity, 75 per cent. Ship probably in old polar air with warm front approaching from west.
1	37·0	23·6	7	+ 9·5	+13·0	+ 9·5	+13·0	−10·0	+10·0	−0·5	+23·0	181°	22	26	
2	40·7	20·9	14	+24·0	+28·0	+14·5	+15·0	−10·0	+10·0	+4·5	+25·0	190	25	29	
3	41·0	20·9	21	+36·0	+41·5	+12·0	+13·5	−10·0	+10·0	+2·0	+23·5	185	22½	26½	
4	43·8	21·2	28	+50·0	+52·0	+14·0	+10·5	−10·0	+10·0	+4·0	+20·5	191	19½	23½	

A third method of obtaining the resultant wind velocity and direction is by means of the pilot-balloon slide rule, in the following manner :—

> Clamp the two inner slides together so that similar numbers are opposite each other. Set V_N or V_E, whichever is the larger, on the scale of the lower slide against 45° on the tangent scale and read off on the tangent scale the angle opposite V_E or V_N, whichever is the smaller set on the scale of the lower slide. Let this angle be θ. Then on the scale of the upper slide set the value of V_E or V_N, whichever is the smaller against θ on the sine scale. The number on the upper slide opposite 90° on the sine scale gives the velocity of the wind, V, in knots (more precisely V is given in hundreds of feet per minute which, divided by 101, gives knots). The wind direction is obtained, knowing the signs and values of V_E and V_N, by applying the appropriate rule from the table on page 24 giving the relation between θ and ϕ.

(*c*) **Second Graphical Method.**—As before, we know h (the vertical height of the balloon at the end of t minutes from the commencement of the flight) from the rate of ascent of the balloon ; also E, the angle of elevation and A, the true bearing of the balloon.

The distance travelled horizontally by the balloon at the end of the first minute is $h_1 \cot E_1$, at the end of two minutes $h_2 \cot E_2$, at the end of three minutes $h_3 \cot E_3$, and so on. The values of $h \cot E$ can be found from a table of logarithms.

The value of $h \cot E$ can also be found graphically.

On a sheet of paper, *see* Fig. 11, draw horizontal and vertical lines, the former representing the height of the balloon and being drawn for every 700 feet (with the usual rate of ascent), the latter

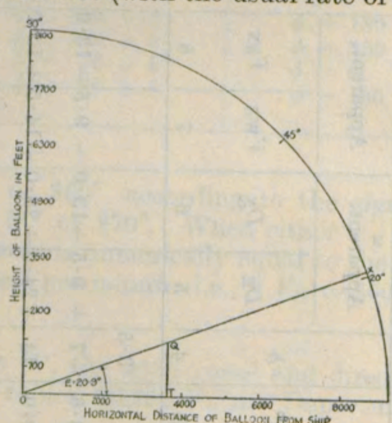
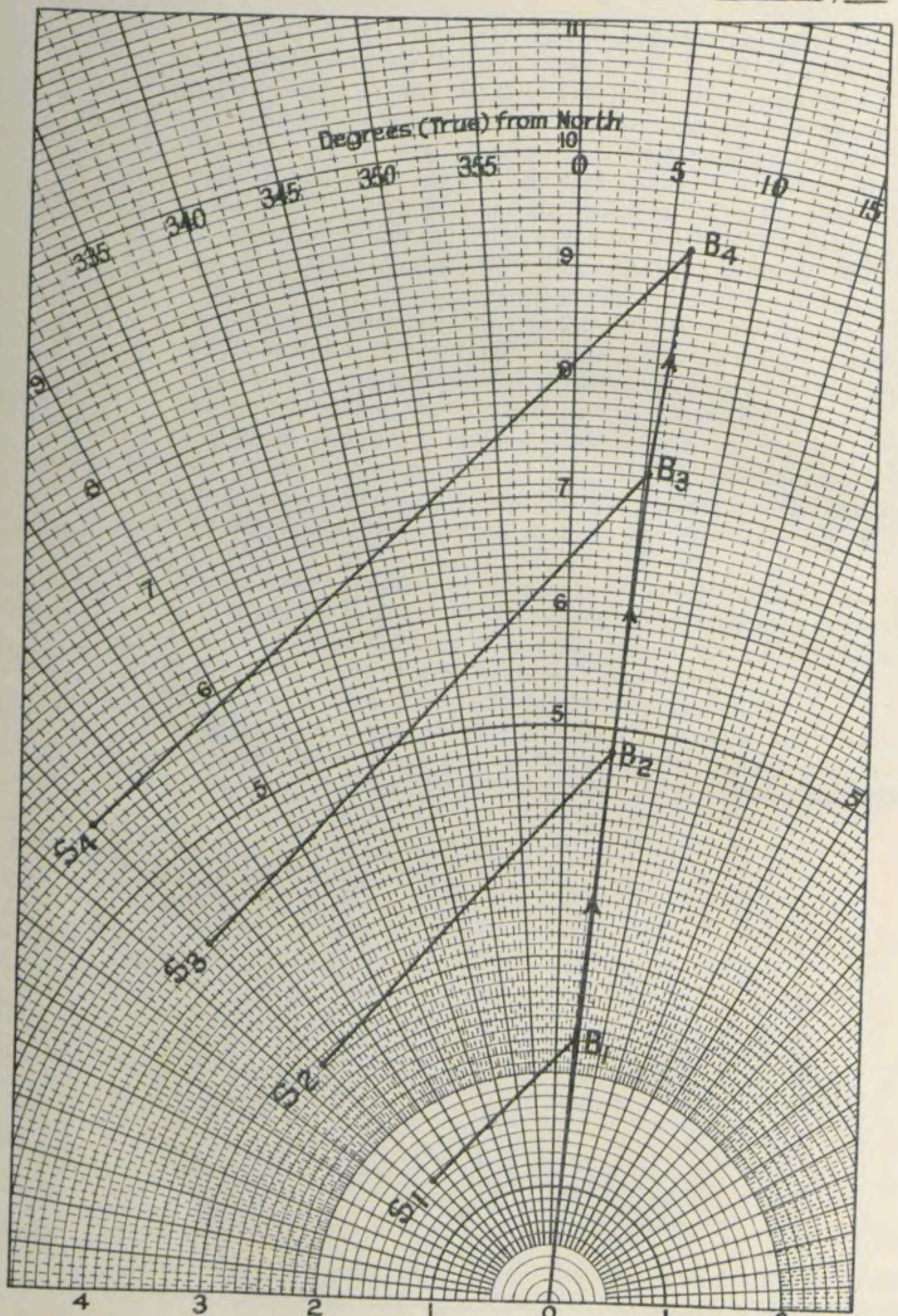


FIG. 11.

representing distance, being drawn on the same scale, for every 400 feet. (Separate diagrams should be constructed for use with other rates of ascent, e.g., 500 ft./min. and 600 ft./min.). A convenient scale is 2,000 feet to the inch. With the origin O as centre, draw a quadrant of a circle (a convenient radius is $4\frac{1}{2}$ inches) and mark on it degrees, as shown. Lay a narrow ruler OX from

Fig. 12.

To face p. 27



(237)H22682/12602 500. 11/32. (3821 C&R Ld.

O to cut the quadrant scale at the point corresponding to the elevation angle E of the balloon. From the point Q where the sloping line OX meets the horizontal line through the point on the left-hand side, which represents the height of the balloon at the time, drop a perpendicular QT to the base line. Then the distance OT is the horizontal distance of the balloon from the ship. The larger the ruled sheet the more accurately can this be obtained. Thus, if $E = 20 \cdot 9$, $h = 1{,}400$ feet, we have from the diagram, $h \cot E = \mathrm{OT} = 3{,}620$ feet.

The observations and calculations are recorded as shown in Table II.

Columns 1 to 4 are completed from the observations : t is in minutes and h is in hundreds of feet.

Column 5 is cot E, column 6 is the value of $h \cot E$ in feet. To obtain columns 7, 8 and 9, proceed as follows :—

Lay a copy of the radial chart on a drawing board and decide on a convenient scale, say, 1 unit (distance between 2 thick lines) of radial paper = 1,000 feet. Lay off from the centre the course (true direction in degrees from north) of the ship and its distance (in feet) run between each observation (*see* Fig. 12). If the speed of the ship is 10 knots, the distance travelled in one minute is 1,010 feet, or approximately 1 unit on the chart. From the points S_1, S_2, S_3, etc., so obtained lay off the bearing (true direction as given by A) of the balloon and the horizontal distance, $h \cot E$, from the beginning of the flight (from column 6), thus obtaining points B_1, B_2, B_3. Join successive points OB_1, B_1B_2, B_2B_3, etc., and determine the bearing (true direction in degrees from north) and length (inches and tenths) of each of these lines. The bearing from north should be obtained in each case and 180° added to it to obtain the wind direction (i.e., the direction *from* which the wind is coming). This should be entered in column 7. The length of each line gives the velocity to be entered in columns 8 and 9. Using the above scale, 1 inch $\equiv 10 \cdot 2$ m.p.h. $\equiv 9$ knots (approximately). This example has been plotted (*see* Fig. 12).

Accuracy of Observations : Method of Entry.—In view of the great difficulty in obtaining really accurate values of A and E in ships, it is in general sufficiently accurate :—

(1) to enter apparent D_E and D_N to nearest $\frac{1}{2}$ for first 3 or 4 minutes ; subsequently only to nearest *whole* number,

(2) to treat ship's V_E and V_N as above.

(If ship's D_E and D_N are being used, then ship's V_E and V_N must be taken to nearest 1/10 and multiplied by the number of minutes, the nearest whole number to this product being entered, otherwise a cumulative error will be introduced),

(3) to enter ϕ to nearest 5° (nearest 10° when $V < 5$ knots) and V to nearest knot only.

TABLE II.—*Graphical Method.*

Pilot-balloon ascent from H.M.S. X. Position—Lat. 50° N.
Date, 10.7.1926. Time, 1000 G.M.T. Long. 1° W.
Course, 315°. Speed, 14 knots.
Rate of ascent of balloon, 700 ft./min. Surface wind, 180°; 18 knots.

t	A Degrees (true)	E	h	Cot E	Distance h Cot E	Wind direction Degrees (true)	Wind speed Knots	Wind speed m.p.h.	Remarks.
1	2	3	4	5	6	7	8	9	10
1	37·0°	23·6°	7	2·2889	1603	179°	23	26	Depression centred south of Iceland, secondaries moving northward across British Isles, high over Bay of Biscay. Barometer falling slightly. Clouds: Cu. 4/10; A.St. 6/10. Height of base of low cloud, 3,000 feet approximately. Temperature, 64° F. Relative humidity, 75 per cent. Ship probably in old polar air with warm front approaching from west.
2	40·7°	20·9°	14	2·6257	3666	190°	25	29	
3	41·0°	20·9°	21	2·6257	5500	185°	24	27	
4	43·8°	21·2°	28	2·5782	7219	190°	21	23	

Calculation of Winds at high Levels.—Above 10,000 feet the observations are not in general sufficiently accurate to justify the computation of wind speed and direction at minute intervals, i.e., for 500-feet or 700-feet layers. Between 10,000 feet and 16,000 feet the mean wind in layers approximately 2,000 feet thick should be computed. Subsequently, the wind at the 20,000-feet level and above should be computed by steps of 5,000 feet. For balloons ascending at 700 ft./min. the following table indicates the layers to be taken for the 10,000-feet level and above.

Feet.		Feet.	Min.	
*10,000	as mean wind from	9,100 to 11,200,	13–16	(3 min. run)
12,000	,,	11,200 ,, 12,600,	16–18	(2 ,, ,,)
*13,000	,,	11,900 ,, 14,000,	17–20	(3 ,, ,,)
14,000	,,	13,300 ,, 14,700,	19–21	(2 ,, ,,)
*16,000	,,	15,400 ,, 16,800,	22–24	(2 ,, ,,)
*20,000	,,	17,500 ,, 22,400,	25–32	(7 ,, ,,)
25,000	,,	22,400 ,, 27,300,	32–39	(7 ,, ,,)
30,000	,,	27,300 ,, 32,900,	39–46	(8 ,, ,,)

* = International heights.

In each case the differences between the apparent D_E and D_N at beginning and end of period must be divided by the number of minutes in the period (given in brackets at end of lines) and then the ship's V_E and V_N added to it. Lastly, the resultant is found in the usual way.

Observations at minutes intermediate to those actually used in calculation of winds at 10,000 feet and above need not be worked out, but they should be made and recorded in case a check is required on the observations actually used.

Averaging Wind Speeds and Directions.—It should be borne in mind throughout that the resultant for any minute is not the wind at the height reached at the end of that minute, but is the mean wind in the layer traversed by the balloon during that minute. Thus, the first minute gives, not the wind at 700 feet, but the mean wind from 0 to 700 feet, i.e., approximately that at 350 feet. If the 5,000 feet be required (for instance), the 7th min. wind should not be used, as that is mean wind from 4,200 to 4,900 feet; the mean of 7th and 8th min. should be taken, as this gives mean for layer from 4,200 to 5,600 feet, i.e., for layer centring near 5,000 feet.

Note that to obtain the mean value for two minutes already worked out, the arithmetic mean of the two individual values must *not* be used, but the means of the V_E and V_N for the two minutes must be found and the resultant then looked out.

Ordinarily, the initial ½-minute reading may be ignored, but, if worked out, true D_E and D_N must be *doubled* to give V_E and V_N. In working out the minute value the ½ minute should be entirely ignored. On no account should the ½ minute D_E and D_N be subtracted from the minute D_E and D_N.

Cases of sudden variations in velocity or direction or of both together should be carefully examined. It will often be found that one minute gives a velocity markedly above and the next minute gives a velocity markedly below the general level of the preceding and following minutes (or vice versa). This is almost certainly due to an inaccurate elevation reading and *only* the mean value for the two minutes concerned should be used. Similar cases of changes in direction may be due to inaccurate azimuth readings. Errors of 10° in A and E should be looked into; several such cases in A and one in E have been detected.

§ 8.—Errors.

It has already been stated that the observations on the pilot balloon should be taken with the greatest possible accuracy. It will be profitable to consider the kind of errors introduced in the calculated wind by errors of stated magnitude in the observations. In general, the wind deduced from the pilot-balloon ascent should change more or less regularly from one minute to the next, and any sudden change which is found and which is not supported by the neighbouring observations, though it does not necessarily mean an error of observation, yet suggests the desirability of considering this as the possible cause. In particular a change in wind either of velocity or direction, which is reversed by the next reading, is almost always due to an error. The explanation of this is plain from the following conditions.

If in the diagram below

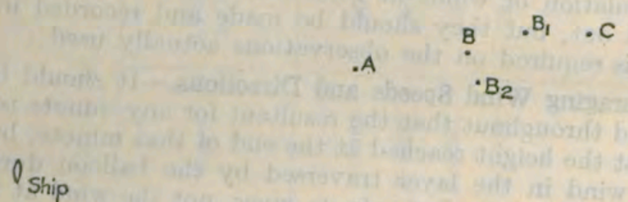


Fig. 13.

the true position of the balloon at three successive minutes is indicated by the points marked A, B and C, let it be assumed that while A and C are correctly observed, an error is made in calculating either the distance or the bearing of the point B so that the position of the balloon is plotted at B_1 or B_2 respectively. In the case where the error is made in calculating the distance it is clear that the calculated velocity relative to the ship for the minute $A - B_1$ will be in excess of the actual relative velocity, while that from $B_1 - C$ will be below it. In the case where the error is made in bearing, the calculated relative wind from $A—B_2$ will be veered from the true direction AB, while that from $B_2 - C$ will be backed from BC. In each case an error in the intermediate reading causes a sudden change of wind to be reversed in the following minute.

It is necessary to form an idea as to how accurately the position of the balloon must be known at each minute in order to give fairly accurate results. A wind of 1 knot corresponds with a movement of about 100 feet per minute, so that if the position is accurately observed at one minute and is 100 feet in error at the following minute, the error in the deduced wind over that minute will be 1 knot.

Errors which may occur are as follows :—

(1) Errors in elevation.
(2) Errors in azimuth.
(3) Errors in height, owing to the rate of ascent differing from the assumed rate of ascent.

(1) **Errors in Elevation.**—These become increasingly important at low elevations and at great distances. Thus, if the balloon is at an elevation of 50° at the end of 5 minutes, the height being then 3,500 feet, an error of 1° in the observed elevation will only lead to an error in position of 100 feet and is, therefore, not of importance. If, however, the elevation is 10° at the end of 5 minutes, the true distance of the balloon will be 19,800 feet, and if the elevation is inaccurately observed as 11°, the calculated distance will be 18,000 feet, involving an error of 1,800 feet.

(2) **Errors in Azimuth.**—The effect of an error of 1° in the azimuth is dependent solely upon the distance of the balloon from the ship. At a distance of 6,000 feet, the effect of such an error will be that the balloon is inaccurately placed by 100 feet while at 20,000 feet distance, the error in position will be 350 feet and thus becomes of some importance.

It will be observed that as regards both the observations of elevation and azimuth, errors of the order of 1° are of little importance when the balloon is close to the ship, but may become of considerable importance towards the end of the flight, particularly in a strong wind when the balloon is at a low elevation and 4 or 5 miles distant.

(3) **Errors in Height.**—As the height of the balloon is normally determined on the assumption that the rate of ascent is 700 feet per minute, the errors introduced by departure from this rate will be considered. If the ship is stationary, the effect of an error in the rate of ascent which persists throughout the flight is simple. Such an error means that all the calculated wind speeds are subject to a proportional error, wind directions being unaffected. Thus, if the balloon actually ascends at 600 feet instead of 700 feet per minute, all speeds will be too high in the proportion 7 to 6. The heights to which the winds are ascribed will also, of course, be in error. A wind which is found 5 minutes after the start is ascribed to a height of 3,500 feet, whereas it occurs, in the case mentioned, at a height of 3,000 feet. It is unusual for a balloon to ascend at a markedly different rate from the normal over the whole of the flight. A more common case is for the balloon to be caught in an ascending or descending current at some stage, so

that while it may ascend at 700 feet per minute for, say, the first 3 minutes, in the fourth minute it may be drawn up 800 feet or ascend only 600. If the wind is uniform the same rule applies as that just stated, viz., the wind speed calculated in this minute will have an error in proportion to the error in the rate of ascent. If, however, the wind changes with height, this rule will cease to be strictly true, although it may still be taken as a rough guide, except in cases where, for example, there is a reversal of wind above, when no simple rule of this kind can be given. The rules above apply to a stationary ship. If the ship is moving they cease to be applicable to the actual wind deduced from the observations, though they have some application to the speed of the wind relative to the speed of the ship.

§ 9.—Relative Merits of Pilot-balloon Ascents and Smoke Shell and Stannic Chloride Bursts.

The errors associated with methods of wind-finding by pilot-balloon ascents have been discussed in the last section, and while it is desirable to keep the sources of error in mind, it is seldom that the errors are large enough seriously to vitiate the results obtained. The great advantage of the pilot balloon over other methods is that it gives a complete picture of the wind structure from the surface up to the greatest height reached by the balloon, the mean wind in each separate layer of air being measured.

Thus the results will show the regions in which the wind is changing considerably with height and which are, therefore, unsuitable for flying. The smoke shell, stannic chloride and titanium tetrachloride methods give the wind at one height (or in a very thin layer) only and give no information about the manner in which the wind is changing with height at each level. It is almost impossible even by using a number of smoke bursts to get a picture of all the different wind currents when these vary normally from layer to layer. Advantages of these methods are that they are very quick in operation and that on days of broken cloud, a smoke burst can be placed through a hole in the cloud and an observation obtained of the wind above the cloud layer, whereas a pilot balloon in these conditions would almost inevitably get lost in or behind a cloud. A serious drawback to the use of smoke bursts in war time, however, is that they are likely to give away the position of the ship ; a pilot balloon, either by day or by night, will not do so.

The most favourable conditions for smoke bursts or tetra-chloride release are when the air is non-turbulent ; turbulence such as occurs about a layer of separation between two different wind currents or when the air is very unstable owing to its temperature conditions, tends to break up the cloud of smoke and render the observations on it less accurate.

In general, it is considered that the best routine to adopt is to send up at least one pilot balloon daily, early in the day, and

then to make occasional smoke-cloud observations later to ascertain whether any important changes in the wind have occurred. The heights of the smoke clouds should, of course, be determined in each case from the ship ; they should not be *assumed* to be at certain heights. This applies especially to shell bursts.

In carriers, a balloon is normally released before flying begins, at about three-hourly intervals subsequently and whenever a change of surface wind or other indications show that a change in the upper wind may be expected.

In a carrier, a series of suitable smoke clouds may be obtained throughout the day by equipping a number of aircraft with titanium tetrachloride release apparatus and instructing them to release bursts over the ship at pre-arranged heights before landing. An aircraft taking off subsequently to the landing on of one of these machines could then be given the wind practically at the time of departure instead of the wind possibly an hour earlier. On most occasions there will not be any considerable difference, but the possibility of an unexpected change in the upper wind should be guarded against.

Table III.—TABLE FOR OBTAINING SHIP'S $D_E D_N$.*

In Hundreds of Feet per Minute.

Course	10 knots		11 knots		12 knots		13 knots		14 knots		15 knots		Course
	N.	E.	N.	E.	N.	E.	N.	E.	N.	E.	N.	E.	
0	10·1	0	11·1	0	12·2	0	13·2	0	14·2	0	15·2	0	90°
5°	10·1	0·9	11·1	1·0	12·1	1·1	13·1	1·1	14·1	1·2	15·1	1·3	85°
10°	10·0	1·8	11·0	1·9	12·0	2·1	13·0	2·3	14·0	2·5	15·0	2·6	80°
15°	9·8	2·6	10·8	2·9	11·7	3·1	12·7	3·4	13·7	3·7	14·7	3·9	75°
20°	9·5	3·5	10·5	3·8	11·4	4·2	12·4	4·5	13·3	4·9	14·3	5·2	70°
25°	9·2	4·3	10·1	4·7	11·0	5·1	11·9	5·6	12·9	6·0	13·8	6·4	65°
30°	8·8	5·1	9·6	5·6	10·5	6·1	11·4	6·6	12·3	7·1	13·2	7·6	60°
35°	8·3	5·8	9·1	6·4	9·9	7·0	10·8	7·5	11·6	8·1	12·4	8·7	55°
40°	7·8	6·5	8·5	7·2	9·3	7·8	10·1	8·5	10·9	9·1	11·6	9·8	50°
45°	7·2	7·2	7·9	7·9	8·6	8·6	9·3	9·3	10·0	10·0	10·7	10·7	45°
	E.	N.	E.	N.	E.	N.	E.	N.	E.	N.	E.	N.	

Course	16 knots		17 knots		18 knots		19 knots		20 knots		21 knots		Course
	N.	E.	N.	E.	N.	E.	N.	E.	N.	E.	N.	E.	
0	16·2	0	17·2	0	18·2	0	19·2	0	20·3	0	21·3	0	90°
5°	16·1	1·4	17·2	1·5	18·2	1·6	19·2	1·7	20·2	1·8	21·2	1·9	85°
10°	15·9	2·8	17·0	3·0	18·0	3·2	19·0	3·3	19·9	3·5	21·0	3·7	80°
15°	15·6	4·2	16·6	4·5	17·6	4·7	18·6	5·0	19·6	5·2	20·5	5·5	75°
20°	15·2	5·5	16·2	5·9	17·1	6·2	18·1	6·6	19·0	6·9	20·0	7·2	70°
25°	14·7	6·8	15·6	7·3	16·5	7·7	17·4	8·1	18·4	8·6	19·3	9·0	65°
30°	14·0	8·1	14·9	8·6	15·8	9·1	16·7	9·6	17·5	10·1	18·4	10·6	60°
35°	13·3	9·3	14·1	9·9	14·9	10·5	15·8	11·0	16·6	11·6	17·5	12·2	55°
40°	12·4	10·4	13·2	11·1	14·0	11·7	14·7	12·4	15·5	13·0	16·3	13·7	50°
45°	11·5	11·5	12·2	12·2	12·9	12·9	13·6	13·6	14·3	14·3	15·0	15·0	45°
	E.	N.	E.	N.	E.	N.	E.	N.	E.	N.	E.	N.	

Course	22 knots		23 knots		24 knots		25 knots		26 knots		27 knots		Course
	N.	E.	N.	E.	N.	E.	N.	E.	N.	E.	N.	E.	
0	22·3	0	23·3	0	24·3	0	25·3	0	26·3	0	27·3	0	90°
5°	22·2	1·9	23·2	2·0	24·2	2·1	25·2	2·2	26·2	2·3	27·2	2·4	85°
10°	22·0	3·9	23·0	4·0	23·9	4·2	24·9	4·4	25·9	4·6	26·9	4·8	80°
15°	21·5	5·8	22·5	6·0	23·5	6·3	24·5	6·5	25·4	6·8	26·4	7·1	75°
20°	21·0	7·6	21·9	8·0	22·8	8·3	23·7	8·6	24·7	9·0	25·7	9·3	70°
25°	20·2	9·4	21·1	9·8	22·0	10·2	22·9	10·7	23·8	11·1	24·7	11·5	65°
30°	19·3	11·1	20·2	11·7	21·1	12·2	22·0	12·7	22·8	13·2	23·7	13·7	60°
35°	18·3	12·8	19·1	13·3	19·9	13·9	20·7	14·5	21·6	15·1	22·4	15·7	55°
40°	17·1	14·3	17·8	14·9	18·6	15·6	19·4	16·3	20·2	16·9	20·9	17·5	50°
45°	15·8	15·8	16·5	16·5	17·2	17·2	17·9	17·9	18·6	18·6	19·3	19·3	45°
	E.	N.	E.	N.	E.	N.	E.	N.	E.	N.	E.	N.	

The above table shows the distance in hundreds of feet which the ship travels in a northerly and easterly (or southerly and westerly) direction for different courses per minute.

* Compiled by Lieutenants J. W. Josselyn and R. S. Murray-Smith, R.N.

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TABLE IV.

TABLE FOR OBTAINING RESULTANT WIND DIRECTION AND SPEED IN KNOTS FROM COMPONENTS IN HUNDREDS OF FEET PER MINUTE.

Angles in Italics.

Speeds in Clarendon.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1	45 / 1	27 / 2	18 / 3	14 / 4	11 / 5	9 / 6	8 / 7	7 / 8	6 / 9	6 / 10	5 / 11	5 / 12	4 / 13	4 / 14	4 / 15	4 / 16	3 / 17	3 / 18	3 / 19	3 / 20	3 / 21	3 / 22	2 / 23	2 / 24	2 / 25	2 / 26	2 / 27	2 / 28	2 / 29	2 / 30	1
2		45 / 3	34 / 4	27 / 4	22 / 5	18 / 6	16 / 7	14 / 8	13 / 9	11 / 10	10 / 11	9 / 12	9 / 13	8 / 14	8 / 15	7 / 16	7 / 17	6 / 18	6 / 19	6 / 20	5 / 21	5 / 22	5 / 23	5 / 24	5 / 25	4 / 26	4 / 27	4 / 28	4 / 29	4 / 30	2
3			45 / 4	37 / 5	31 / 6	27 / 7	23 / 8	21 / 8	18 / 9	17 / 10	15 / 11	14 / 12	13 / 13	12 / 14	11 / 15	11 / 16	10 / 17	9 / 18	9 / 19	9 / 20	8 / 21	8 / 22	7 / 23	7 / 24	7 / 25	7 / 26	6 / 27	6 / 28	6 / 29	6 / 30	3
4				45 / 6	39 / 6	34 / 7	30 / 8	27 / 9	24 / 10	22 / 11	20 / 12	18 / 13	17 / 13	16 / 14	15 / 15	14 / 16	13 / 17	13 / 18	12 / 19	11 / 20	11 / 21	10 / 22	10 / 23	9 / 24	9 / 25	9 / 26	8 / 27	8 / 28	8 / 29	8 / 30	4
5					45 / 7	40 / 8	36 / 9	32 / 9	29 / 10	27 / 11	24 / 12	23 / 13	21 / 14	20 / 14	18 / 15	17 / 16	16 / 18	16 / 18	15 / 19	14 / 20	13 / 21	13 / 22	12 / 23	12 / 24	11 / 25	11 / 26	10 / 27	10 / 28	10 / 29	9 / 30	5
6						45 / 8	41 / 9	37 / 10	34 / 11	31 / 11	29 / 12	27 / 13	25 / 14	23 / 15	22 / 16	21 / 17	19 / 18	18 / 19	18 / 20	17 / 21	16 / 22	15 / 23	15 / 23	14 / 24	13 / 25	13 / 26	13 / 27	12 / 28	12 / 29	11 / 30	6
7							45 / 10	41 / 11	38 / 11	35 / 12	32 / 13	30 / 14	28 / 15	27 / 15	25 / 16	24 / 17	22 / 18	21 / 19	20 / 20	19 / 2·	18 / 22	18 / 23	17 / 24	16 / 25	16 / 26	15 / 27	15 / 28	14 / 29	14 / 29	13 / 30	7
8								45 / 11	42 / 12	39 / 13	36 / 13	34 / 14	32 / 15	30 / 16	28 / 17	27 / 18	25 / 19	24 / 19	23 / 20	22 / 21	21 / 22	20 / 23	19 / 24	18 / 25	18 / 26	17 / 27	17 / 28	16 / 29	15 / 30	15 / 31	8
9									45 / 13	42 / 13	39 / 14	37 / 15	35 / 16	33 / 16	31 / 17	29 / 18	28 / 19	27 / 20	25 / 21	24 / 22	23 / 23	22 / 23	21 / 24	21 / 25	20 / 26	19 / 27	18 / 28	18 / 29	17 / 30	17 / 31	9
10										45 / 14	42 / 15	40 / 15	38 / 16	35 / 17	34 / 18	32 / 19	30 / 19	29 / 20	28 / 21	27 / 22	25 / 23	24 / 24	23 / 25	23 / 26	22 / 27	21 / 28	20 / 28	20 / 29	19 / 30	18 / 31	10
11											45 / 15	43 / 16	40 / 17	38 / 18	36 / 18	35 / 19	33 / 20	31 / 21	30 / 22	29 / 23	28 / 23	27 / 24	26 / 25	25 / 26	24 / 27	23 / 28	22 / 29	21 / 30	21 / 31	20 / 32	11
12												45 / 17	43 / 17	41 / 18	39 / 19	37 / 20	35 / 21	34 / 21	32 / 22	31 / 23	30 / 24	29 / 25	28 / 26	27 / 27	26 / 27	25 / 28	24 / 29	23 / 30	22 / 31	22 / 32	12
13													45 / 18	43 / 19	41 / 20	39 / 20	37 / 21	36 / 22	34 / 23	33 / 24	32 / 24	31 / 25	29 / 26	28 / 27	27 / 28	27 / 29	26 / 30	25 / 31	24 / 31	23 / 32	13
14														45 / 20	43 / 20	41 / 21	39 / 22	38 / 23	36 / 23	35 / 24	34 / 25	32 / 26	31 / 26	30 / 27	29 / 28	28 / 29	27 / 30	27 / 31	26 / 32	25 / 33	14
15															45 / 21	43 / 22	41 / 22	40 / 23	38 / 24	37 / 25	36 / 26	34 / 26	33 / 26	32 / 27	31 / 29	30 / 30	29 / 31	28 / 31	27 / 32	27 / 33	15
16																45 / 22	43 / 23	42 / 24	40 / 25	39 / 25	37 / 26	36 / 27	35 / 28	34 / 29	33 / 29	32 / 30	31 / 31	30 / 32	29 / 33	28 / 34	16
17																	45 / 24	43 / 24	42 / 25	40 / 26	39 / 27	38 / 27	36 / 28	35 / 29	34 / 30	33 / 31	32 / 32	31 / 32	30 / 33	30 / 34	17
18																		45 / 25	43 / 26	42 / 27	41 / 27	39 / 28	38 / 29	37 / 29	36 / 30	35 / 31	34 / 32	33 / 33	32 / 34	31 / 35	18
19																			45 / 27	44 / 27	42 / 28	41 / 29	40 / 30	38 / 30	37 / 31	36 / 32	35 / 33	34 / 33	33 / 34	32 / 35	19
20																				45 / 28	44 / 29	42 / 29	41 / 30	40 / 31	39 / 32	38 / 32	37 / 33	36 / 34	35 / 35	34 / 36	20
21																					45 / 29	44 / 30	42 / 31	41 / 32	40 / 32	39 / 33	38 / 34	37 / 35	36 / 35	35 / 36	21
22																						45 / 31	44 / 31	43 / 32	41 / 33	40 / 34	39 / 34	38 / 35	37 / 36	36 / 37	22
23																							45 / 32	44 / 33	43 / 34	41 / 34	40 / 35	39 / 36	38 / 37	37 / 37	23
24																								45 / 34	44 / 34	43 / 35	42 / 36	41 / 36	40 / 37	39 / 38	24
25																									45 / 35	44 / 36	43 / 36	42 / 37	41 / 38	40 / 39	25
26																										45 / 36	44 / 37	43 / 38	42 / 38	41 / 39	26

For Components larger than those shown halve both Components: use these halved values in the table and double the Resultant speed (But not the Angle)

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PART II.—UPPER AIR TEMPERATURES.

Temperature records at different heights over the sea can be obtained by means of (a) aircraft, (b) balloons.

(a) **Aircraft.**—*Instruments.*—For obtaining upper air temperatures from aircraft a strut psychrometer is used in conjunction with an aeroplane aneroid graduated in millibars or with an ordinary altimeter when no aneroid is available.

The *strut psychrometer* consists essentially of two large thermometers of the flat-bulb type, filled with red spirit. The bulbs are protected from radiation by a nickeled cover with honeycombed ends and a water reservoir is provided in the base. Either thermometer may be used as a wet bulb but it is essential that when fitted to the aeroplane the leading thermometer should be the dry bulb.

The psychrometer is strapped to one of the wing struts of the aeroplane (assumed to be a biplane) at a distance not less than about 7 feet from the fuselage in a good position for reading from the pilot's seat. It is absolutely essential that the instrument should be clear of hot air from the engine. If the slip-stream from the propeller is thrown to the right, the psychrometer should be on the left, and vice-versa.

Special care should be taken to keep the wick and muslin clean. The reservoir should be filled with water every day.

The aeroplane aneroid.—For obtaining the barometric pressure on an aeroplane an accurate aneroid is used. These aneroids are graduated from 1,050 mb. to 400 mb., the lower part of the range being shown on an inner scale concentric with the outer scale. To avoid errors of parallax in reading the aneroid should be mounted in the cockpit with its face perpendicular to the line of sight from the pilot's or observer's eye.

The aneroid should be set at the same reading as the ship's mercurial barometer corrected for index error, latitude and temperature, but not reduced to sea level. The adjustment is carried out by turning the dial after raising the clamp. If left undisturbed the aneroid should keep the correct setting, but this should be checked at frequent intervals.

Another type of aneroid is sometimes issued which cannot be set except by the makers. In this case it should be placed alongside the mercurial barometer and from time to time a note made of the comparative readings.

Reports of Observations.—Observations of upper air temperatures are recorded in the meteorological log of the ship making the observations, but, in addition, H.M. ships are requested to forward copies of upper air temperature records to the Hydrographer for transmission to the Superintendent, Naval Division, Meteorological Office, and for tabulation in the Meteorological Office.

The observations, however, are of considerable value to the forecaster also, and it is particularly requested, therefore, that fleet carriers in wireless touch with the British Isles or Malta, report immediately any observations of upper air temperatures made by them. Already on several occasions, fleet carriers have reported these observations to the Meteorological Office, Air Ministry, and the observations, besides being of assistance in forecasting, have been published in the *Daily Weather Report.*

Method of observation.—In order to promote uniformity of practice in making these observations, it is desirable that aircraft from H.M. ships taking upper air observations should, as far as possible, adopt the methods detailed in the following extract from the "Instructions for Meteorological Observations in Aeroplanes," issued by the Meteorological Office, Air Ministry.

It should be noted that these instructions provide also for the reporting of upper air temperatures at altimeter heights of 1,000 feet, 2,000 feet, 3,000 feet, etc., where the aircraft is not equipped with an aneroid graduated in millibars.

INSTRUCTIONS FOR METEOROLOGICAL OBSERVATIONS IN AEROPLANES.

Height.—The flight should be made if possible to a height corresponding to a barometric pressure of 550 millibars (about 16,000 feet), somewhere in the neighbourhood of the aerodrome; when greater heights can be reached the readings are always of value. The machines should be fitted with turn indicators; this will frequently permit the pilot to climb up through the clouds when their base is not too low.

Electrically heated clothing and a supply of oxygen are also desirable adjuncts.

Readings.—Observations should be made at the surface and when the altimeter reads 1,000 feet above the surface; thereafter at 950, 900, 850, 800, 750, 700, 650, 600 and 550 millibars, respectively. The surface temperature should be read from thermometers in the screen at the beginning and end of the flights. The aeroplane observations should be made both on the ascent and the descent, *both dry and wet bulb being read to the nearest *tenth degree Fahrenheit*, and the machine should be *flown level at each height for two minutes* before the readings are made, in order that the thermometer may reach the current temperature. The readings made on the ascent should be used for the telegrams, and all the readings should be recorded and a copy sent by post weekly on Form 2075.

At temperatures below 32° F., just before the water freezes on the wet bulb, it is sometimes found that the wet bulb reads higher than the dry. Great care must be taken on these occasions not to confuse the dry bulb with the wet bulb. The wet-bulb reading is ignored in these cases (the figures - - - - - being used in the telegrams). After freezing, the wet bulb will usually continue

* With existing apparatus observations can only be made to the nearest half degree.

to fall below the dry for some time until the coating of ice on the muslin has evaporated. The readings cannot be regarded as true wet-bulb temperatures after the first 2 or 3 minutes from the time of freezing, but they should be telegraphed, as they will be at least as high as the true wet-bulb readings and often give valuable information as to the humidity.

Inversions.—It is sometimes found that the temperature rises rapidly for a few hundred feet, instead of falling in the usual manner. This is especially the case above clouds with level tops or above haze with a sharply defined upper surface. The amount of these "inversions," with the pressure and temperature at their upper and lower limits, should be recorded, and to do this accurately, the temperature should be read at the bottom of the "inversions" and then the engine should be throttled down and the machine climbed slowly till the temperature ceases to rise. On the descent the pressure and amount of the inversion should again be noted (with the machine descending slowly on half-throttle), as it may not be at exactly the same level as on the ascent.

Coding of Reports.—The reports of upper air temperatures should be transmitted by W/T to Admiralty, addressed "Weather London, via Admiralty," or to Malta, addressed "Meteor, Malta," in the same way as the ordinary weather reports sent in by H.M. Ships.

Reports should be in code and *for observations made in conjunction with an aeroplane aneroid graduated in millibars*, the code should be :—

$$\text{THUM PQLLL 111GG } B_0B_0B_0B_0B_0 \; T_0T_0T_0W_0W_0W_0$$
$$T_1T_1T_1W_1W_1W_1 \ldots\ldots\ldots T_{10}T_{10}T_{10}W_{10}W_{10}W_{10}$$
$$B_{10}B_{10}B_{10}$$

THUM is the index word indicating that the message gives upper air temperatures at intervals of 50 mb. The first two groups give day of week, position and time of observation, the symbols being the same as those used in the code for ordinary weather reports. $B_0B_0B_0B_0B_0$ gives the pressure at mean sea level at the beginning of the flight in millibars and tenths of a millibar (e.g., 1,019·5 mb. is reported as 10,195 and 997·5 mb. is reported as 09975). TTT is the dry-bulb temperature to tenths of a degree and WWW the corresponding wet bulb. The suffixes 0, 1, 2 . . . 9, 10 refer to sea level, 1,000 *feet*, 950 mb., 900 mb., 850 mb. . . . 600 mb., 550 mb. $B_{10}B_{10}B_{10}$ is normally the aneroid reading at the tenth observation (550 mb.) after leaving the ground, but if a lesser height is reached the aneroid reading at the highest level at which a temperature observation is made is inserted instead. This final aneroid reading is incorporated in the message as a check. In order that some reading may be obtained between the ground and the 950 mb. level under all conditions, the 1,000-*feet* level is incorporated in the message; the 1,000-*millibar* level cannot be used as there are occasions when ground pressure itself is below 1,000 mb.

For observations made in conjunction with an altimeter graduated in feet, the code should be :—

$$\text{THUM FEET PQLLL 111GG } B_0B_0B_0B_0B_0 \; T_0T_0T_0 \; W_0W_0W_0$$
$$T_1T_1T_1W_1W_1W_1 \; T_{10}T_{10}T_{10}W_{10}W_{10}W_{10} \; \text{XXXXX}$$

where the index words THUM FEET indicate that the message gives surface pressure and temperature, and upper air temperatures at heights of 1,000 feet, 2,000 feet, 4,000 feet, and so on at intervals of 2,000 feet. The altimeter reading at which the final temperature observation ($T_{10}T_{10}T_{10}W_{10}W_{10}W_{10}$) is taken, is added to the message as a check (XXXXX). It is important that the altimeter should be set to read zero at sea level immediately before the flight.

Inversion groups should be sent after the usual groups in the form BBBTTT, $B^1B^1B^1T^1T^1T^1$, where BBB is the pressure in millibars, to the nearest 10 millibars, when an aneroid is used or the height to the nearest hundred feet (the first figure being 0 for heights below 1,000 ft.) when an altimeter is used. TTT, the temperature at the base of the inversion to the nearest tenth of a degree. $B^1B^1B^1T^1T^1T^1$ are the corresponding figures at the top of the inversion, i.e., at the point where the temperature ceases to rise.

The word inversions should precede the groups.

If preferred, inversions may be given *en clair*, e.g., "Inversion 47·3 to 55·8 from 870 mb. to 860 mb.", or "Inversion 36·4 to 39·3 from 4,600 feet to 5,300 feet."

It should be noted that the decoding of the message is entirely dependent upon the index word or words, and it is essential that the correct index word or words precede each message.

(*b*) **Balloons.**—The balloons are of larger size than those used in pilot-balloon observations. They are sent up in pairs in tandem and carry a self-recording instrument, which gives the temperature in relation to the pressure. A sea anchor float is also attached. The balloons are followed by the ship as long as they are in sight, and an estimate of where they are likely to fall is made.

On attaining a great height, say 40,000 feet or 50,000 feet, one of the balloons will burst; the remaining balloon, being unable to support the instruments, descends until the sea anchor float reaches the water. The balloon is now able to support the instrument some feet above the surface of the water and is prevented from drifting by the sea anchor float until recovered by the ship, which has followed it. The balloons take about an hour to go up and an hour to come down.

In order to minimize the chance of losing the apparatus, and in cases where the sea room is limited, a device can be attached by which the upper balloon can be released at a pre-arranged height. The device consists of an aneroid box which expands as the pressure on it decreases, and by so doing releases a catch which holds the upper balloon.

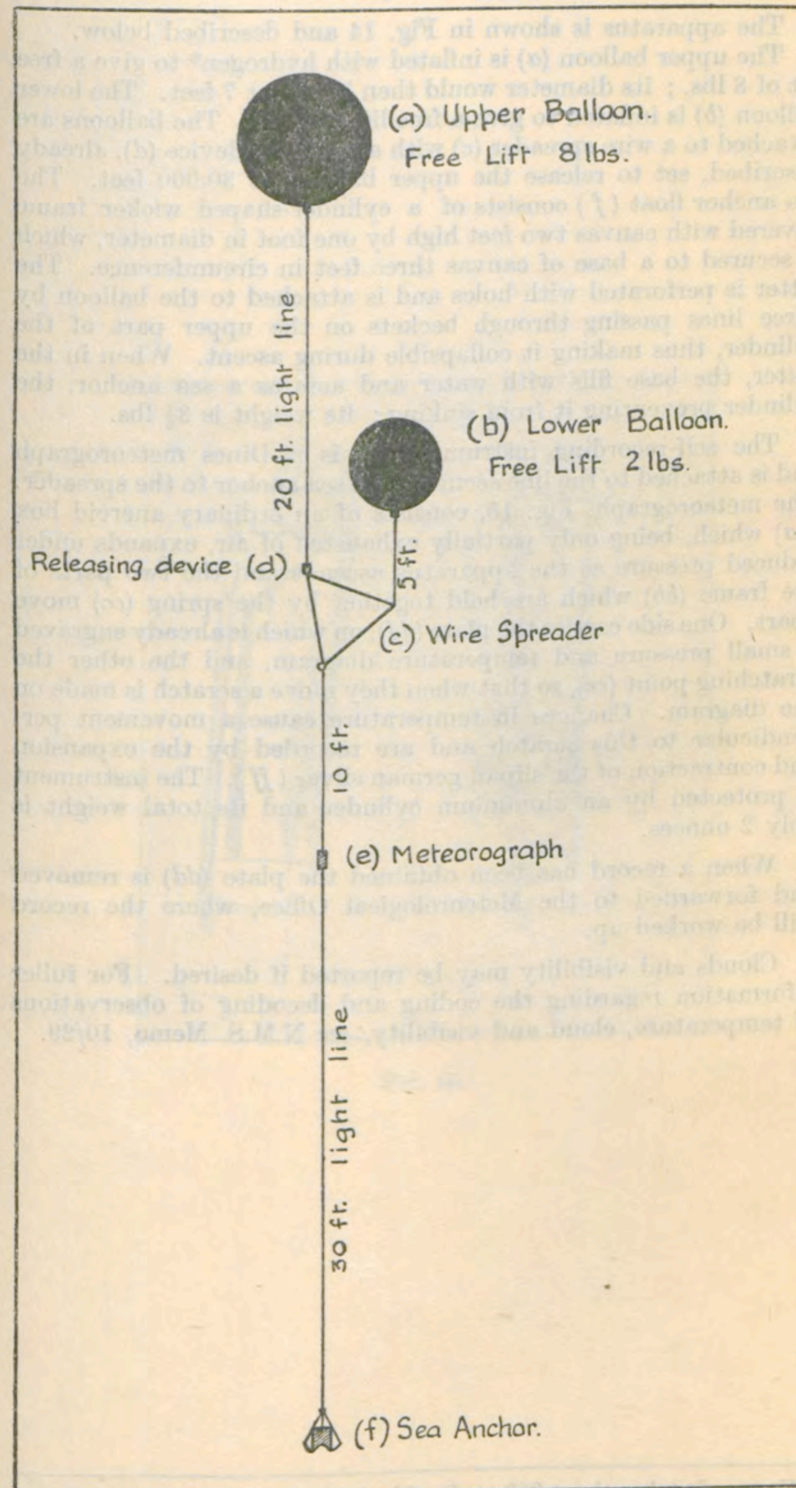

FIG. 14.

The apparatus is shown in Fig. 14 and described below.

The upper balloon (*a*) is inflated with hydrogen* to give a free lift of 8 lbs.; its diameter would then be about 7 feet. The lower balloon (*b*) is inflated to give a free lift of 2 lbs. The balloons are attached to a wire spreader (*c*) with a releasing device (*d*), already described, set to release the upper balloon at 30,000 feet. The sea anchor float (*f*) consists of a cylinder-shaped wicker frame covered with canvas two feet high by one foot in diameter, which is secured to a base of canvas three feet in circumference. The latter is perforated with holes and is attached to the balloon by three lines passing through beckets on the upper part of the cylinder, thus making it collapsible during ascent. When in the water, the base fills with water and acts as a sea anchor, the cylinder preventing it from sinking; its weight is 3¼ lbs.

The self-recording instrument (*e*) is a Dines meteorograph and is attached to the line securing the sea anchor to the spreader. The meteorograph, Fig. 15, consists of an ordinary aneroid box (*aa*) which, being only partially exhausted of air, expands under reduced pressure as the apparatus ascends and the two parts of the frame (*bb*) which are held together by the spring (*cc*) move apart. One side carries the plate (*dd*), on which is already engraved a small pressure and temperature diagram, and the other the scratching point (*ee*), so that when they move a scratch is made on the diagram. Changes in temperature cause a movement perpendicular to this scratch and are recorded by the expansion and contraction of the slip of german silver (*ff*). The instrument is protected by an aluminium cylinder and its total weight is only 2 ounces.

When a record has been obtained the plate (*dd*) is removed and forwarded to the Meteorological Office, where the record will be worked up.

Clouds and visibility may be reported if desired. For fuller information regarding the coding and decoding of observations of temperature, cloud and visibility, *see* N.M.S. Memo. 10/29.

* NOTE.—It takes about 300 cu. ft. of hydrogen to inflate the two balloons.

[*To face page* 40.

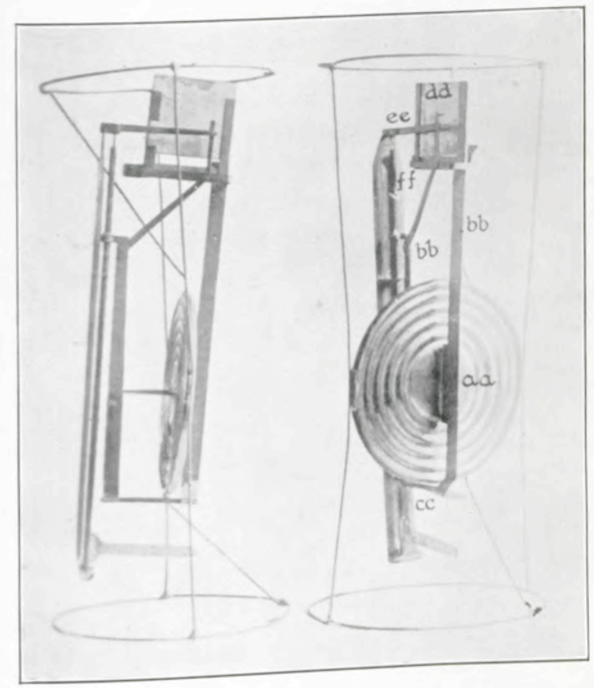

FIG. 15.

APPENDIX.

THE FRONTAL THEORY AND AIR NAVIGATION.

Air Masses and Fronts.—The majority of naval observers are sufficiently familiar with the meteorological idea of an air mass or air stream to render it unnecessary in this note to give a detailed description of air-mass analysis and the polar-front theory, but a brief reference to the fundamental definitions would appear to be desirable in order that the usefulness of these ideas in air navigation may be appreciated.

An air mass is defined as a mass or stream of air which is more or less uniform in meteorological properties (such as temperature) and past history, each air mass differing from other air masses in these respects. It follows from this definition that if we have two different air masses adjacent to one another, the air temperature will remain practically constant in passing, at any level, through one air mass and practically constant (at a different value, however) on passing through the other at the same level; in passing through the surface of separation of the two masses, however, the temperature will change comparatively rapidly from one value to the other, i.e., the value of the temperature is not continuous across the boundary. The surface of separation is accordingly termed a surface of discontinuity, a frontal surface or more loosely a front. Strictly speaking, the line in which the surface of separation cuts the earth's surface is the front. Although theoretically the boundary between the two air masses is a surface, in practice it is a transition layer, usually narrow, formed by the mixing of the two air masses. Within this transition layer there is usually an inversion of temperature or at least a marked falling off in the lapse rate. Fronts can be divided into two main types, cold fronts and warm fronts. At a cold front the colder, heavier air is impinging upon and gaining from the warmer, lighter air, forcing the latter up the frontal surface by undercutting it. At a warm front the warmer air is impinging upon and gaining ground from the colder air and at the same time climbing up over it. A third type of front—the occlusion—will be discussed later.

Change of Wind and Temperature at a Front.—It is generally possible to divide up the air covering any large portion of the earth's surface at any instant into several different air masses, separated from each other by fronts. These air masses will be in motion, the speed and direction of motion of one air mass usually differing from those of another. In other words, the winds as well as the temperature on the two sides of a front will be different. This will be apparent from an examination of any weather chart upon which fronts and air masses have been marked. In examining such a chart, however, it should be remembered that owing to the effect of surface heating, the surface temperatures on the two sides of a front may not differ greatly; at heights above about 2,000 feet, where the effect of the earth's surface becomes negligible, the difference becomes marked.

Application in the Navigation of Aircraft.—If the wind is found by an aircraft flying at 3,000 feet, the speed and direction of the wind experienced by the aircraft will usually remain the same or at least change only slowly while the aircraft is in the same air mass. On passing through a front into a new air mass, however, the wind experienced will change to that characteristic of the new air mass and serious errors may be introduced if the former values of the wind speed and direction continue to be used in the navigation of the aircraft. It is highly desirable, therefore, that the navigator should know when the aircraft has passed through a front in order that the new wind may be found without delay. Although the various kinds of front have characteristic cloud formations it is not always possible to determine when an aircraft has passed through a front from weather observations alone. By fitting a strut thermometer to an aircraft, however, it is possible to ensure a definite indication when the aircraft has passed through a front; when the aircraft is flying *level* through an air mass the reading of the strut thermometer will remain practically constant, but on passing through a front the reading will alter to the temperature of the new air mass into which the aircraft is passing. The passage through the front then becomes immediately apparent to the navigator and steps can be taken to find the new wind without delay. It is necessary particularly to emphasise that a change in the strut thermometer reading when the aircraft is flying level should be taken as a warning to *find* the new wind. In the present state of meteorological knowledge it is not possible to give a set of rules which will enable the new wind to be calculated. *Courageous* has proposed some tentative rules for use in special cases and on several occasions the rules have been of assistance in navigating the aircraft; it is recognised by all concerned, however, that these rules should only be used as a last resort, when it is quite impossible to find the new wind. The latter is the only safe course. The rules proposed by *Courageous* are dealt with below.

Usefulness of preliminary Study of the Weather Chart.—It is now the practice in the meteorological offices of aircraft carriers to indicate on the chart the positions of fronts. It is also possible to estimate from the chart the speed and direction of travel of each front. It is very important that the observer, before taking off, should note the type of each front which he is likely to meet during the flight, the approximate position in which he will meet it and the change of wind that occurs there. From the chart the meteorological office can determine the change in the surface wind and, in temperate latitudes, the change in the wind at 2,000 feet (this will be the change in the gradient wind, the speed of which can be calculated from the pressure gradient, and the direction of which is that of the surface isobars). This information will indicate to the observer the sort of change to expect when the strut thermometer indicates that he has passed through the front and, if it is impossible for the aircraft to find the wind, will enable a rough correction to be made for the change in wind experienced by the aircraft. It should be remembered, however, that there is a considerable change of wind with height depending upon the prevailing temperature distribution in the upper air. The change in wind experienced by the aircraft can be regarded as approximately equal to the change in gradient wind only when the aircraft is flying at or below about 3,000 feet. At greater heights the change in wind bears no simple relation to the change in wind at the surface or to the gradient wind. If pilot-balloon observations from both sides of the front are available, however, the wind change for each level can be estimated.

In estimating the time at which the aircraft will meet a front, allowance should, of course, be made for the slope of the frontal surface (approximately 1 in 200 in the case of a warm front, 1 in 100 in the case of a cold front); thus an aircraft flying at 5,000 feet in a direction opposite to the direction of motion of a warm front will pass through the frontal surface when the front itself (at sea level) is still about 200 miles away.

When considering the results of the examination of the weather chart, it should be borne in mind that owing to lack of sufficient data, especially over the sea, a front may be missed on the chart. It is necessary, therefore, to look at the strut thermometer at frequent intervals, even in those portions of the flight which would appear from the chart to be clear of fronts.

Fronts associated with Depressions: rough Rules.—In temperate latitudes most fronts are usually associated with depressions; very little is known about frontal phenomena in other regions, although it is reasonable to suppose that they exist everywhere. The leading edge of the warm sector of a depression functions as a warm front, the rear edge of the sector being a cold front. The cold front travels faster than the warm front and the warm sector is eventually lifted off the earth's surface or "occluded." A front (an "occlusion") is then formed between the air mass in the rear of the depression and the air mass in advance of the depression.

An aircraft flying below the occluded warm sector will experience one change of wind only. If the aircraft is sufficiently high, however, it will enter and leave the occluded warm sector, thus experiencing two wind changes, although only one will be observed in the surface wind. Behind the primary cold front or the occlusion there are generally one or more secondary cold fronts formed by successive masses of colder air.

The main feature characteristic of fronts associated with depressions is a veer of wind in the Northern Hemisphere and a back in the Southern as the front passes by a station. The rule can be supplied in the following manner in the navigation of aircraft.

I.—If flying round the centre of a depression (in the Northern Hemisphere) in a clockwise direction, allow for a veer in the wind in passing through a front; if flying in an anticlockwise direction, allow for a backing of the wind.

For the corresponding rule for the Southern Hemisphere, read "back" for "veer" and vice versa.

The above rule gives the sense in which the wind direction changes; it is impossible, however, to formulate equally reliable rules for the magnitudes of the changes in direction and speed. The following very rough guides are based mainly upon rules tentatively proposed by *Courageous* as a result of experience in the Mediterranean. They apply only when the aircraft is flying at or below 2,000 feet; the variation of wind change with height is so dependent upon the particular meteorological conditions prevailing at the time that no rules for other heights can be given.

II.—Allow for a shift of 45° on passing through a warm front, cold front or occlusion; allow for a shift of 30° on passing through a secondary cold front.

III.—Allow for an increase in wind speed of 5 knots in passing through a warm front from colder to warmer air or on passing through an occlusion; assume no change in wind speed at a cold front unless observation of the surface wind indicates an increase.

IV.—Check your assumption by observation of the change in surface wind and amend it if necessary.

Rules II and III can be regarded as giving only a very rough indication of the changes occurring and as previously emphasised should be used only as a last resort, when it is quite impossible to find the new wind from the aircraft. The only safe rule which can be given in the present state of knowledge is :—

If the strut thermometer reading changes by more than 2° F. while the aircraft is flying level, FIND THE NEW WIND.

Reliability of the Method.—The above method of detecting wind changes is dependent upon the existence of—

(*a*) an appreciable difference of temperature on the two sides of the front,

(*b*) a relatively narrow transition layer between the two air masses, so that the temperature change experienced in flying horizontally through the front will be sufficiently abrupt to be noticed by the observer.

If, in any particular case, these two conditions do not obtain, an observer will be unable to detect the change of wind from the readings of his strut thermometer. Further, relatively slow changes of wind direction and speed may occur within the same air mass, owing to curvature of the isobars and changes in the isobaric gradient; the strut thermometer will fail to indicate these changes also.

It is essential, therefore, to realise the limitations of the method and to remember that if the air temperature has not altered appreciably or has altered only slowly, this does *not* indicate that the wind has remained the same. When the air temperature does change appreciably, however, it is highly probable that there is an associated change in the wind. Hence the use of the strut thermometer will enable an observer to detect some of the wind changes experienced by aircraft in flight, but not all of them.

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An aircraft flying below the occluded warm sector will experience one change of wind only. If the ground is sufficiently high, however, it will [illegible] and below the occluded warm sector, thus experiencing two wind changes, although only one will be observed in the surface wind. Behind the primary cold front of the occlusion there are generally one or more secondary cold fronts formed by successive masses of colder air [illegible]

The main [illegible] of [illegible] is [illegible] a book [illegible] the [illegible] the [illegible] by [illegible]. The rule can be supplied in the following [illegible] navigation of aircraft.

I.—[illegible] flying round the centre of a depression (in the Northern [illegible]) [illegible] in a clockwise direction, allow for a veer in the wind [illegible] passing through a front; if flying in an anticlockwise direction, allow for a backing of the wind.

For the corresponding rule for the Southern Hemisphere, read "back" for "veer" and vice versa.

The above rule gives the sense in which the wind direction changes; [illegible] impossible to give [illegible] formulate any rule regarding the [illegible] of the changes in direction and speed. The following very rough guides are based mainly upon rules [illegible] in the Mediterranean. They apply only when the aircraft is flying at or below 2,000 feet; the [illegible] of wind change with height is so dependent upon the particular meteorological conditions prevailing at the time that no rule for other heights can be given.

II.—Allow for a shift of 45° on passing through a warm front, cold front or occlusion; allow for a shift of 30° on passing through a secondary cold front.

III.—Allow for an increase in wind speed of 5 knots in passing through a warm front from colder to warmer air or on passing through [illegible]; assume no change in wind speed at a cold front unless the [illegible] of the surface wind indicates an increase.

IV.—Check your assumption by observation of the change in surface wind and speed if it is necessary.

Rules II and III can be regarded as giving only a very rough indication of the changes occurring, and as previously emphasised should be used only as a last resort, when it is quite impossible to find the new wind from the observation. The only safe rule which can be given in the present state of knowledge is—

If the air thermometer reading changes by more than 2° F. while the aircraft is flying level, FIND THE NEW WIND AT ONCE.

Reliability of the Method.—The above method of detecting wind changes is dependent upon the existence of

(*a*) an appreciable difference of temperature on the two sides of the front;

(*b*) a relatively narrow transition layer between the two air masses so that the temperature change experienced in flying horizontally through the front will be sufficiently abrupt to be noticed by the observer.

If, in any particular case, these two conditions do not obtain, the observer will be unable to detect the change of wind from the readings of his strut thermometer. Further, relatively slow changes of wind direction and speed may occur within the same air mass, owing to curvature of the isobars and changes in the isobaric gradient; the strut thermometer will fail to indicate these changes also.

It is essential, therefore, to realise the limitations of the method and to remember that if the air temperature has not altered appreciably or has altered only slowly, this does not indicate that the wind has remained the same. When the air temperature does change appreciably, however, it is highly probable that there is an associated change in the wind. Hence the use of the strut thermometer will enable an observer to detect some of the wind changes experienced by aircraft in flight, but not all of them.

(9254) Wt. [illegible] 500 [illegible] H&S [illegible]