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ROYAL NAVAL AIR SERVICE

Navigation, Magnetism and Deviation of the Compass

A Manual for the use of Aerial Navigators

By

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ROGER WELLES,
Captain, United States Navy,
Director of Naval Intelligence.

NOTE.

The compilers desire to acknowledge their indebtedness to the authors of the undermentioned works which have been consulted and freely quoted. Also to Naval Instructor John White, R.N., for many valuable suggestions, and to Commander S. B. Norfolk, R.N., for reading and revising the proofs and much useful advice and assistance:—

ADMIRALTY MANUAL OF NAVIGATION, 1915.
HANDBOOK OF PILOTAGE, 1912.
NAVIGATION (ELEMENTARY). Rev. W. Hall, B.A., R.N.
MODERN NAVIGATION. Rev. W. Hall, B.A., R.N.
NAVIGATION—NOTES AND EXAMPLES. Naval Instructor S. F. Card, B.A., R.N.
NAVIGATION AND NAUTICAL ASTRONOMY. Commander W. R. Martin, R.N.
THE ELEMENTS OF PILOTAGE AND NAVIGATION. Commander M. H. ANDERSON, R.N.
THE MAGNETIC COMPASS IN AIRCRAFT. Captain F. O. Creagh-Osborne, R.N.
MARINE SURVEYING. Rev. J. L. Robinson, B.A., R.N.

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The Earth is an oblate spheroid. Its polar diameter is 7,900 miles and its equatorial diameter 7,926 miles. For all purposes of navigation it is treated as being a sphere.

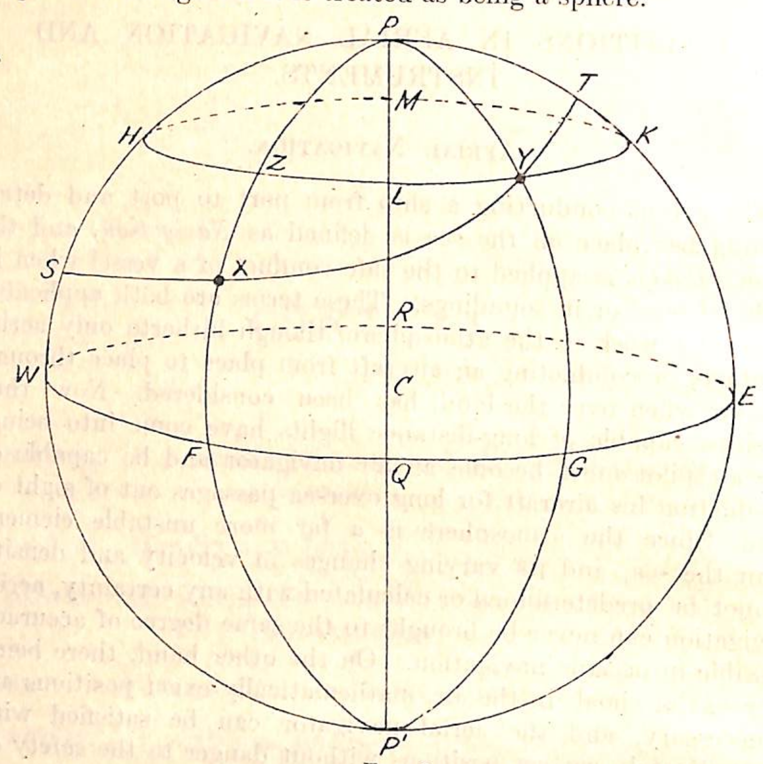

FIG. I.

Axis.—An axis is that diameter about which a body rotates. PP′.

The Earth rotates daily from west to east about its polar diameter; this causes the heavens to appear to rotate from east to west.

Great Circle.—Great circles of the sphere are those whose planes pass through its centre. PFP′, PGP′, and WQER.

Small Circle.—Small circles of the sphere are those whose planes do not pass through its centre. HLKM.

Poles.—The poles of the Earth are the extremities of its axis. P and P′.

Equator is the great circle round the Earth, midway between the poles. WQER.

Meridians are semi-great circles joining the poles. They cut the equator at right angles. PFP′, PGP′.

Parallels of Latitude are small circles whose planes are parallel to that of the equator. HLKM.

Meridians of longitude and parallels of latitude enable us to fix the position of any place on the Earth's surface.

Latitude is measured on the meridians from the equator to the poles and reckoned from 0° to 90°, N. and S.

Longitude is measured on the equator, which is divided into 360°, measured 180° E. of Greenwich and 180° W.

One position on the Earth is connected with another by its difference of latitude or difference of longitude, *e.g.*, X and Y.

D. Lat. is the arc of a meridian intercepted between their parallels of latitude, *e.g.*, XZ.

D. Long. is the length of the *smaller* arc of the *equator*, intercepted between their meridians, *e.g.*, FG.

It should be noted that D. long. is only measured on the equator. In the figure the arc FG on the equator = 90°. The arc ZY is also 90°, but it is evident that each mile of ZY is much smaller than that of FG. ZY is called the *Departure*.

Departure is the amount of easting or westing that an aircraft makes in going from one place to another.

By means of the *Traverse Table* it is possible to find the true course, distance, departure, D. long. or D. lat. between any two places provided any two elements are known.

The shortest track between two places on the Earth's surface is the arc of a great circle. This can best be appreciated by taking a globe and joining any two places on it by means of a piece of string. A great circle, however, cuts all meridians at different angles, so that to proceed along it would necessitate constant alterations in the direction of the vessel's head. It is, therefore, only used when a long voyage is to be made, and it is more convenient for the mariner to take a path which makes the same angle with every meridian. Such a path is called a *rhumb line*.

Rhumb line is a curve which cuts successive meridians at the same angle, *e.g.*, SXYT. Fig. I.

Distance.—The nautical distance between two places is that part of the rhumb line lying between them measured in nautical miles, *e.g.*, XY.

True Course.—If the air is considered an inert element, the true course is the angle the rhumb line makes with the true meridian, *e.g.*, PXY.

Now, in an airship it is seldom or never the case that she is able to steer the exact course required from place to place, on account of wind; it is necessary therefore to distinguish between the *track* desired and the course actually steered. We can say then that—

Track Angle is the angle the rhumb line makes with the true meridian, *e.g.*, NCX. Fig. II. This will be referred to throughout this work, for brevity, as the *Track*.

True Course is the angle the fore and aft line makes with the true meridian, *e.g.*, NCY. Fig. II.

Drift is the angular difference between the track of an aircraft and her fore and aft line, or, in other words, the difference between the direction made good and the direction steered. It results from the action of the wind and is similar to the leeway made by a sailing vessel. Drift is always in a direction away from the wind.

Run is the course and distance covered in a period of time, *e.g.*, from A to B the run was 89°—80 miles in two hours.

It is necessary to note here that the course, the track and drift are all *angles*. In Fig. II. we should say that the *Track* of airship X is 70°, the *True Course* 90° and the *Drift* 20°.

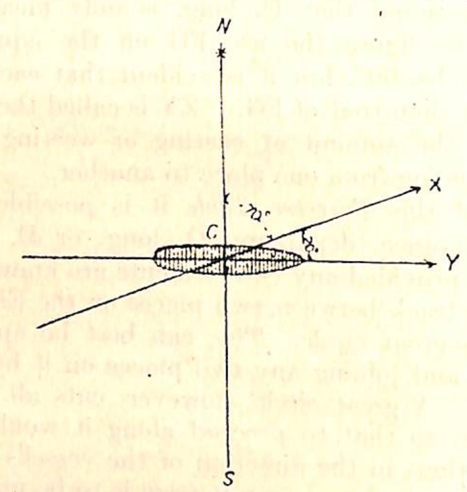

Fig. II.

NCX=Track=70°.
NCY=True Course=90°.
XCY=Drift=20°.

Dead Reckoning according to the old accepted idea of the expression should be the position arrived at as calculated from the course steered and the speed as shown by the air speed indicator. In areial navigation, however, such a reckoning would be of no value whatever, and in a voyage of 300 miles with varying winds the dead reckoning might be 100 or more miles in error. This definition must therefore be modified and should become—

Dead Reckoning is the position arrived at as calculated from the estimated track and the estimated speed made good over the ground.

Departure Point is the point on the map or chart from which the aviator commences his dead reckoning caluclations. In aircraft work it will generally be the areodrome or some spot in the vicinity clearly marked on the map.

These various definitions should be thoroughly understood and committed to memory. Having assimilated them they can now be applied to a hypothetical voyage from any place, A, to another place, B, distant 100 miles.

Take a small scale map or chart. Join A and B by a pencil line. A is the *Departure Point*, B is the objective. Lay a protractor with its centre over A and ascertain the angle made by the line AB with the True Meridian. This is the true course to be made good, or the *Track*. Measure with dividers the length of AB. This is the nautical *Distance*. The speed of the aircraft in still air and its petrol supply are known, so that it is simple to calculate how long it will take to go from A to B and whether we have sufficient fuel for the voyage. Assuming that the air is an inert element we have only to steer in the direction AB and we shall in due time arrive at our destination. In practice, however, it is found that the atmosphere is an extremely unstable element and its vagaries cannot be determined with any certainty. All we can do is to estimate the velocity of the wind and make allowances for *Drift* and increase or loss of speed, obtaining thereby the approximately correct course to steer and the speed over the ground. Now the course taken from the chart is the true course and our compass does not indicate true direction; we must therefore know how to convert the true course to the compass course. With these several calculations we can determine our approximate track and speed from A toward B, and these data enable us to find a *Dead Reckoning* position which may be somewhere near the correct one. In order to be able to make these dead reckoning calculations the would-be aerial navigator must know how to allow for the effects of wind, how to determine the velocity of the wind, and how to use the navigational instruments required to enable him to steer in the desired direction and to fix his position from time to time *n route*.

The several instruments required for navigational purposes in aircraft are:—

1. Compass.
2. Bearing Plate (Pelorus).
3. Aircraft Course and Distance Indicator.
4. Drift Indicator and Corrector.
5. Sextant.
6. Protractor.
7. Station Pointer.
8. Air Speed Indicator.
9. Altimeter or Aneroid.
10. Statoscope.
11. Engine Revolution Indicator (Tachometer).
12. Petrol Gauge.
13. Bubble Level (Inclinometer and Cross Level).

Of the foregoing instruments only the first seven will be described here; the remainder will be fully described in the Airship Manual.

Navigating Instruments.

(1) Compass.

This instrument indicates direction or bearing. It enables the observer:—

(*a*) To proceed in any required direction from one place to another.

(*b*) To ascertain the direction or bearing from his own position of any visible object.

(*c*) To ascertain his position by cross bearings of surrounding objects.

Modern compasses are of two kinds, *Magnetic* when influenced by the Earth's magnetism and *Gyroscopic* when influenced by the Earth's rotation.

The gyroscopic compass is a true compass and is probably the compass of the future, but it is not at present adaptable to aircraft, and is such a complicated instrument, requiring special study, that it will not be described here.

The magnetic compass consists of three principal parts—

(1) Bowl.
(2) Needle.
(3) Card.

The bowl is of some non-magnetic metal, in the centre of which a magnetised steel needle, or system of needles, is attached to a circular card so pivoted and suspended that it is free to rotate about its centre and take up a definite position under the influence of the Earth's magnetism. If the needle is unaffected by local magnetic forces it points to *Magnetic North* and the great circle passing through the poles of the needle is called the *Magnetic Meridian* of that place.

Magnetic compasses are either *dry* or *liquid*.

In the first the bowl is empty and the card rotates in air and in the second the bowl is filled with liquid. The dry card is useless where the compass is liable to be subjected to excessive vibration or violent and irregular motion so that liquid compasses only are used in aircraft.

The compass and its management is fully dealt with in the Chapter on Magnetism and Deviation of the Compass.

Compass Card.—The compass card is divided at its outer edge into 360 divisions or degrees, marked from the North point 0° (or 360°) with the hands of a watch through East, South, and West. Fig. III.

Each quadrant thus contains 90°.

Each degree contains 60 minutes, and each minute 60 seconds of arc, written thus:—Degrees °, minutes ′ seconds ″. Minutes and seconds are not shown on the card.

When bearings are given with this card the degrees and parts of a degree only are mentioned without reference to N., S., E., or W., thus—35°; 147°; 281° 30′; 350°.

In using this type of card the opposite or reciprocal of any degree may be found by adding or subtracting 180°.

Rule.—Under 180°, for reciprocal add 180°.
Over 180°, for reciprocal subtract 180°.
Thus 65. Reciprocal is 245°.
" 320°. Reciprocal is 140°.

In the Mariners' Compass the card is graduated in degrees on a different system and also in points. The card is divided into four quadrants of 90° each, which are read from 0° N. to 90° E. and 90° W., and from S. 0° to 90° E. and 90° W. Bearings or courses are given as N. 70° E.; S. 38° E.; S. 49° W.; N. 57° W.

Each quadrant is further divided into eight points, making 32 points in the whole card: one point being thus equivalent to 11° 15′ 0″. These are shown in Fig. III.

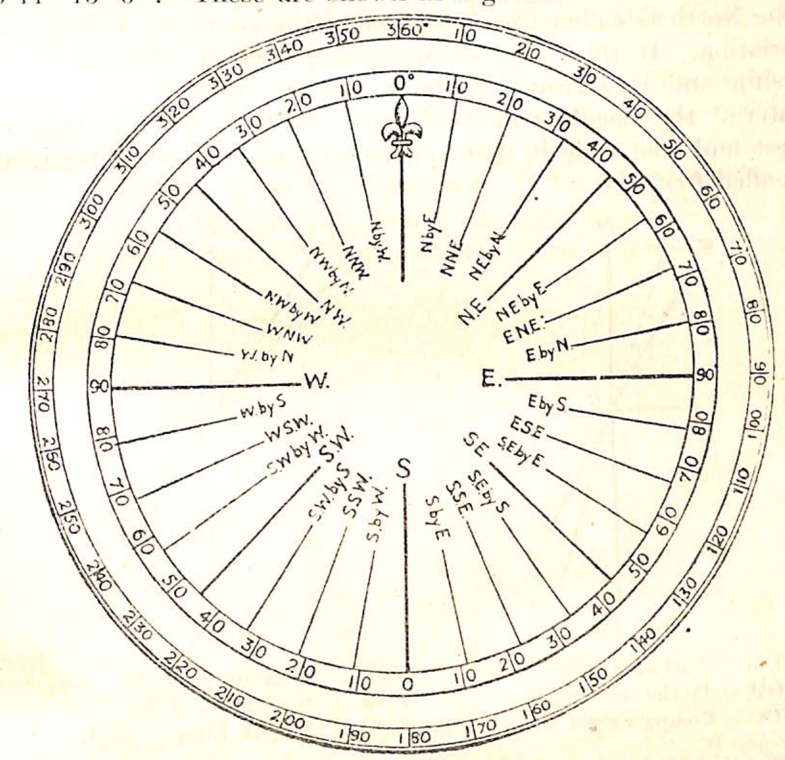

Fig. III.

The reciprocal of any point is found by changing the letters N. or S., E. or W.; *e. g.*, N.N.E. reciprocal, S.S.W.; S.W. by S. reciprocal, N.E. by N.

When using the card graduated from 0° to 360° it will be well to remember the degrees corresponding to the Cardinal and Quadrantal points.

The Cardinals are 0°, 90°, 180°, 270°.

The Quadrantals are 45°, 135°, 225°. 315°.

Lubber's Point or Lubber Line.—In every compass used for the purpose of directing an aircraft from one place to another, the direction of the craft's head is shown by a small metal horizontal pointer fixed to the compass bowl, or a vertical line painted on the inside of the bowl. It should be so placed that a line joining it with the center of the compas is exactly in the fore and aft axis of the craft or in a line parallel to that axis.

In steering a course by compass the direction of the craft's head is indicated by the reading on the card where it is cut by the Lubber Line.

Variation and Deviation.—It has been mentioned that the compass needle in a compass influenced solely by the Earth's magnetism points to the magnetic North and not to the true or geographical North.

The angle which the needle when deflected makes with the *True* North is called the *Variation* of the compass or Magnetic Variation. If this same compass is placed in the car of an airship and is surrounded by a certain amount of magnetic material the needle will be further deflected to the East or West and the angle it then makes with the *Magnetic* meridian is called *Deviation*.

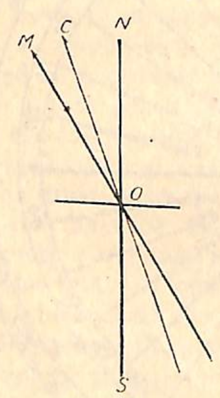

FIG. IV.

NOM = Variation = 10° W.
COM = Deviation = 2° E.
NOC = Compass Error = 8° W.

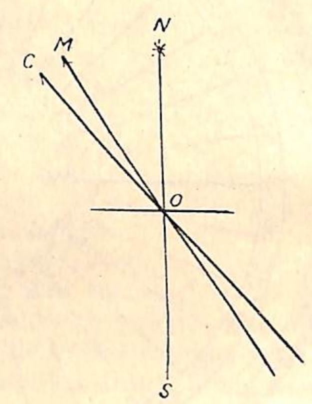

FIG. V.

NOM = Variation = 10° W.
COM = Deviation = 2° W.
NOC = Compass Error = 12° W.

The resultant error of the compass needle from the *True Meridian*, which may be the sum or difference of the Variation and Deviation, is called the *Compass Error*. Thus with Variation 10° W. and Deviation 2° E., the compass error is 8° W. With Variation 10° W. and Deviation 2° W., the compass error is 12° W.

Variation and Deviation are both fully dealth with in the chapter on Magnetism, and it will only be necessary to consider

them here where they affect the laying off and correction of bearings and courses.

Variation is not the same everywhere and changes with time. Its value at any place is given on a chart or map and the amount of the annual change. It can thus be corrected and brought up to date.

Deviation changes with every direction of the craft's head. The amount for each point is given in a table which is obtained by observation and calculation. The table will be found on a small tablet attached to the aircraft compass.

Bearings and Courses.

Since maps and charts are based on the True Meridian and give True Bearings and True Courses, whereas the compass either indicates magnetic or compass directions, we must find a method of connecting one with the other so that charts and compasses may be used in combination.

Bearing is simply another word for direction. The direction of any object is determined by its angular difference from the direction of some fixed point such as the geographical north pole, when it is said to have a *true bearing*. If the point of reference is the Magnetic North it is said to have a *magnetic bearing* and if the reference point is Compass North it has a *compass bearing*.

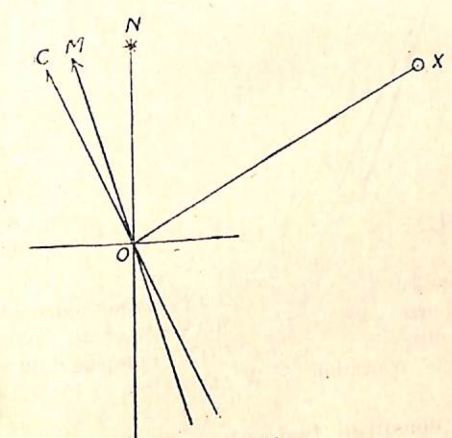

FIG. VI.

NOX=True Bearing=60°.
MOX=Magnetic Bearing=70°.
COX=Compass Bearing=73°.
Variation=10° W., Deviation=3° W.

True Bearing is the angle between the observer's true meridian and the great circle passing through his position and the object. Fig. VI.

Magnetic Bearing is the angle between the observer's magnetic meridian and the great circle passing through his position and the object. Fig. VI.

Compass Bearing is the angle between the observer's compass needle and the great circle passing through his position and the object. Fig. VI.

As bearings are never taken of objects at any very great distance the arc of the great circle joining the observer and the object may be considered as a straight line. Provided the distance of the object is not over 35 miles no appreciable error is thus introduced.

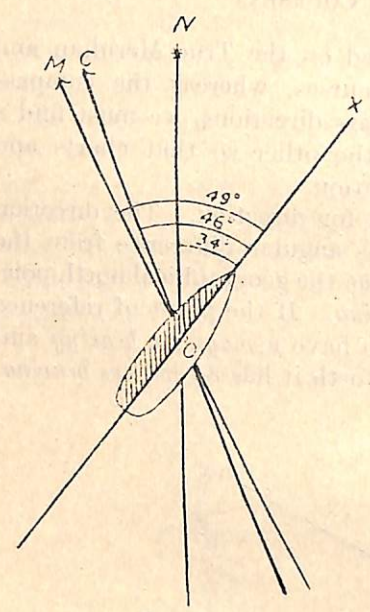

Fig. VII.

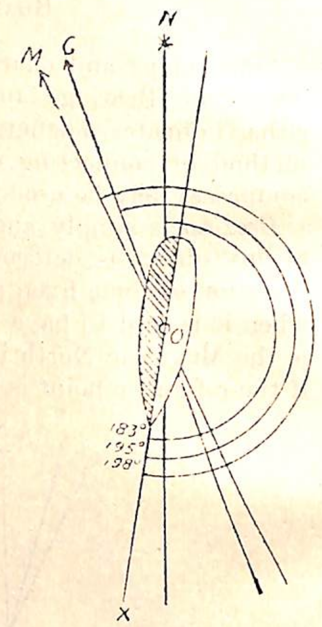

Fig. VIII.

NOX=True Course=34°.
MOX=Magnetic Course=49°.
COX=Compass Course=36°.

NOX=True Course=183°.
MOX=Magnetic Course=198°.
COX=Compass Course=195°.

Variation 15° W., Deviation 3° E.

Courses are measured from the north point to the fore and aft line of the aircraft.

True Course is the angle between the True Meridian and the fore and aft line of the aircraft. Figs. VII and VIII.

Magnetic Course is the angle between the Magnetic Meridian and the fore and aft line of the aircraft. Figs. VII and VIII.

Compass Course is the angle between the compass needle and the fore and aft line of the aircraft. Figs. VII and VIII.

Correction of Compass Courses and Bearings.—When taking a true course from the chart it is necessary to know how to apply Variation and Deviation in order to find the course to steer by compass. Conversely, having steered a certain compass course it is necessary to convert it to magnetic or true in order to lay it down on the chart.

The methods of application of Variation and Deviation are precisely the same and it will only be necessary to consider one or the other. Take the application of Variation to convert a True Course to Magnetic, or Magnetic Course to True.

Having steered a magnetic course we wish to correct it to true so as to lay it down on the chart.

In Figs. IX. and X. the outer circle represents the True and the inner circle magnetic. In Fig. IX. the variation is 10° W. and in Fig. X. it is 10° E.

Imagine the observer at the centre of the compass looking in the required direction, and bear in mind that the degrees on the card increase to the right (clockwise) and decrease to the left (anti-clockwise).

In Fig. IX. Magnetic north is seen to correspond with a spot 10° to the *left* of True north. Consequently if given a magnetic course with Westerly Variation to find the true, the reading on the true circle will always be to the *left*. (As West is to the left of North this is easy to remember.) Thus in Fig. IX. the magnetic course is 360° or north, Variation 10° W., the true course is 350° or N. 10° W.

In Fig. X. Magnetic north corresponds with a spot 10° to the *right* of True north. Consequently if given a Magnetic Course with Easterly Variation to find the True, the reading on the True circle will always be to the *right*. (East is on the right of North.) Thus in Fig. X. the magnetic course is 360° or North, Variation 10° E., the true course is 10° or N. 10° E.

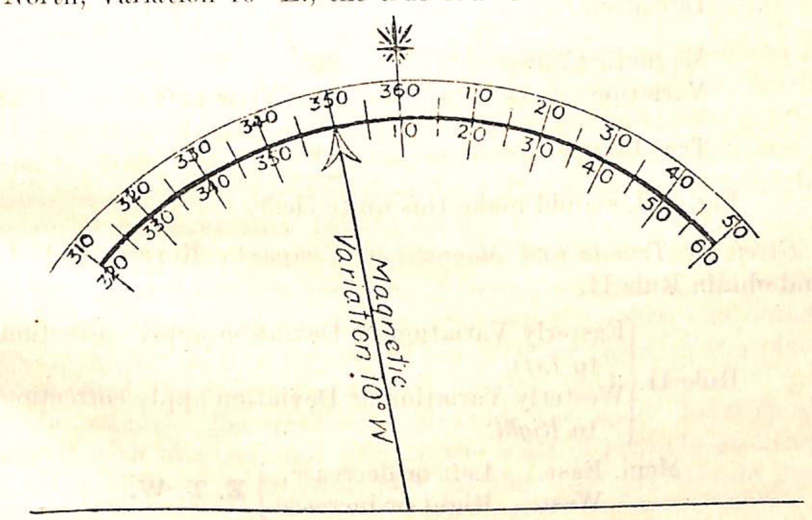

Fig. IX.

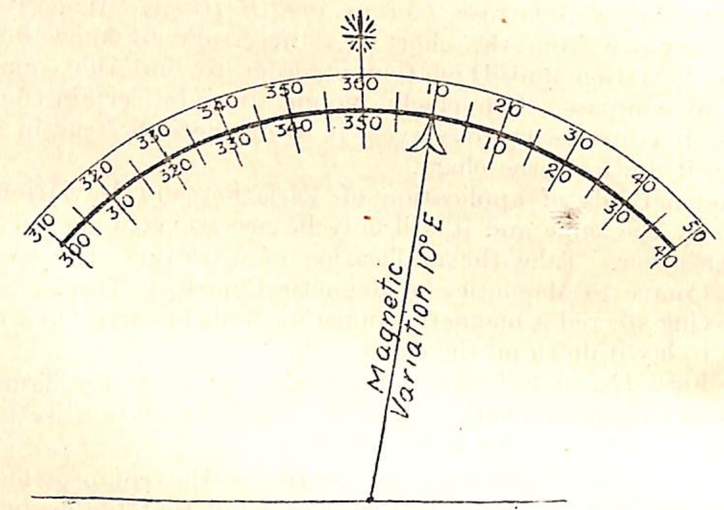

FIG. X.

The application of Deviation to work from Compass to obtain Magnetic is precisely the same and the rule is:—

Given Compass or Magnetic to find the True—

Rule I. { With *Easterly* Deviation or Variation apply correction to the *Right*.
With *Westerly* Deviation or Variation apply correction to the *left*. }

Mem. East. Right or increase }
West. Left or decrease } **W. C. E.**

Example.—*Compass* Course to find *True* Course.

Compass Course	- -	46°
Deviation	- - -	3° E. or Right.
Magnetic Course	- -	49°
Variation	- - -	15° W. or Left.
True Course	- - -	34°

Fig. VII. should make this quite clear.

Given the True to find Magnetic or Compass.—Reverse Rule I. and obtain Rule II.

Rule II. { Easterly Variation or Deviation apply correction to *Left*.
Westerly Variation or Deviation apply correction to *Right*. }

Mem. East. Left or decrease. }
West. Right or increase. } **E. T. W.**

Example.—*True* Course to find *Compass* Course:—

True Course	- -	183°
Variation	- - -	15° W. or Right.
Magnetic Course	- -	198°
Deviation	- - -	3° E. or Left.
Compass Course	- -	195°

See Fig. VIII.

The letters W.C.E. and E.T.W. committed to memory may be of assistance to the observer.

Compass to True - **W.C.E.** or East Right and West Left.
True to Compass - E. **T.** W. or East Left and West Right.

Recollect that when working from True to Compass apply Variation first, then Deviation.

When working from Compass to True apply Deviation first, then Variation.

Deviation in the table is for a Compass or Magnetic heading, and never for the True.

When correcting Compass *bearings* to True, the amount of the deviation is that for the direction of the craft's head at the time the bearing is taken and not that of the bearing.

The foregoing rules as to right and left apply equally to the Mariners' Card, but it will be simpler and avoid any chance of error if bearings or courses given in the Mariners' Card graduation are first converted to the 0°—360° graduation. Thus:—

S. 26° E. = 180° − 26° = 154°.
S. 30° W. = 180° + 30° = 210°.
N. 49° W. = 360° − 49° = 311°.

If time admits, and the observer is in doubt, he should always draw a figure as in Figs. VII. and VIII.

How to take off a Course or Bearing from a Chart.—From A to B. Lay a pair of parallel rulers along the line joining A and B, and then transfer them to the nearest compass rose on the chart. Read off the True or Magnetic course, which must then be corrected for Variation and Deviation to obtain the compass course to steer from A to B.

To lay off a Course or Bearing on a Chart.—Reverse the above procedure. Convert the compass course to Magnetic. Place the rulers over the compass rose on the chart, and obtain the magnetic or true course. Then transfer them to the place from which the course was steered, and lay off the course.

To measure the Distance.—Measure the space between A and B with dividers, and refer to the scale of latitude at either side of the chart, or in a plan to the scale of latitude and distance.

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How to take off a Course or Bearing from a Map.—From A to B. Join A and B by a pencil line. Place a protractor with its centre over A, being careful to have the 0° to 180° line parallel to the side of the map or to the central meridian.

Then the reading where the line AB cuts the graduated arc is the true course.

Variation and Deviation must then be applied to find the Compass Course.

To measure the Distance.—Measure the space between A and B with dividers, and refer it to the line scale at the foot of the map.

Note.—In calculating the amount of the Variation be careful always to correct it to date.

Take the nearest compass rose on the chart to the position. When the distance between two places is great, and the Variation changes considerably, take the mean of the Variation at the two places.

For very accurate work it is better to use the engraved compasses on the chart rather than a protractor, but in ordinary aerial navigation this degree of accuracy is not necessary, and a good protractor can be used.

(2) Bearing Plate or Pelorus.

This is simply a dummy compass card fitted with vanes for taking bearings, and is used when the compass is so placed in an aircraft that bearings cannot be taken from it. The instrument is fully described in the chapter on Magnetism and Compass, page 68.

(3) Drift Correctors.

The drift corrector is a mechanical means of obtaining the amount the course has to be altered to starboard or port, to allow for drift or leeway caused by the velocity of the wind, in lieu of plotting.

The various types are based on the following information:—

(i) Known air speed of the airship and the course steered.

(ii) Estimated velocity of the wind.

There are several types in existence, but the most useful is that known as the Aircraft Course and Distance Indicator, which is fully described in Chapter IV., page 44.

(4) Drift Indicators.

Drift indicators differ from the foregoing in that they show the actual course made good. In these instruments it is essential that the surface of the earth or sea is visible from the aircraft.

Observations are made of fixed objects on the earth's surface over which the aircraft is traveling, the direction in which they enter and leave the field of vision is noted, and this line of direction referred to the compass course steered during the observations, which gives the actual course being made good. Course is then altered until the direction made good and the direction proposed are in correspondence.

A simple drift indicator is a *Bearing Plate* with a skeleton centre attached on a bracket to the side of the aircraft. The course made good can be read off on the instrument itself and corrected if necessary. The time taken to pass over certain objects a known distance apart having been noted with a stop watch, the ground speed can also be calculated.

A more complicated and much more accurate instrument is the *Aircraft Bomb Sight,* which is also available as a drift and ground speed indicator and drift corrector. The following is a brief description of the instrument only so far as it is an aid to navigation:—

Aircraft Bomb Sight.—This instrument consists of a prismatic telescope directed downwards to the earth below. It hangs pendulum-wise on ball bearings, and the line of vision is deflected 15° forward of the vertical by means of a double prism arrangement. The support is made in the form of a turntable, also on ball bearings, to enable the instrument to be turned in azimuth to allow for the drift of the airship. The optical system consists of two prisms, an objective and an eyepiece; the two latter form an astronomical telescope, whilst the two prisms' in addition to deviating the light through the angle of 15°, also form an inverting system, thus rendering the provision of inverting lenses unnecessary.

In the field of view is a graduated sight, carrying a cross line at the point vertically below the instrument, and having a movable cross line which can be set by the rotation of a milled drum. This drum is turned by hand in accordance with the scale of heights given on the instrument, and the arrangements are such that for all heights the distance on the ground between these two cross wires is 300 metres. This constant distance is used for timing the ground speed, and the watch employed for the purpose, which is attached to the instrument, is graduated directly in metres per second to save arithmetic.

When the ground speed has thus been obtained, the amount of the drift can be calculated. On the fore and aft side of the fixed base of the instrument a lubber line is marked, which is accurately parallel to the fore and aft line of the aircraft. A bearing plate is fitted on the outside, graduated from 0° to 360°, which is independent of the fixed base and of the telescope, and this can be set to the course steered. On the outside of the telescope support is an arrowhead indicating the direction of the longitudinal wires inside the field of the telescope. The arc on the bearing plate having been set to the course steered, the observer turns the telescope until objects on the ground in his field of view pass along the longitudinal wires. The amount of the drift in degrees can then be read off on the graduated arc outside.

It will thus be seen that the instrument serves as a Drift and Ground Speed Indicator, and as a Drift Corrector, in addition to its proper purpose as a bomb sight.

(5) Sextant.

The sextant is a portable instrument used for measurement of angles, and it enables the observer to measure angular distances up to about 130° in any plane.

There are two principal types of the instrument in use at sea:—

(*a*) The *observing* sextant for astronomical work.
(*b*) The *sounding* sextant for horizontal and vertical angles between terrestrial objects.

The former is at present of no practical use in aerial navigation, but a special pattern for astronomical work in aircraft has been designed and is called the *Bubble Clinometer Sextant.* This instrument renders astronomical observations possible in the air and results to a certain degree of accuracy should be obtained with it by practice. It is, however, questionable whether aircraft will have to depend on astronomical observations for fixing their positions, unless making an ocean passage, when so many more simple methods of doing the same thing are available. On the other hand, the sounding sextant, in conjunction with the station pointer, should be extremely useful for fixing positions by horizontal angles between terrestrial objects.

Bubble Clinometer Sextant.

The instrument consists of a telescope A attached to an arc D by a frame B. (Fig. XI. A.) A movable arm or radius bar C with spiral limb attached, actuated by an endless tangent screw E with a divided wheel-head F. A small dry battery is carried in the handle of the instrument to illuminate the cross wires in the telescope, the spirit-level K, and the divided arc and wheelhead.

The telescope of the instrument, when in use, is directed at the sun or star and the arm carrying the spirit-level is moved until the bubble floats in the middle of its run. This bubble is seen reflected in the field of the telescope at the side of the cross wires on the diaphragm L. The object is brought into the centre of the cross wires in coincidence with the bubble, as

shown in Fig. XIb. The readings of the arc and the divided micrometer head of the tangent screw are then taken. The arc is divided into degrees and the micrometer wheel into minutes.

For the free movement of the radius bar a spring lever G releases the endless tangent screw from the teeth of the rack on the arc D. The radius bar can then be moved up or down and clamped at the desired point.

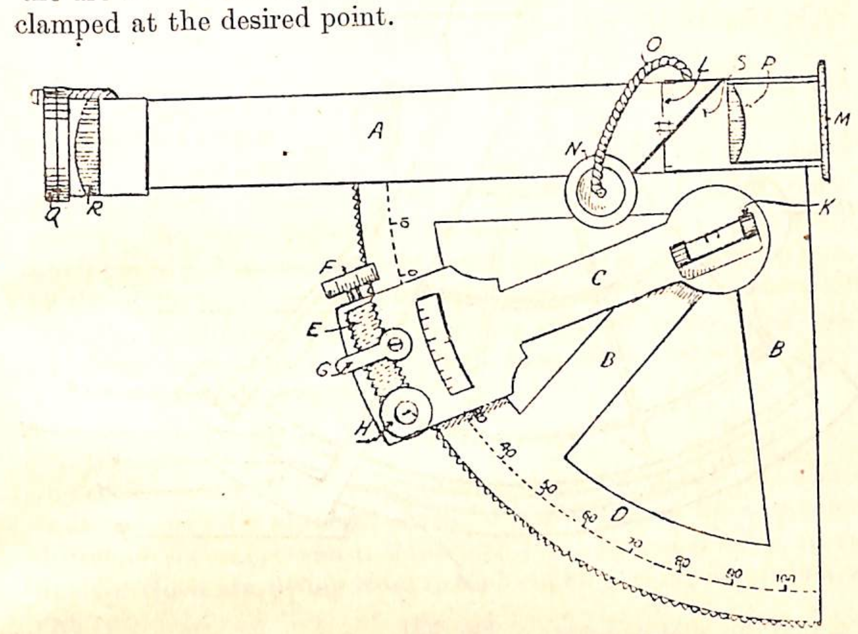


Fig. XIb.

1. Telescope. 2. Bubble reflected. 3. Sun.

Fig. XIa.

A. Telescope.
B. Frame.
C. Movable Arm or Radius Bar.
D. Arc.
E. Endless Tangent Screw (Underneath).
F. Divided Wheel Head.
G. Spring Lever.
H. Milled Head of Tangent Screw.
K. Bubble Level.
L. Diaphragm.
M. Aperture in Eyepiece.
N. Electric Lamp Holder.
O. Flexible Lead from Battery.
P. Eye-piece Lens.
Q. Shades.
R. Object Glass.
S. Reflector.

The battery in the handle of the instrument is actuated by a push button conveniently placed, and a small resistance coil is attached to the same for the purpose of varying the intensity of the light. A revolving shutter is also arranged round the lamp fitting, carrying a small lens, so that the arc or wheelhead may be read at will.

The Sounding Sextant.

This instrument differs from the observing sextant in that it has no shades to the mirrors, it is generally smaller, the horizon glass is all silvered and is enlarged, the vernier only reads to the nearest minute of arc and the end of the arc nearest the eye is usually rounded off. The telescopes are short with a large field.

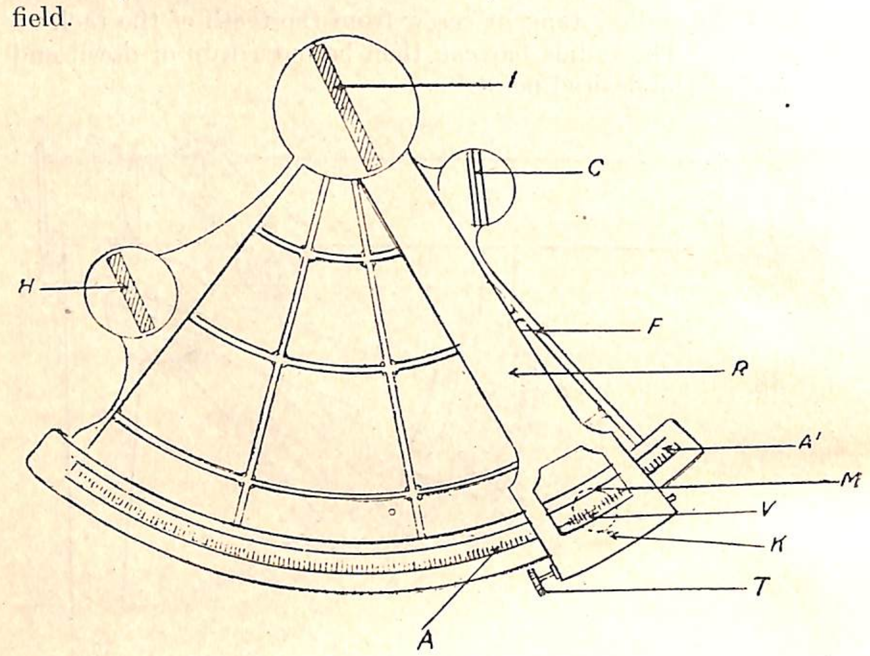


Fig. XII.

A. Arc.
A'. Arc of Excess.
C. Collar for Telescope.
F. Frame.
H. Horizon Glass.
I. Index Glass.
K. Clamping Screw. (Below.)
M. Magnifying Glass. (Above.)
R. Radius Bar.
T. Tangent Screw.
V. Vernier.

Description of the Sounding Sextant.

The *frame* carries the several parts and is carried on three legs.

A *radius bar*, movable about the centre, has at its extremity an *index* which travels on the arc.

The *arc* is graduated to 30′ from right towards left. The right extension of the arc called the *arc of excess* is graduated like the arc, but from left to right.

Index Glass.—Centred over the centre of the instrument and attached to the radius bar is a plane mirror termed the index glass.

Horizon Glass.—On the left outer radius of the instrument another glass is fixed which in the sounding sextant is wholly

silvered. This should be parallel to the index glass when the index is at zero, and is termed the horizon glass.

The *telescope* screws into a *collar*.

At the end of the index bar is the *vernier plate* travelling along the edge of the arc. This is fitted underneath with a *clamping screw* and at the side with a *tangent screw*, which allows a small movement of the vernier after the vernier plate has been clamped.

A *magnifying glass* is fitted to read off the divisions on the arc and the vernier. *See* Fig. XII.

Laws of Construction.—These depend upon certain facts deduced from simple laws of reflection of light from plane mirrors, the most important of which teaches that the angle observed is double the angle between the planes of the reflectors, or the angle which is read off on the arc. In order to allow for this the graduations on the arc are marked twice their real value and in consequence the angle read off is the actual angle observed between the two objects.

To Read Off the Sextant.

Vernier.—A vernier is an arrangement by means of which readings may be obtained from any graduation to a greater degree of accuracy than it is divided for. It is a smaller, more finely divided arc fitting close to and running along the primary arc.

The arc of the sounding sextant is divided to half degrees, but by means of the vernier it can be read off to one minute. An index or pointer on the vernier indicates the degrees and half degrees on the primary scale which must be read off, and the vernier itself gives the additional minutes. For example, if the reading on the primary scale is 2° 30′ and the two lines on the primary and vernier scales coincide at 13′ on the vernier, this is the amount in minutes on the vernier which must be added, making the complete reading 2° 43′.

To determine the degree of accuracy to which a sextant can be read the following formula can be used—

$$a=\frac{l}{n}$$

Where a = accuracy of reading; l = value of the smallest division on the primary scale; n = the number of divisions on the vernier.

Example:—

Primary scale divided to half degrees. Number of divisions on the vernier, 30. What is the accuracy of reading?

$$a=\frac{l}{n}=\frac{30'}{30}=1'.$$

Arc of Excess.

The arc proper of the sextant is divided from zero to the left, but in every sextant the graduation is continued for two or three degrees to the right which is called the arc of excess. This is read from *left to right* as also is the vernier when set off the arc.

The Adjustments of the Sextant.

It is necessary that the instrument should be kept in adjustment. The adjustments are:—

(1) The index glass must be perpendicular to the plane of the instrument. (Error of perpendicularity.)

(2) The horizon glass must be perpendicular to the plane of the instrument. (Side error.)

(3) The horizon glass must be parallel to the index-glass when the index points to zero. (Index error.)

(4) The line of collimation (*i.e.*, the axis of the telescope) must be parallel to the plane of the instrument. (Collimation error.)

The adjustments must be made in the above order.

To Adjust.

1. Index set to about the middle of the arc. Hold the arc away from the eye. Look obliquely into the index glass. Arc and its reflection should be in one line. This should be the case when the index bar is moved from end to end of the arc. Correct by screw at the back of the glass. This error is seldom found and is generally left to the instrument maker.

2. Index at zero. Hold sextant horizontal. Look through the collar at the horizon glass and bring the sea horizon, if available, failing which some distant horizontal line, so that it is seen each side of the mirror. True and reflected horizon should be in one line. Or hold the instrument vertically and look at some object such as a flagstaff. Slightly work the index bar, passing the reflected over the true object. If they do not coincide but pass each side of one another there is side error. Correct by screw at back and in the centre of the horizon glass, or by the key underneath the mirror.

3. Index at zero. Hold instrument *vertically*. The Sun's diameter on and off the arc is usually measured, but in the sounding sextant this cannot be done. Select a well-defined horizontal line, such as the sea horizon, if available, or the edge of a chimney or roof *at least half a mile distant*.* Bring the true and reflected images into exact coincidence. If the vernier now shows zero, there is no index error. Otherwise note the reading. If on the arc it is −, and off the arc it is +.

* Unless the object selected is at least half a mile distant an error called arallax will result, which may be greater than the index error.

If under 2′ or 3′ the error is recorded but not adjusted. Correct by capstan screws below the horizon glass or by the screw at back and at one side of the horizon glass.

4. This adjustment need not be considered in the sounding sextant.

To Observe an Angle.

In observing the angular distance between two objects with the sextant, the instrument should be held in the plane joining the objects. Hold the instrument with the right hand, arc to the left. Look through the collar and over the horizon glass at the left hand object and work the index bar until the reflection of the right hand object is brought underneath and in coincidence with the left. Clamp the vernier plate, work the tangent screw, if necessary, and then read off the angle.

When the horizontal angle between two objects at different levels is required, this can be obtained by holding the instrument horizontally and bringing the reflection of the right hand object in coincidence with some point vertically below the left, or if the latter is on the lower level bringing a point vertically below the right hand object in coincidence with the left.

A vertical angle can be observed by holding the instrument vertically, directing it at the lower object and reflecting the upper object down to it.

In using the sextant the observer, before commencing his work, should remove all side error, if it exists, and know accurately the amount of the index error of his instrument. The latter should be applied as a correction to all observations when accuracy is necessary.

(6) Protractor.

There are various types of protractor in use, but only one of these will be described. The aviator should select from the many patterns on the market that which best suits his methods.

The Creagh-Osborne Protractor.

This is a transparent celluloid protractor. It is square in shape, with a central circular arc divided from 0 to 360 in degrees. At the top and bottom edges are scales in metres and yards corresponding to the more generally used scales in continental maps, viz., $\frac{1}{80000}$ and $\frac{1}{100000}$. Attached at the centre is a silk thread. The sides can be used for ruling straight lines.

To take off Bearings.—Place the centre on the observation point, taking care that the north and south line corresponds with the true or magentic north and south line on the map. Stretch the thread across the object on the map, and read off the bearing where it cuts the graduated arc. (*See* Fig. XIII.)

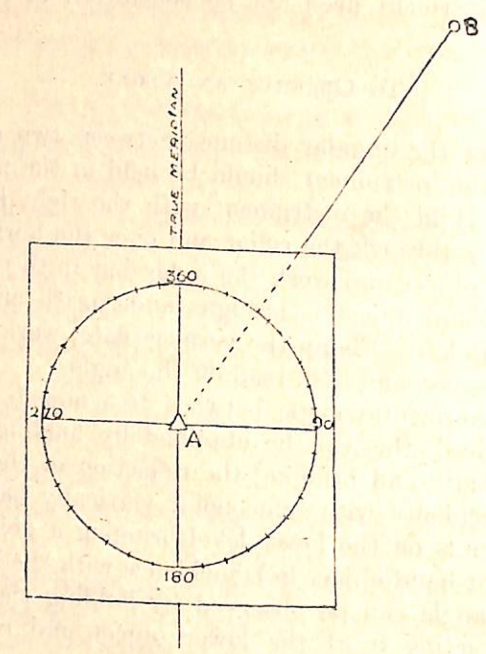


Fig. XIII.

To take a True Bearing from the map with Creagh-Osborne Protractor. B bears 35° (True) from A.

This protractor is very useful for those unaccustomed to compass work, as the arc is graduated similarly to the compass card used, and no mental calculations are required when laying off bearings, as in the case of the semicircular protractor.

To lay off a Bearing or Course.—Proceed as above and make a pencil mark on the line indicated by the thread in the desired direction. Using the side of the protractor as a rule, join the centre and the point thus obtained by a pencil line.

(7) The Station Pointer.

This is of metal with a circular graduated arc and three legs, two of which are movable and the centre one fixed. The bevelled edges of the three legs radiate from the centre of the instrument and that of the fixed leg corresponds with the zero of the graduated arc, which is marked from 0° to 180° on either side of the zero. The two movable legs can be revolved about the centre and clamped at any point on the arc. The centre of the circle is indicated by a small nick in the bevelled edge of the fixed leg.

To use.—The two angles observed between three objects are set on the arc by the two movable legs. The instrument is then laid on the chart and so manipulated that the beveled edges of the three legs are over the three objects. The center of the instrument then gives the observer's position, which can be marked on the chart by pencil.

As this form of the instrument has a certain amount of weight it is not so well suited to aircraft work as the Cust Station Pointer and is only likely to be found in the larger craft where a chart table is available.

The Cust Station Pointer.

This is a square or oblong celluloid protractor with a circular graduated arc divided in degrees in two semicircles from 0° to 180°. At the center is a small hole. One side of the protractor is specially prepared so that it will take pencil lines, which can be easily erased. To use the station pointer take the centre object as 0° and lay off right and left the observed angles and the check angle. Place it over the map with the pencil lines on the underside and manipulate it until the rays drawn pass through the positions of the observed points on the map. Then prick through the center, which is the observer's position. As the prepared side of the instrument should be the underside when placed on the map, to avoid errors of parallax due to the thickness of the material, the angles when laid off should be reversed so that when the instrument is turned to place on the map they are on their correct side.

Example.—Observed angles, A 62° B 48° C.

With the prepared side uppermost lay off 62° on the right and 48° on the left. Then reverse the instrument and place on the map, when A and C will be on their proper sides.

CHAPTER II.

POSITION LINES.

Fixing Positions.

Positions are found in aerial as in sea navigation by the intersection of two or more position lines.

A *position* line is any line which can be drawn on a chart or map, on which the airship is known to be.

A *fix* is the point at which two or more position lines intersect.

Position lines are obtained in a variety of ways and may appear as straight lines or as circles. The best fix is one resulting from the intersection of two or more position lines observed at the same time, provided that the angle of intersection is large. A position so found is called an "absolute" fix in contradistinction to a "running" fix.

A running fix is one in which the two position lines are obtained with a considerable interval of time between them, *e. g.*, a fix from two bearings of the same object at different times. As the value of this depends on the accuracy of the reckoning kept and the correct estimation of the wind effect in the interval, which presents great difficulty in aerial navigation, a running fix will never be dependable and an absolute fix should be obtained when possible.

Recollect when taking bearings or angles for fixing positions that the time of the observation should be carefully noted.

Methods of fixing Positions.

A. *Absolute Fix:—*

(1) Cross Bearings.
(2) Bearing and Angle.
(3) Transit and Angle or Transit and Bearing.
(4) Sextant Angles.
(5) Astronomical Observations.

B. *Running Fix:—*

(1) Bearings of one or two objects and run in interval.
(2) Doubling the angle on the bow and Four Point bearing.

It is improbable that the methods in B. will be of any real value in aerial navigation.

A. (1) (*a*) *Cross Bearings.*—Select two objects the bearings of which give as near a right angled cut as possible. Take a bearing of a third object as a check. This last not only checks the accuracy of the fix, but ensures that the bearings are laid off from the correct objects on the chart.

Select near objects in preference to distant ones. A small error in the observed bearing will have a greater effect the farther the object.

In taking bearings the object which is changing its bearing most rapidly should be observed last. Thus an object nearly ahead or astern first and one on the beam last.

Write down the names of the objects in the note book before observing, then take the bearings as quickly as possible, losing no time between the observations. Note the bearings

observed and record the time of the *last* bearing as the time of the fix.

In taking down the names of the objects observed write them down thus:—

First object—	Bearing—	Time of fix
Second object—	Bearing—	
Check object—	Bearing—	
e.g., in Fig. I. -	Church 318°	2.38 p.m.
	Hill 42°	
	Tower 80°	

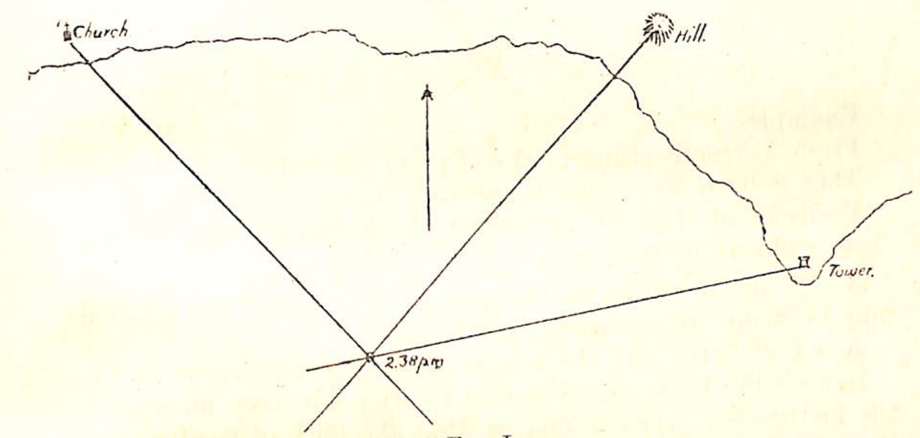


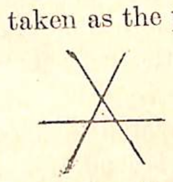
Fig. I.

When converting the compass bearings obtained to Magnetic or True remember that the deviation to apply is that for the *direction of the craft's head* at the time of observation. Correct the variation to date, and when laying off the bearings use the compass rose on the chart nearest to your estimated position.

Avoid drawing unnecessarily long lines on the chart and rule all pencil lines lightly, so that they can be easily erased.

Having found the position draw a small circle round the spot to indicate the "fix" and note the time against it.

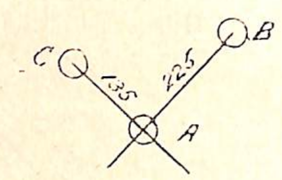
When owing to small errors of observation any three lines of bearing do not intersect at a point the small triangle formed is called a "cocked hat," and in such case the central point of the cocked hat should be taken as the position.



A. (1) (*b*) *Position plotted by Reciprocal Bearings.*—In an Ordnance map no True or Magnetic graduated compass rose is given, as in a chart, and parallel rulers cannot therefore be used unless graduated, without resort to the protractor. The simplest method of finding a position in such case is by laying off back* or reciprocal bearings.

It is obvious that if an object B has a certain bearing from A, then A has the opposite or reciprocal bearing from B.

Given cross bearings from a point A of objects B and C, first calculate the reciprocal bearings *from* those objects, and when these are laid off on the map the point where they intersect is the position of A.



Example:—
From A, true bearings of B and C, 45° and 315°.
Then A bears 225° from B and 135° from C.
Positions of B and C are known, back bearings laid off from them will give position of A.

A. (1) (*c*) If a Cust station pointer is available the bearings may be easily and accurately plotted.

Join the centre with the zero to serve as the true meridian.

Lay off the bearings, converted to true, and then manipulate the instrument over the map so that the lines of position pass through the several objects observed, *taking care to keep the true meridian on the instrument parallel to the true meridian on the map.* Then prick through the observer's position at the centre.

A. (2) *Bearing and Angle.*—It may happen that only one conspicuous object can be observed by compass. In this case a fix can be obtained by taking a bearing of that object and at the same time observing the sextant angle, or angle by bearing plate, between it and some other object. An object as nearly as possible at right angles to the bearing should be selected.

To lay off a bearing and angle, lay off the bearing first. If a station pointer is available, put the angle on one leg, put the centre leg coincident with the bearing line, and slide the station pointer along till the leg set to the angle is over the object.

If only a protractor is available, mark with a dot any point A in the bearing line and lay off the required angle from this point. Then through the object draw a line parallel to this

* The term *back* bearing is also given to a bearing taken abaft the beam of an airship in contradistinction to a forward bearing.

and the point where it cuts the line of bearing will be the required position.

Fig. II. Point bears 342°; angle to Church is 72°.

As this method requires two instruments and two observers it is not likely to be frequently used in an airship if other methods can be utilised.

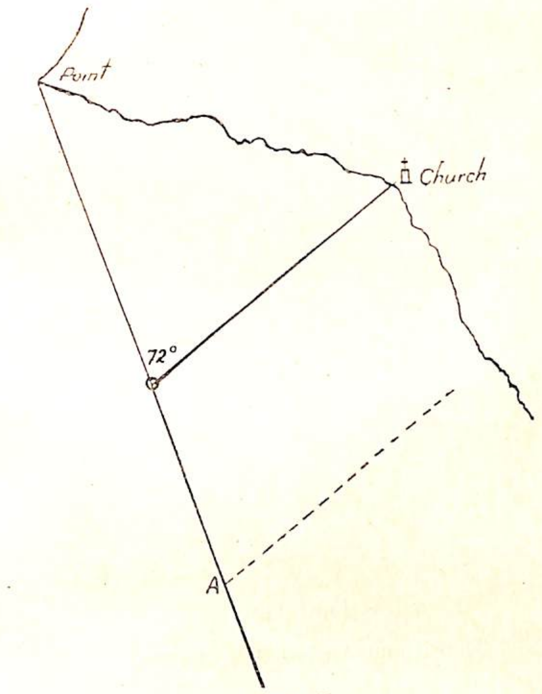


Fig. II.

A. (3) *By Transit and Angle, or Transit and Bearing.*—One of the most accurate forms of position line is a transit, that is to say, when two objects are in line with one another. This is one of the easiest position lines to obtain and quite the most useful for aircraft work. The symbol ϕ is used to denote a transit. Thus A ϕ B indicates that A, the nearer object, is in transit with B, the more remote. A transit will not, however be absolutely reliable unless the objects are carefully chosen and are not too close together. A safe distance apart is at least one-third of the distance of the nearer object from the observer. Thus A is one mile from B and three miles from the observer.

Having selected two suitably placed objects, take an angle to a third object C. This angle should be as near 90° as possible, and in any case not less than 30°.

To plot. Join A and B and produce in your direction. From any point in this position line draw an angle equal to that observed X′C′. Through C draw a line parallel to this, and where, it cuts AB produced at X is the required position. The angle can as easily be laid off on tracing paper and pricked through. (Fig. III.)

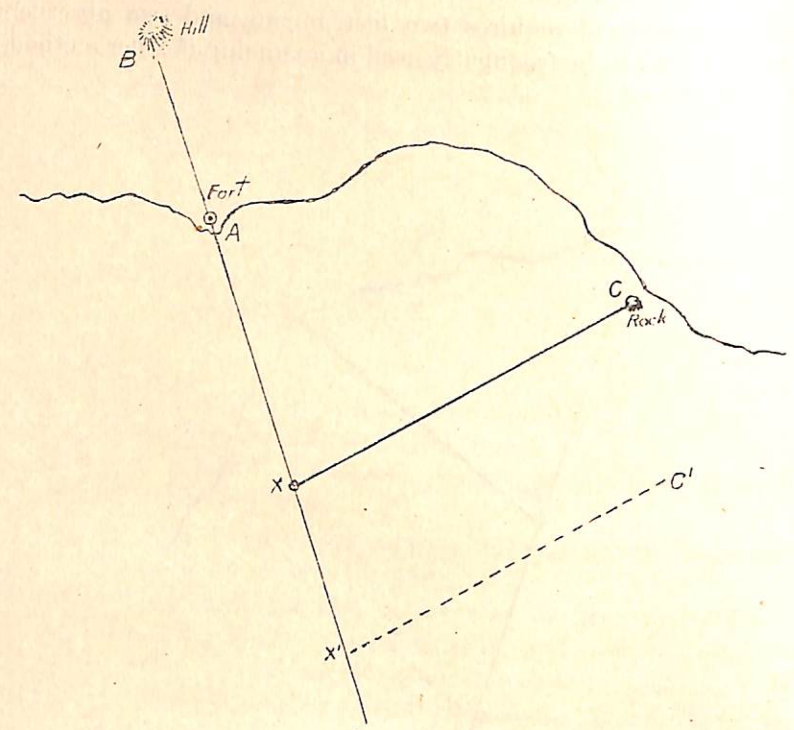


Fig. III.

Transit and Angle.—A ϕ B 77° C.

If it is more convenient, a bearing of a third object C can be taken instead of an angle. The bearing converted to true or magnetic can be laid off as before described.

The observant aerial navigator will constantly be able to get position lines by transits, as these occur every moment. Two such position lines obtained at the same time give an absolute fix, and no instruments are required for so finding a position. An example of this is when the craft is flying on leading marks and a transit cutting this leading line nearly at right angles is observed.

A. (4) *Sextant Angles.*—The sextant is a most useful instrument for accurately fixing the position of an aircraft by angles between terrestrial objects, if these are suitably chosen.

The usual method is called the *Three Point Method.* This depends on the fact that the angles subtended by the chord of the segment of a circle measured from any point on the circumference are equal. (Euclid, III. 21.)

In Fig IV. the angles ACB, ADB and AEB are all equal, so that if the angle subtended by AB has been observed, the observer's position must be somewhere on the circumference of a circle, the size of which depends on the angle observed. This gives a circle of position, and the observer in this case must be somewhere on the arc ADB.

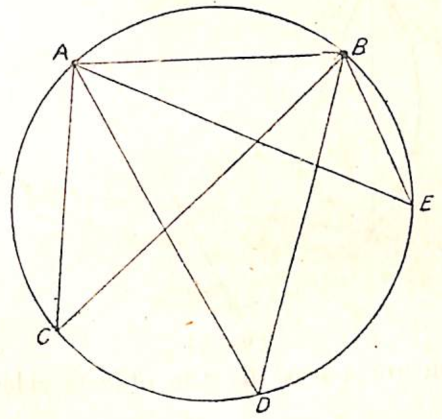


Fig. IV.

If in addition to the angle subtended by AB the angle subtended by BX is also observed, a second circle of position is obtained, and where the two circles cut is the position of the observer. (*See* Fig. V.)

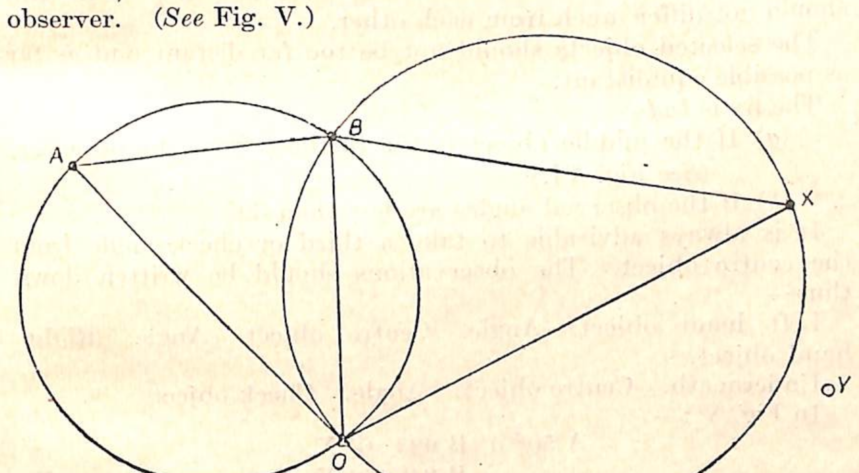


Fig. V.

If the objects A, B and X are suitably selected the fix is good, but if it so happens that the circle through A, B and the observer also passes through X, as in Fig. VI., the fix is bad and of no use. For the position of the observer may be at O or O′ or anywhere on the arc AOXB.

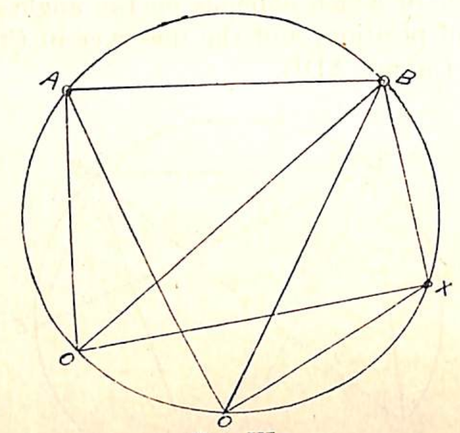


Fig. VI.

In order to ensure a *good* fix the objects selected should be so placed that—

(*a*) The middle object is nearest the observer.
(*b*) They are in a straight line.
(*c*) The observer is inside the triangle formed by joining them.

The observered angles should be as near 90° as possible and should not differ much from each other.

The selected objects should not be too far distant and as far as possible equidistant.

The fix is *bad*—

(*a*) If the middle object is the furthest from the observer. (*See* Fig. VI.)
(*b*) If the observed angles are less than 30°.

It is always advisable to take a third or check angle from the centre object. The observations should be written down thus—

Left hand object.—Angle. Centre object. Angle. Right-hand object.

Underneath.—Centre object. Angle. Check object.

In Fig. V.:—

A 50° 0′ B 62° 0′ X.
B 84° 30′ Y.

In practice the circles are never drawn, but the observed angles are laid off and the position found by a station pointer, of which the Cust station pointer is the most useful type, or they can be plotted by tracing paper.

When no station pointer is available tracing paper is used. Draw a vertical line in the centre of the paper. From a point O

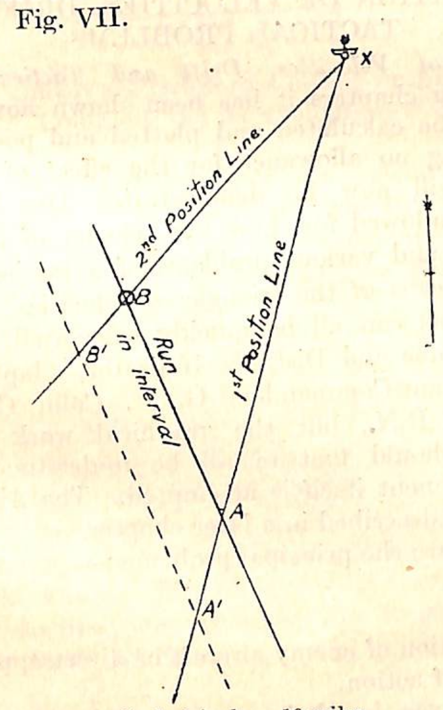
at the bottom of this lay off right and left the observed angles. Place the paper over the map and manipulate it until the rays pass through the observed points A, B, X, and Y. Then prick through O, which is the observer's position.

A. (5) *Astronomical Observations.*—Positions may be found when making long passages out of sight of land by astronomical observations of the sun or stars. The altitude of the object is observed by means of the Bubble Clinometer Sextant, and the time accurately recorded. With the zenith distance of the body so obtained, and the assistance of special tables (Ball's), the true bearing of the object can be determined, and a position line laid down on the chart. A second position line may be obtained from the true bearing of a second celestial object or any terrestrial one, the interesection of the two position lines giving a fix.

The Admiralty "Manual of Navigation" should be consulted to obtain the methods of calculating by Nautical Astronomy the observations so taken.

B. (1) *Bearings of one or two Objects and run in interval.*—Take the bearing of an object and the time.

After an interval take the bearing again, or take the bearing of a second object, *and* the time. Lay the bearings off, calculate the ground covered by the craft in the interval, and fit the distance in between the lines on the track the craft is making good. Fig. VII.



Scale 1 inch = 10 miles.
Fig. VII.

This will not give accurate results, as it is essential that the speed and direction of the craft are known correctly.

B. (2) *Doubling the Angle on the Bow.*—The angle on the bow means the angle between the craft's' fore-and-aft line and the object reckoned to starboard or port.

Observe the bearing of an object, say 30°, on the starboard bow, and take the time. When the angle on the bow is doubled, *i.e.*, is 60°, take the time again.

B. (2) *Four Point Bearing.*—The object is first observed when it is on the Bow, *i.e.*, 45° from right ahead, and secondly when on the Beam, *i.e.*, 90° from right ahead.

Theoretically, in both cases, the distance run between the observations is then the distance of the observer from the object at the second observation. In practice, however, this method of fixing is extremely unreliable, the accuracy of the result depending entirely on the correct estimation of the track and ground speed of the craft in the interval. It is only referred to here since it is a recognised method of fixing a position in sea navigation, but it is of no practical value in aerial work.

CHAPTER III.

COMPOSITION OF VELOCITIES, DRIFT AND TACTICAL PROBLEMS.

Composition of Velocities, Drift and Tactical Problems.—In the foregoing chapters it has been shown how courses and distances may be calculated and plotted and positions arrived at when making no allowance for the effect of wind on the aircraft. It will now be demonstrated how drift can be calculated and allowed for, how the velocity of the wind may be determined, and various problems of a tactical nature can be solved by means of the triangle of velocities.

These problems can all be quickly calculated by means of the Aircraft Course and Distance Indicator, adapted for aerial use by Lieutenant-Commanders G. R. Colin Campbell and G. B. Harrison, R.N., but the graphical work necessary in plotting them should first of all be understood thoroughly before the instrument itself is attempted. The Aircraft Course Indicator is fully described in a later chapter.

The following are the principal problems:—

(1) Drift.
(2) Wind.
(3) Interception of enemy aircraft or direct approach.
(4) Radius of action.

The above cover in their method of application several other problems.

Compensation and Resolution of Forces.—If two forces act on a body in the same direction their resultant is equal to their sum, and if in opposite directions to their difference.

Thus, an airship having an air speed of 50 knots has a fair wind of 20 knots. Her ground speed will then be 70 knots. With the wind directly against her the ground speed will be 30 knots.

When two forces act at a point of a rigid body in different directions their resultant can be obtained by the *parallelogram of forces*.

Parallelogram of Forces.—Two forces acting at a point can be represented in magnitude and direction by the two sides of a parallelogram drawn from one of its angular points. Their resultant is then represented both in magnitude and direction by the diagonal of the parallelogram passing through that angular point.

The direction and magnitude of the resultant can be found by calculation or by plotting.

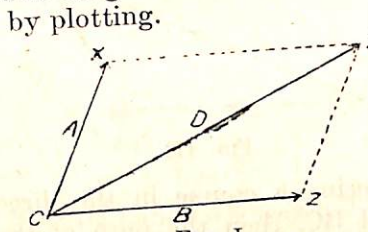
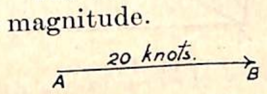


Fig. I.

In Fig. I., A and B are two forces acting in different directions at the point C. Complete the parallelogram CXYZ. Then D is their resultant.

Composition of Velocities.—Since the velocity of a point is known when its direction and magnitude are both known, the velocity of a moving point can be conveniently represented by a straight line AB. The arrow indicates direction, and the length of the line its magnitude.



Scale, 1 inch = 20 knots.

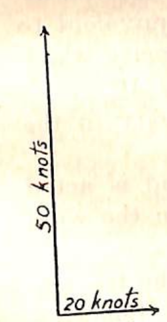


Fig. II.

A body may have simultaneously velocity in two or more different directions. An airship is forced by her engines due North at 50 knots, the wind acting on her at the same time is from the West, 20 knots. The airship will, therefore, have two velocities, one towards the North and the other towards the East.

Parallelogram of Velocities.—If a moving point possesses simultaneously velocities which are represented in magnitude and direction by the two sides of a parallelogram drawn from a point, they are equivalent to a velocity which is represented in magnitude and direction by the diagonal of the parallelogram passing through the point. The velocity which is equivalent to two or more velocities is called their *resultant* and these velocities are called the *components* of this resultant.

In Fig. (I.) D is the resultant velocity of the two component velocities A and B.

Trinagle of Velocities.—If a moving point possesses simultaneously velocities represented by the two sides AB and BC of a triangle taken in order, they are equivalent to a velocity represented by AC.

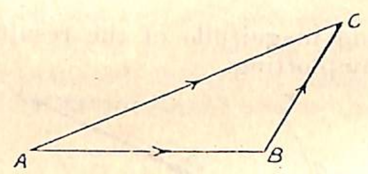


Fig. III.

An airship is steering a course in the direction AB and is acted on by a wind BC, then the path of the airship will be represented by AC.

Change of Velocity.—A body is moving with a velocity represented by AB and at some subsequent time by that represented by AC.

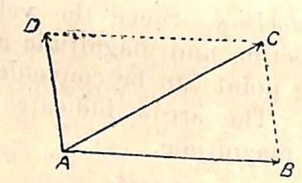


Fig. IV.

Join BC, and complete the parallelogram ADCB.

Then velocities represented by AB and AD are equivalent to the velocity AC. Hence the velocity AD is the velocity which must be compounded with AB to produce the velocity AC.

The velocity AD is therefore the change of velocity in the given time.

An airship is proceeding in the direction AB, and is acted on by a wind and forced in the direction AC. Then the wind is represented by the direction AD.

The foregoing examples illustrate the principle of the triangle of velocities which is the basis upon which all the following problems are worked.

(1) *Drift.*

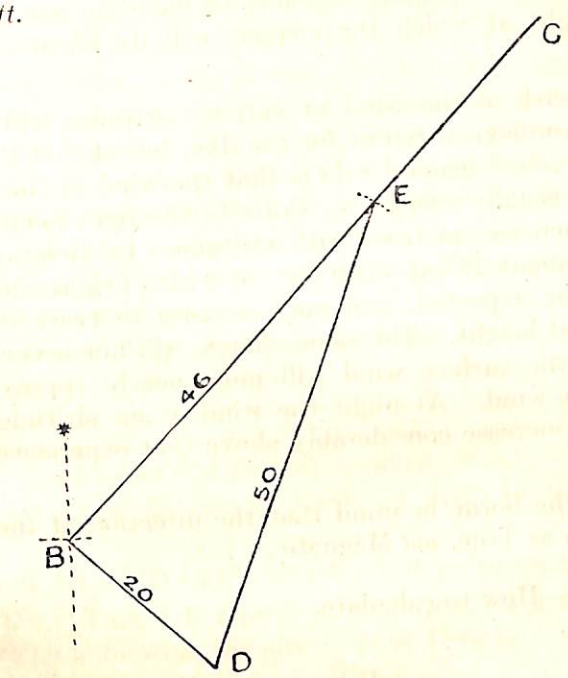


Fig. V.

Scale 1 inch = 20 sea miles.

Aircraft proceeding from B to C.
Track from B to C = 45°. Air speed 50 knots.

Wind N.W. 20 knots.

Required true course to steer, ground speed, and drift.

Join B and C.

From B lay off BD = 135° – 20 knots. Direction in which wind is blowing.

From D describe an arc of a circle with radius 50 knots (speed of aircraft) cutting BC at E.

The direction DE is that to steer to make good the direction BC, and this remains, no matter the distance between B and C, so long as the direction and force of the wind and speed of the airship remain the same. The *true course* is the angle that DE makes with the true meridian = 21°. The distance BE is the *ground speed* or the distance made good in one hour = 46 knots. The *drift* will be the difference between the track and the true course = 24°.

In allowing for velocity of the wind remember that the wind at the surface is never the same in velocity as that at an altitude. Allowance must therefore be made for wind according to the height at which the aircraft will fly when on passage from B to C.

The velocity of the wind at various altitudes will be given in the meteorological report for the day, but should this not be available a rough general rule is that the wind in the Northern hemisphere usually veers, *i. e.*, shifts to the right hand or clockwise and increases in force with altitude. In direction it may veer up to about 20° at 3,000 feet, at which height the gradient wind may be expected, and may increase to twice its surface speed at that height. The same change will not occur over the sea, where the surface wind will more nearly approximate to the gradient wind. At night the wind at an altitude may be expected to increase considerably above that experienced on the surface.

It should be borne in mind that the direction of the wind is always given as True, *not* Magnetic.

(2) *Wind.*—How to calculate.

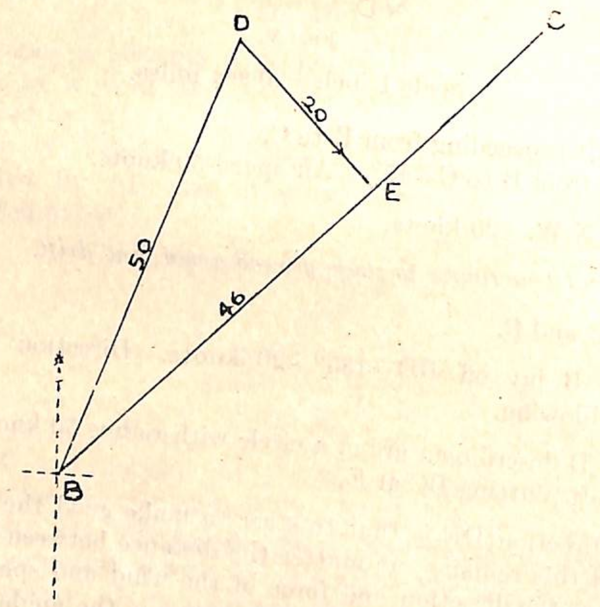


Fig. VI.

Scale 1 inch = 20 sea miles.

In practice it is sometimes possible to arrange that the airship remains stationary for a short time over a certain spot

with her head pointing directly at the wind. The direction can then be determined at once and the speed will be that indicated by the tachometer* in the airship, that is to say, the speed which the craft should be making in still air according to the revolutions of her engines. This is not, however, always possible to carry out, and it entails loss of time. A method of calculating the wind when under way and without losing speed is as follows:—

In Fig. VI. Aircraft proceeding from B to C.

Track from B to C = 45°. Ground speed 46 knots (obtained from observation of ground objects).

Course steered 21°. Air speed, 50 knots.

Required, direction and force of the wind.

From B draw BC = 45°. Mark off BE = 46 knots = ground speed.

From B draw BD = 21°. Mark off BD = 50 knots = air speed.

Join DE. Then DE represents the direction and force of the wind, which is blowing the airship from D to E.

Wind direction, N.W. Force, 20 knots.

Similarly, if the course steered, the air speed, direction and force of the wind are given, the track and ground speed can be calculated.

(3) *Interception of Enemy Aircraft or Ship,* or direct approach to given range.

This problem has two cases—

(*a*) Where both attacker and attacked are equally affected by wind; or where there is no wind.

(*b*) Where the attacker only is affected by wind.

Case (*a*).—This problem is solved in precisely the same manner as that for drift.

Example.—Find the true course to be steered by an airship B to intercept an enemy aircraft C bearing 30°, distant 60 miles from B, and *steering* 270°.

B's Air speed = 50 knots. C's Air speed = 45 knots.

* The Air Speed Indicator may be used in lieu. The pilot should avail himself of the instrument in which he places the greater confidence.

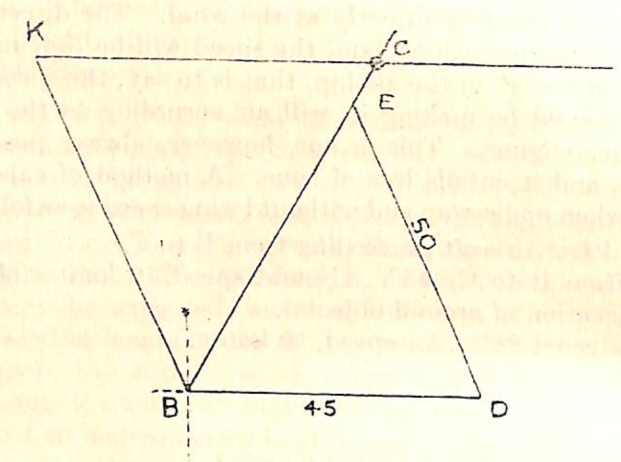


Fig. VII.

Scale 1 inch = 30 sea miles.

In this example there is no wind, but since both B and C are equally affected by the wind it can in any case be disregarded.

From B draw BC = 45° – 60 miles. Then C is enemy's position. Lay off 270° from C.

Imagine there is a wind blowing exactly opposite in velocity to C's course, viz., 90° – 45 knots. Then C is stationary, and BC is the direction which B desires to make good.

The problem then becomes to find B's course to point C, allowing for a wind the velocity of which is C's direction and speed reversed.

From B lay off BD = 90° – 45 miles. With D as centre and DE as radius = 50 miles (B's speed), draw the arc of a circle, cutting BC in E. Join DE. Through B draw BK parallel to DE, cutting C's course at K.

Then the direction BK is B's true course (338°), which will intercept C at K, B and C arriving at K at the same time.

To find the time taken by B to reach K:—

$$\text{Time in hours} = \frac{\text{BK in miles}}{\text{B's speed in knots}} = \frac{56}{50} = 1 \text{ hour } 7 \text{ mins.}$$

approximately.

This can be checked by calculating similarly how long C takes to reach K.

In this problem allowance must be made for B to climb to C's height, and this can either be plotted as extra speed of C or decreased speed of B for the first half-hour.

Always over-estimate the enemy's speed rather than underestimate it, and arrange to attack at a greater height if possible.

Aim *well ahead* of the enemy's calculated position. This allows for contingencies such as under-estimation of enemy's speed, &c.

This method will also solve:—

(*a*) Find B's course to join another aircraft.

(*b*) Find B's course to take up a given position with regard to C—say 1 mile ahead or abeam.

(*c*) Find B's course and requisite speed to take up a position in a definite time.

Case (*b*).—To intercept an enemy aircraft making good a certain direction and speed or to intercept an enemy *ship*.

In this problem B is affected by wind and C is not. In practice it will generally be the case that the enemy aircraft will be reported passing over certain places at certain intervals; his direction *made good* and his *ground speed* can then be determined.

Example.—An enemy vessel C is distant from B 40 miles, bearing 20° and making good 135° at 20 knots. Wind East, 20 knots. Find the true course and time taken by an airship to intercept her at 60 knots.

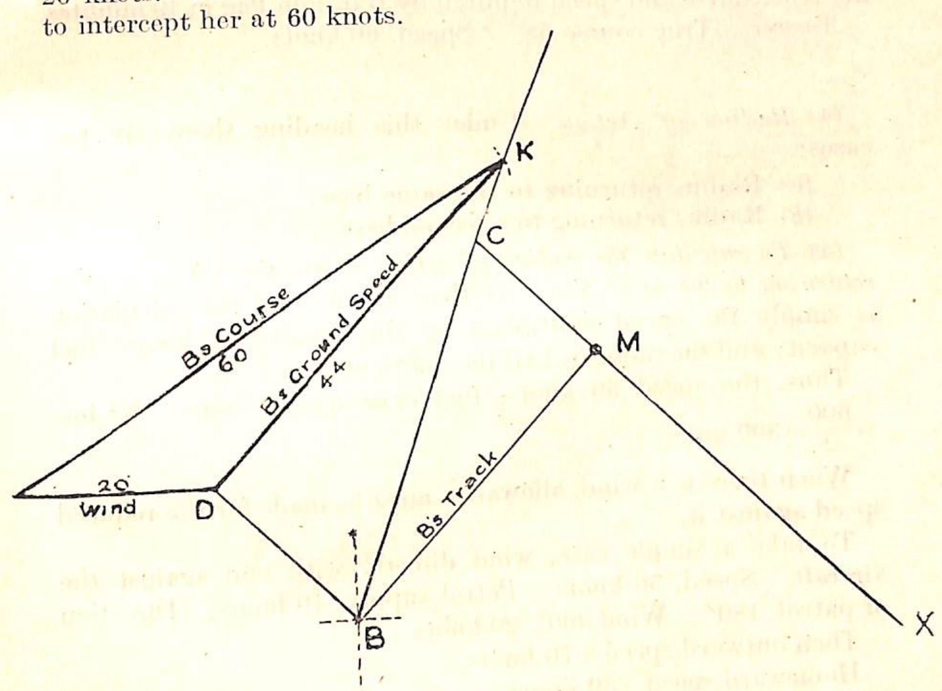


Fig. VIII.

Scale 1 inch = 20 sea miles.

From B lay off BC = 20°—40 miles.

From C lay off CX = 135°. This is direction C is making good.

From B lay off BD=315°—20 knots. C's direction and speed reversed.

From D lay off DE=270°—20 knots. Wind.

From E draw the arc of a circle with radius 60 knots (B's speed) cutting BC produced at K. Join DK.

Draw BM parallel to DK, cutting CX at M.

Then the direction EK is B's true course=58° to intercept C at M.

The direction BM is B's track=45° and DK is B's ground speed=44 knots.

Then $\frac{\text{BM in miles}}{44}=\frac{36}{44}=49$ minutes, or time taken by B to reach M and intercept enemy C.

This problem may be varied by treating C as the flagship and calculating at what speed B will have to proceed to join C in a certain time or her direct approach.

Thus the foregoing may be—

An airship B bears 200°—40 miles from the fleet C, which is steaming 135° at 20 knots. Wind East, 20 knots. Find the true course and speed required by B to join flag in 49 minutes.

Answer.—True course 58°. Speed, 60 knots.

(4) *Radius of Action.*—Under this heading there are two cases:—

(*a*) Radius returning to the same base.
(*b*) Radius returning to a second base.

(*a*) *To calculate the radius of action of an aircraft in a wind returning to the same base.*—If there is no wind the calculation is simply the speed multiplied by the number of hours' fuel capacity and the radius is half the quotient.

Thus, the speed 60 knots, fuel capacity 10 hours. Radius $=\frac{600}{2}=300$ miles.

When there is a wind, allowance must be made for the reduced speed against it.

To take a simple case, wind directly with and against the aircraft. Speed, 50 knots. Petrol supply, 10 hours. Direction of patrol, 180°. Wind 360°, 20 knots.

Then outward speed=70 knots.

Homeward speed=30 knots.

Required the radius of action, or the distance on the outward journey which will allow sufficient fuel for the return against the wind.

Out : In : : 70 : 30 or as 7 to 3.

The petrol supply is 10 hours and the allowance for the outward journey must be $\frac{3}{10}$ths of 10 hours = 3 hours, and for the homeward $\frac{7}{10}$ths of 10 hours, which is 7 hours.

Then out = 3 × 70 = 210 miles } Radius of action.
Then in = 7 × 30 = 210 miles }

As a general rule, however, the wind will be oblique to the course, and in order to calculate the speed out and speed in it will be necessary to plot the problem and make allowance for wind as in explanation on drift.

The speed made good, out and in, can then be determined and the problem solved by White's formula.

$$R = p \times \frac{\text{speed out} \times \text{speed in}}{\text{speed out} + \text{speed in}}.$$

Where R = Radius of action and p = petrol hours.

Example.—Find the radius of action, returning to the same base, of an airship in a direction N.E. Air speed, 50 knots. Petrol supply, 10 hours. Wind West, 20 knots.

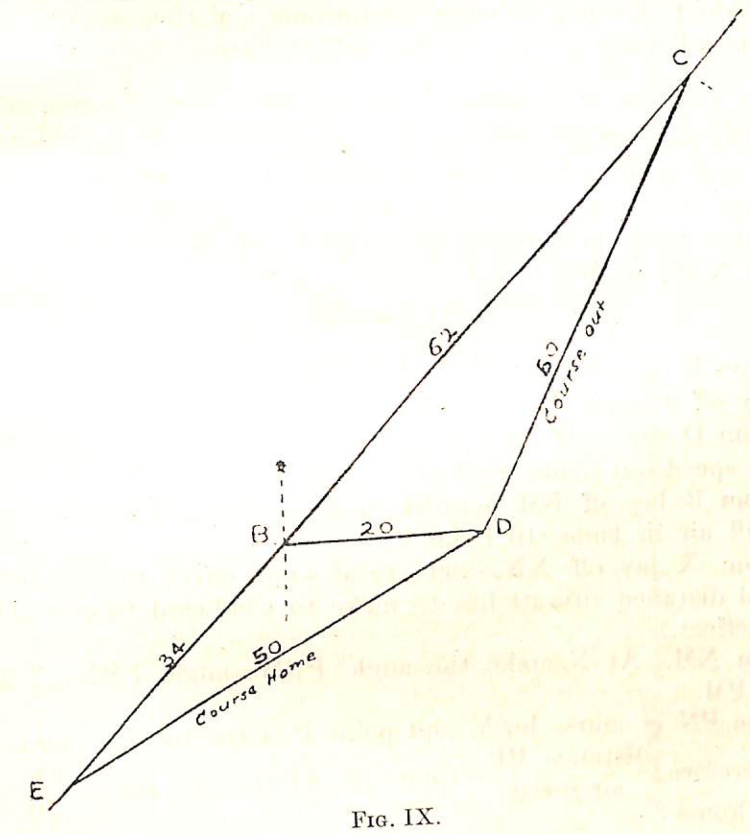


Fig. IX.

Scale 1 inch=20 sea miles.

From B lay off BC=45° and BE=225°.

Then direction BC=outward track and BE homeward track.

From B lay off BD = wind *to* East 20 knots.
From D cut in DC and DE = 50 knots.
Then direction DC = course out, and BC = ground speed out = 62 knots.

Then direction DE = course in, and BE = ground speed in = 34 knots.

Then $R = 10 \times \frac{62 \times 34}{62 + 34} = 10 \times \frac{62 \times 34}{96} = 221$ miles.

Margin of Safety.—Now this represents the extreme radius of action, exhausting all the petrol. It will be well, therefore, to have a margin of safety, to allow for unforeseen contingencies such as increase or alteration in direction of wind, loss of speed, &c., in order to have a safe and working supply of petrol left over at the end of the voyage. A fair and reasonable margin is 25 per cent. of the petrol supply. The radius of action of the above, allowing for the margin of safety, will therefore be 220 less 25 per cent., which is equal to 165 miles. It will be simpler to deduct this before using the formula and thus working with $7\frac{1}{2}$ petrol hours instead of the full 10 hours.

(4) *Case* (*b*), 1*st Solution. To find the radius of action of an aircraft in a wind returning to a second base.*—The problem in this case is to find the time at which to alter course to return.
Take the elements given in the preceding example with the addition that the aircraft has to return to a second base 100 miles N.W. of B.

(*See* Fig. X.)

From B lay off BX – 315° = 100 miles and BC – 45°.
Lay off wind, BD – 90° = 20 knots.
From D cut in DC, airspeed 50 knots. DC is the course out. BC is speed out made good = 62 knots.
From B lay off BM parallel to DC = 500′. (Total distance in still air in time, 10 hours.)
From X lay off XN – 200′, total wind effect in the time. (Total distance aircraft has to make to windward to overcome wind effect.)
Join NM. At N make the angle PNM = angle PMN. Then PN = PM.
Line PN is course back, and point P is the turning point.

Therefore, $\frac{\text{distance BP}}{\text{air speed}}$ = time at which to turn = $\frac{150}{50}$ = three hours.

Through P draw a line PQ parallel to wind to cut BC at Q. Q is the point on the track N.E. at which you must turn, *i. e.*, 183 miles, and QX is the track home.

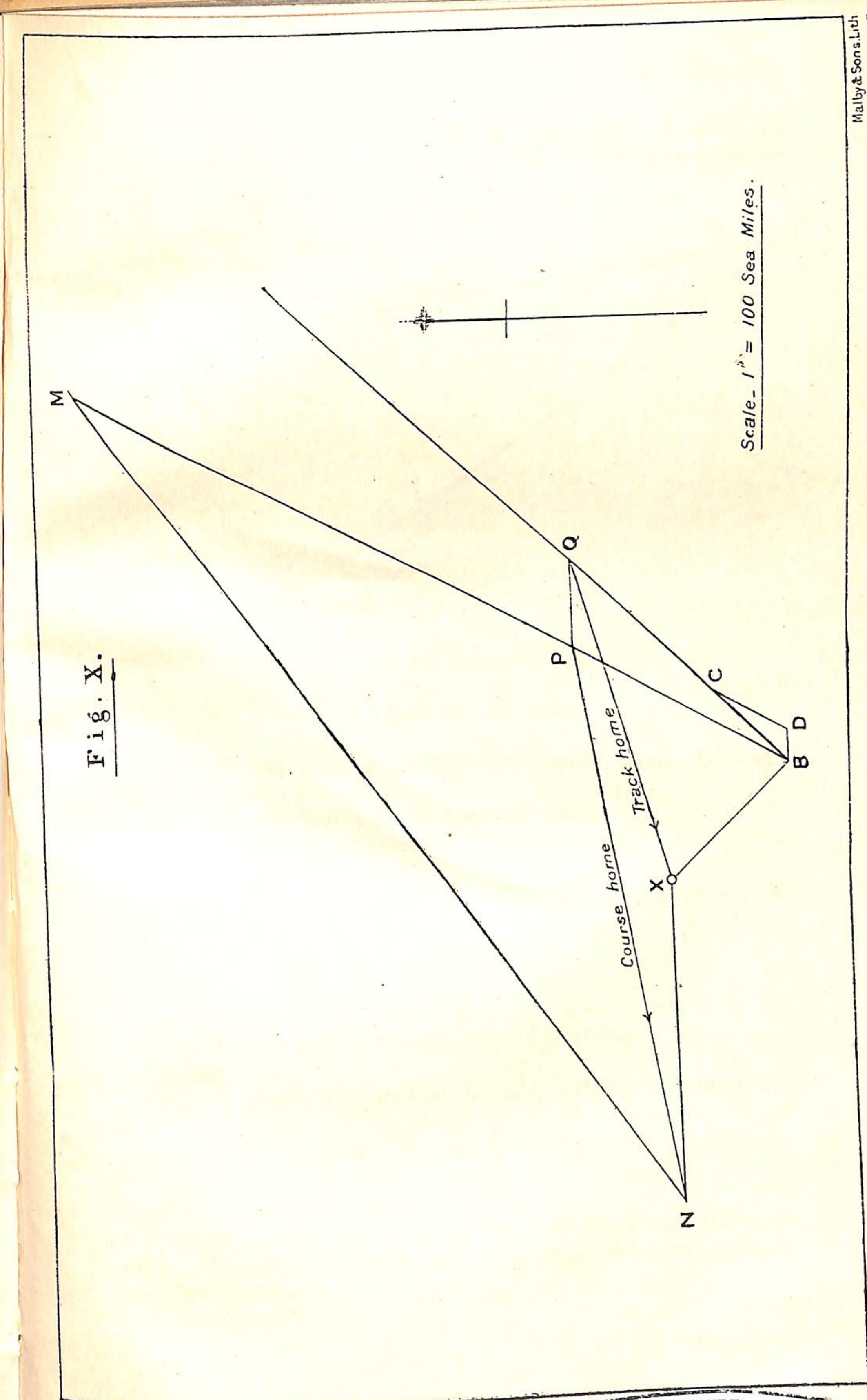


Fig. X.

(4) *Case* (*b*), *2nd Solution* (*White's method*).—To find the radius of action of an aircraft in a wind returning to a second base.

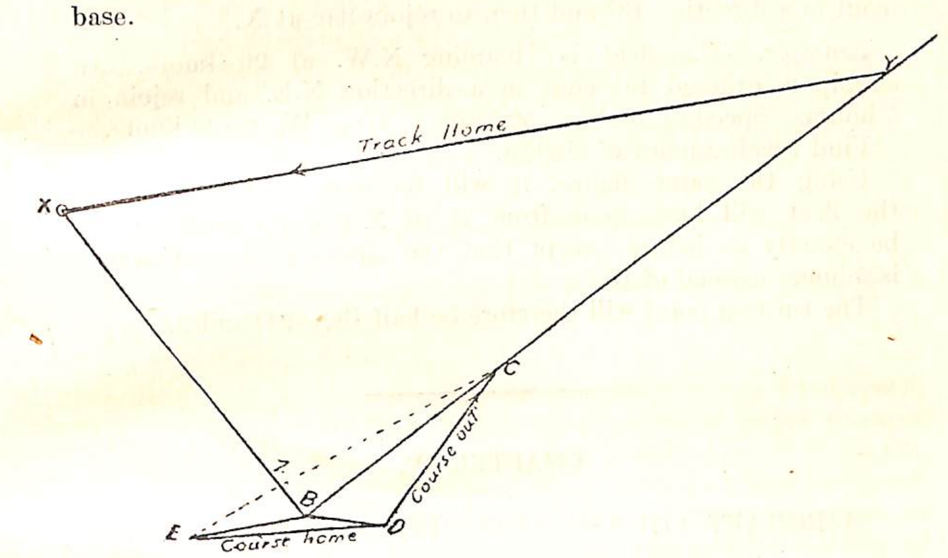


FIG. XI.

Scale 1 inch = 50 sea miles.

From B lay off BX = 315° − 100 miles, and BC = 45° (direction of patrol).

From B lay off BD = wind to East − 20 knots.

From D cut in DC = 50 knots. Speed of airship.

Divide BX at Z where $BZ = \frac{BX}{n}$; where n = number of hours petrol. Then $BZ = \frac{100}{10} = 10$ miles.

Join CZ and produce towards E.

From D cut in DE = 50 knots. Speed of airship.

Join EB.

From X draw XY parallel to ED, cutting BC produced at Y.

Then DC = course out.

Then DE = course home.

BE and YX = track home.

Y is the turning point on the outward track and BY = 183 miles. BC = ground speed = 62 miles and time to turn is therefore approximately 3 hours.

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This problem can be expressed in another way and B may be the first position of the fleet. An aircraft is ordered to scout in a direction BC and then to rejoin flag at X.

Example.—The fleet is steaming N.W. at 20 knots. An airship is ordered to scout in a direction N.E. and rejoin in 5 hours. Speed of airship = 50 knots. Wind West – 20 knots.

Find turning point of airship.

Using the same figure, it will be seen that in 5 hours the fleet will have gone from B to X and the problem will be exactly as before except that the airship's time allowance is 5 hours instead of 10.

The turning point will therefore be half BQ = $91\frac{1}{2}$ miles.

CHAPTER IV.

AIRCRAFT COURSE AND DISTANCE INDICATOR.

The rapid development of aircraft, both of the heavier than air and lighter than air types, together with the great strides already made, and still to be made, in the science of approximately accurate navigation in the air, following on great improvements in the aero compass and the means of obtaining accurate bearings from aircraft, has emphasized the need for some simple form of instrument which will enable the navigators of the air to keep a D.R., not referring to latitude and longitude, but will at any moment enable them rapidly and simply to obtain the bearing and distance of "home" without having to use chart, parallel rulers, dividers, &c., which are cumbersome even in the largest form of aircraft.

The "Battenberg Course and Distance Indicator" is the basis for all instruments of this description, and the Aircraft Course and Distance Indicator is merely a simplified form of the service pattern which has been adapted for use in aircraft by officers in the Admiralty Compass Department. A careful study of the following instructions will, it is trusted, enable aircraft observers to solve most, if not all, of the problems with which they are confronted when scouting with the fleet.

Description of Instrument.

The instrument consists of an outer ring marked every five degrees from 0 to 360, the points of the compass being marked, every two points being lettered.

A central rotating disc, squared, diameter of disc representing 240 miles.

Two arms pivoted at the centre of the disc marked to the same scale as disc.

Two movable pointers working on the two arms. The arms are identical, and are marked A and B for reference.

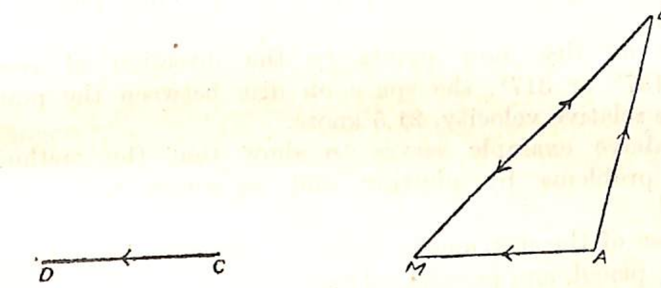
A central clamp for holding instrument rigid when set.

Principle of Instrument.

The principle employed in the solution of all problems is the theory of relative velocities.

Briefly it is as follows:—

If two bodies be moving in definite directions at fixed speed, and if through any point lines be drawn equal in length to those speeds, to any scale, and parallel to the directions in which the bodies are moving, and then the ends of these two lines be joined, a triangle will be formed, the third side of which represents in direction and length (to the same scale) the relative velocity of these bodies to each other.



For example.—A body A is moving along line AB with a velocity represented by the length of AB to any scale. A body C is moving along line CD with a velocity represented by the length of CD to the same scale. Through A draw a line parallel and equal to CD; call it AM. Then MB represents in direction and length, to the same scale, the relative velocity of the two bodies to each other.

By way of illustration how to use the instrument a problem is here worked out—

(*a*) by Plotting,
(*b*) by Course and Distance Indicator.

Problem.—A body at A is moving in the direction North at a speed of 30 knots.

A second body C bearing East of A is moving N.E. at a speed of 20 knots.

Find their velocity relative to each other.

By Plotting.—

Through A draw a line AB North equal to 30 units.

Through A draw a line AM N.E., equal to 20 units.

The line BM running in the direction 137° and equal to 21.5 units will be the relative velocity.

i. e., C relative to A is moving 137° at 21.5 knots.
A relative to C is moving 317° at 21.5 knots.

By Course and Distance Indicator.—

Place arm and pointer A to North and 30.

Place arm and pointer B to N.E. and 20.

Revolve disc till line on disc, parallel to arrow, passes through both pointers, or is parallel to the line joining both pointers.

Arrow on disc now points to the direction of relative course, 137° or 317°, the space on disc between the pointers gives the relative velocity, 21.5 knots.

The above example serves to show that the method of solving problems by plotting and by course indicator are identical.

The use of the instrument, however, dispenses with the need of paper, pencil, and parallel rulers.

Rules for using Instrument.

The following rules for using the instrument are given, as it is hoped that by paying strict attention to them, confusion may be avoided:—

(1) Arm A should when possible represent your own course and speed.

(2) Arm B should when possible represent the objective's course and speed.

(3) Always keep the general lines of the situation in your head; this will obviate the possibility of reading from the wrong end of the arrow.

(4) In all cases an allowance of at least 25 per cent. should be made for errors in estimation of the wind, leakages, &c., in working out range of action.

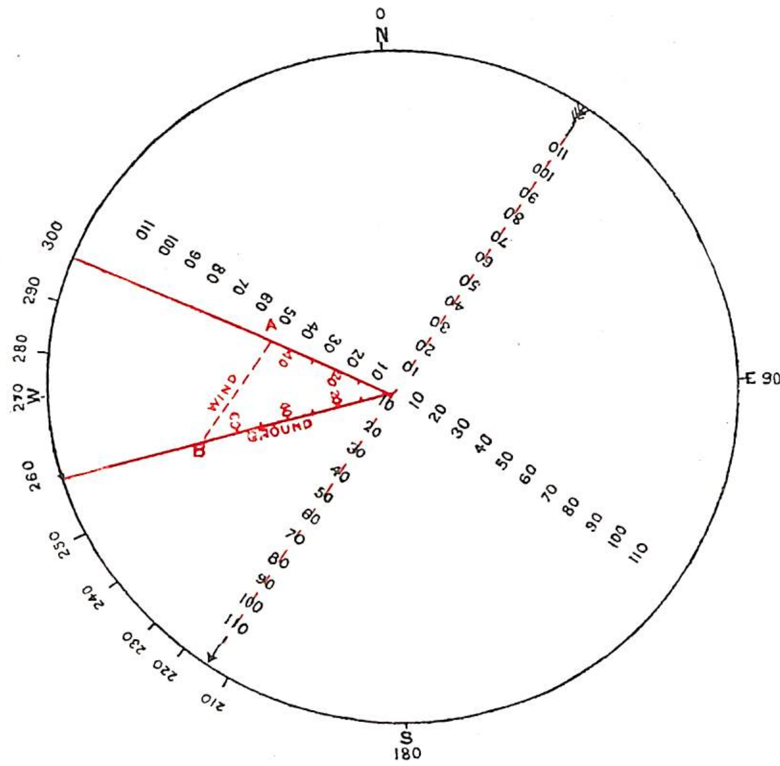


FIG. I.

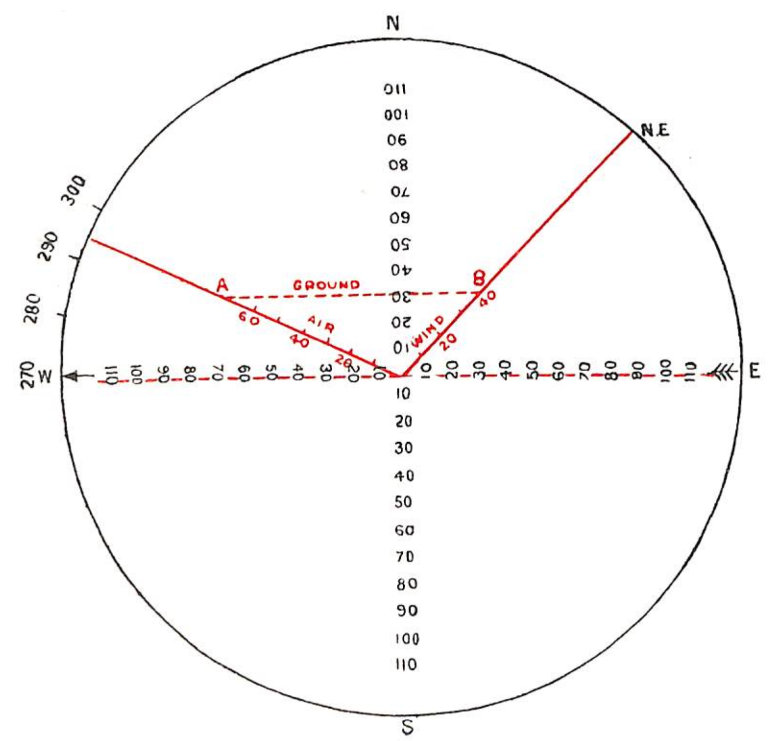


FIG. II.

Problem I.

To determine the "Speed and Direction of the Wind," having observed the Path and Speed made good.

(*a*) Set arm and pointer A to course steered and air speed.
(*b*) Set arm and pointer B to course made good and ground speed.
(*c*) Set disc so that arrow is parallel to line AB.
Arrow points to direction in which wind is blowing. Length of AB is speed of wind.
Example.—Machine steers 300° at 50 knots. Drift observed to be 260° at 70 knots. Find the speed and direction of wind.

(*See* Fig. I.)

(*a*) Set arm and pointer A to 300° and 50.
(*b*) Set arm amd pointer B to 260° and 70
(*c*) Set disc as in (*c*).
Arrow points to 215°. Length AB = 44.
Answer.—Wind blowing from 35° at 44 knots.

Problem II.

To find what "Allowance to make for a Wind."

(*a*) Set arrow on disc to course to be made good.
(*b*) Set arm and pointer B to direction from which wind is blowing and to speed of wind.
(*c*) Set pointer A to air speed of machine.
(*d*) Revolve arm A till pointer A is on same line (parallel to arrow) as pointer B.
Arm points to the course to steer.
The distance between pointers A and B will be ground speed.
Example.—Wind N.E., 40 knots. Machine air speed, 70 knots. Wishes to make good a path W. What course must he steer?

(*See* Fig. II.)

(*a*) Set arrow on disc to W.
(*b*) Set arm and pointer B to N.E. and 40.
(*c*) Set pointer A to 70.
(*d*) Revolve arm A as in (*d*).
Arm A points to 295°. Length AB = 91.
Answer.—Course to steer 295°. Speed along course W., 91 knots.

Problem III.

To determine "Radius of Action."

(*a*) By Problem II. determine the course "out" and the course "home."

(*b*) Set arm A to course out.

(*c*) Set arrow on disc to course home.

(*d*) Set arm and pointer B to total wind.

(*e*) Line through pointer B parallel to arrow cuts arm A at the turning point (distance through air).

Example.—Find your "radius of action" in a direction N.E., wind N.N.W. 20 knots, your air speed 60 knots, you have five hours' fuel.

(*See* Fig. III.)

(*a*) Course out 27° 50 knots. Course home 242° 64 knots.

(*b*) Set arm A to 27°.

(*c*) Set arrow to 242°.

(*d*) Set arm and pointer B to N.N.W. and 100. (Divide scale by 2. Set pointer B to 50.)

(*e*) Line through pointer B cuts arm A at 88, *i.e.*, 176, and time to turn will be $\frac{176}{60}$=2 hrs. 56 mins.

f If arm B be now set to N.E. and arrow be set to direction of wind, line through pointer A cuts pointer B at the distance made good N.E. at time to turn, 73, *i.e.*, 146 miles.

Problem IV.

Course to "Intercept Hostile Aircraft."

Case 1.—When course steered and air speed of hostile craft are known.

(*a*) Set arrow on disc to bearing of objective.

(*b*) Set arm and pointer B to course and speed of hostile aircraft.

(*c*) Set pointer A to air speed of machine.

(*d*) Revolve arm A till pointer A is on same line (parallel to arrow) as pointer B. Arm A points to course to steer. The distance AB will be "speed of approach" and time to intercept will be distance off divided by AB.

Example.—A hostile aircraft is reported bearing N.E. 120 miles away, steering West at 50 knots. Your air speed is 100 knots. What course must you steer, and how long will it take to intercept her?

(*See* Fig. IV.)

(*a*) Set arrow on disc to N.E.

(*b*) Set arm and pointer B to West and 50.

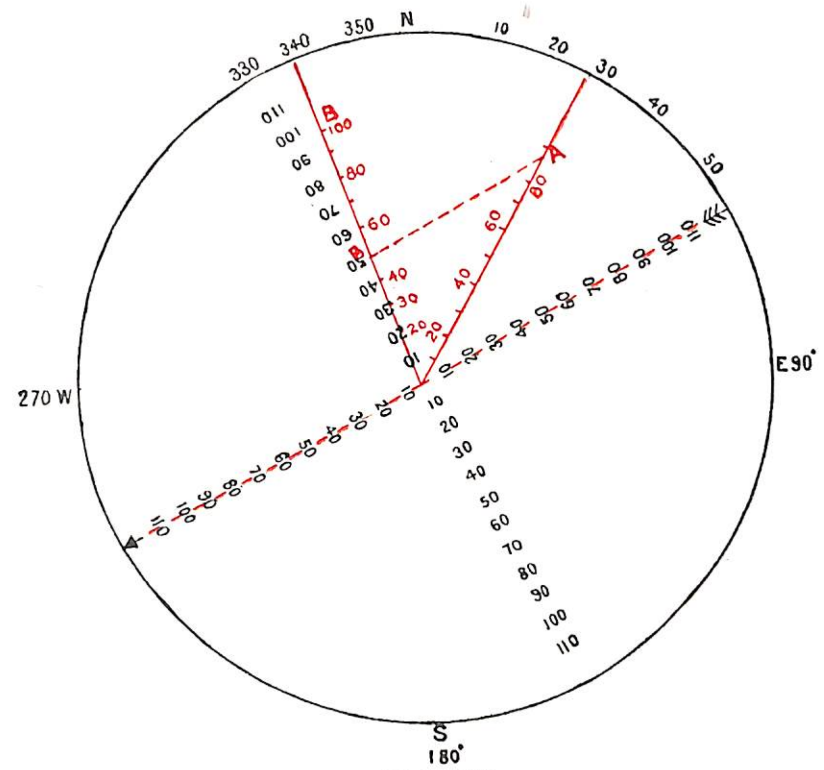


FIG. III

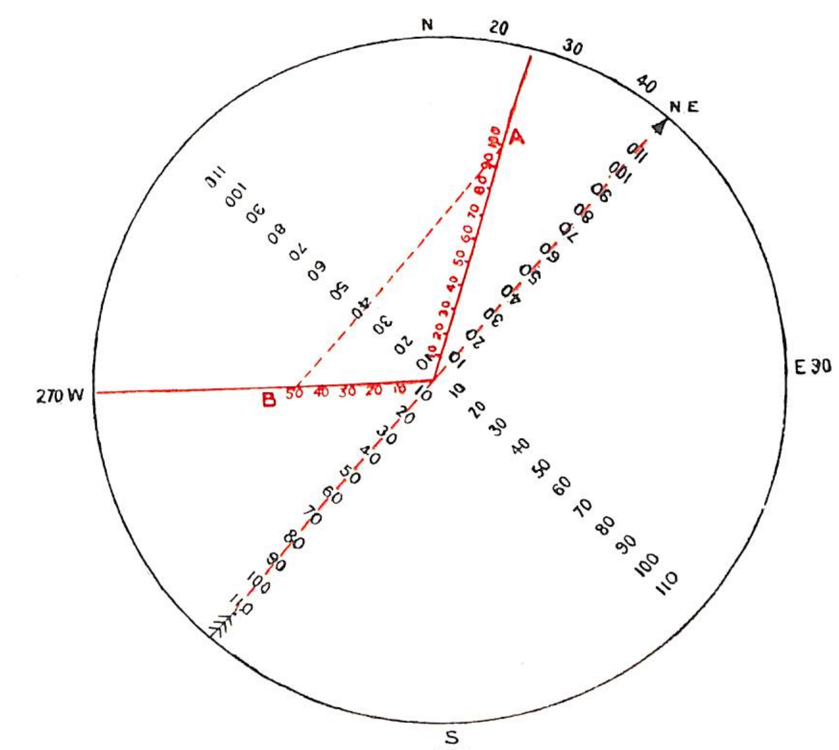


FIG. IV.

Malby & Sons Lith.

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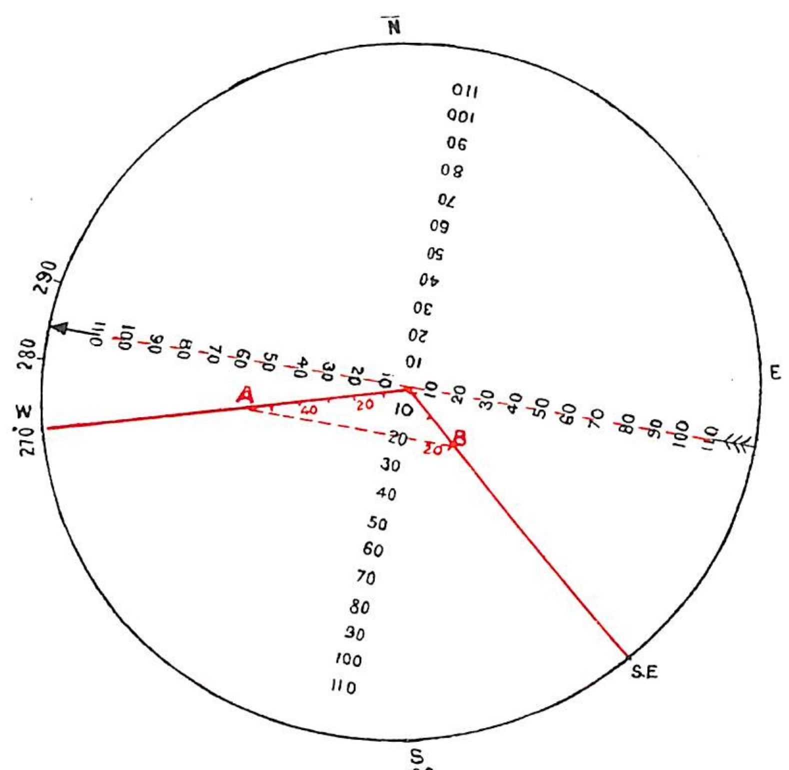

FIG. V.

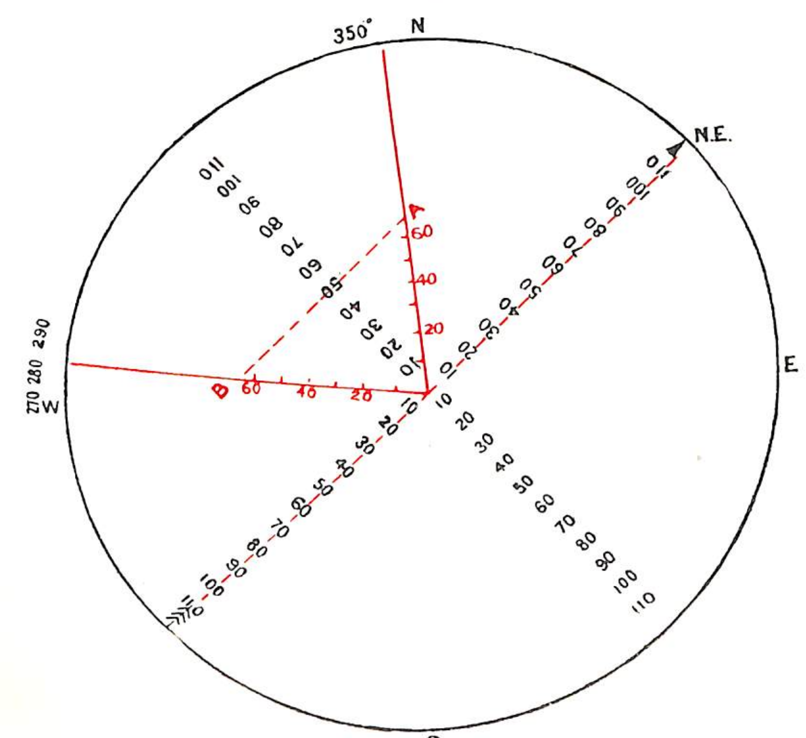

FIG. VI.

To face page 49

(*c*) Set pointer A to 100.
(*d*) Revolve arm A as in (*d*).
Arm A points to 25°. Length of AB 128.

Answer.—Course to steer 25°. Time $=\frac{120}{128}=0$ hr. 56 mins.

Case 2.—When track and speed made good of hostile aircraft are known.

N. B.—This problem is exactly the same as closing on a ship or fleet.

The simplest way of solving all problems where three velocities occur, *i. e.*, wind, objective's, and your own, is to reduce them to two by resolving the wind and your objective's into one; this is done by considering the wind to have the opposite effect on your objective to what it would have on you, and resolving this and your objective's velocities into one (*i. e.*, you find course steered and air speed of objective) you then use this result as the actual velocity of your objective.

(*a*) Set arm and pointer A to course and speed of objective.
(*b*) Set arm and pointer B to direction in which wind is blowing and velocity of wind.
(*c*) Revolve disc till arrow is parallel to line BA. Arrow points to direction of resultant velocity of objective and wind, and distance BA is resultant velocity.
(*d*) Set arm and pointer B to resultant obtained in (*c*).
(*e*) Set arrow to bearing of objective.
(*f*) Set pointer A to your air speed.
(*g*) Revolve arm A till pointer A is on same line parallel to arrow as pointer B.

Arm A points to course to steer. Distance AB is speed of approach.

Example.—A hostile aircraft is reported at 10 p. m. passing over a place, A; at 10.30 p. m. she is reported passing over B, West 25 miles of A. Place B bears N.E. 120 miles from you. Your air speed 70 knots. What course must you steer to intercept her, and at what time will you do so? Wind N.W., 20 knots.

(*See* Fig. V.)

(*a*) Set arm and pointer A to W. and 50.
(*b*) Set arm and pointer B to S.E. and 20.
(*c*) Revolve disc as in (*c*), and arrow points to 283°, and distance BA is 66.

(*See* Fig. VI.)

(*d*) Set arm and pointer B to 283° and 66.
(*e*) Set arrow to N.E.

(*f*) Set pointer A to 70.
(*g*) Revolve arm A as in (*g*), and arm A points to 353°.
Length of AB 78.

Answer.—Course to steer, 353°. Time taken $=\frac{120}{78}=1$ hour 32 mins.

Problem V.

Sent out to scout on a bearing, to know when to alter course to rejoin Fleet at a fixed time, and what course to steer to do so.

The method of solving this problem by plotting is given to simplify the solution of it by course indicator.

"By Plotting."

Example.—Fleet steaming East, 20 knots. Wind N.E., 25 knots. Your speed, 60 knots. You are ordered to scout on a bearing North and rejoin the Fleet in 4 hours.

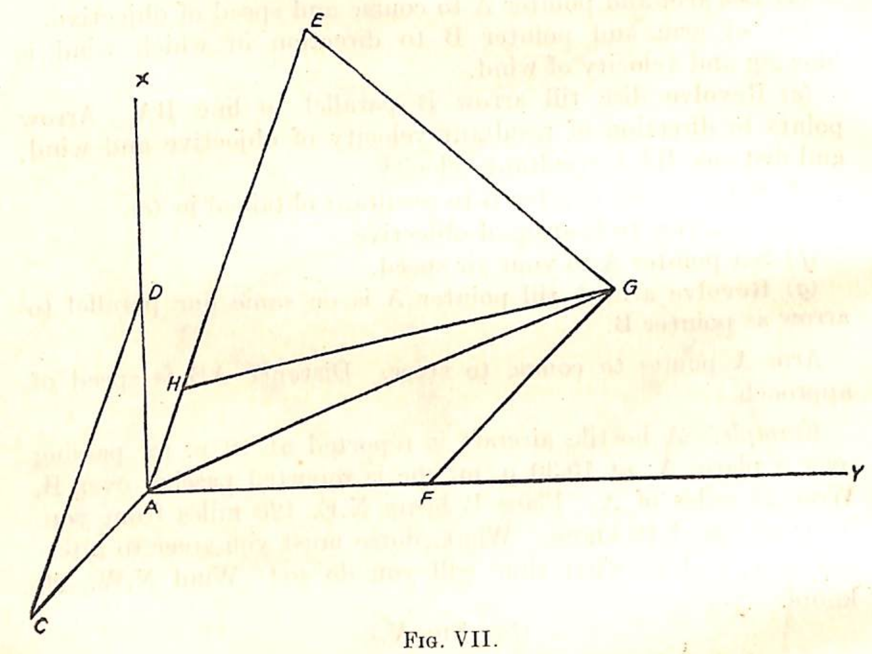

Fig. VII.

Let A be position of Fleet.
From A lay off AX, North.
From A lay off AF, East, equal to 80, course and distance Fleet will go in the 4 hours. F is position of Fleet at end of 4 hours.
From F lay off FG equal to 100′ N.E. (the total wind effect in the 4 hours, assuming that wind is blowing Fleet in opposite

direction to what it would do to the aircraft, and aircraft is in still air).

Join AG (this is now considered as the course and distance gone by the Fleet in the 4 hours).

From A lay off the course to steer to make good North, allowing for wind, AE.

Make AE equal to 240′. (Total distance machine can fly in the time).

Join EG, and at G with EG construct an angle equal to AEG.

Angle HGE is equal to HEG.

HE is now equal to HG, and, since machine can fly from A to E, it can fly from A to H, and from H to G, and these are the courses to steer; and when the machine gets to G the wind will have carried it to F, the actual position of Fleet at end of 4 hours.

The length AH, divided by air speed (*i.e.*) $\frac{118}{60}$, gives the time to turn, *i.e.*, in 1 hour 58 minutes.

Sent out to scout in a given direction, to know when to alter course to rejoin Fleet at a fixed time, and what course to steer to do so.

Note.—This problem may also be stated: "Radius of action returning to a second base."

(*a*) Work out as in Problem II. course allowing for wind to make good direction ordered.

(*b*) Place arm and pointer A in direction Fleet is steaming and to distance Fleet goes in the time.

(*c*) Place arm and pointer B in direction in which wind is blowing and to total wind effect in the time.

(*d*) Revolve disc till pointers are on same line parallel to arrow. Note the direction and distance from pointer A to B.

(*e*) Set arm and pointer A to result obtained in (*a*), and to total distance you can fly in the time.

(*f*) Set arm and pointer B to result obtained in (*d*).

(*g*) Set disc so that line joining the two pointers is parallel to arrow and arrow points towards Fleet.

(*h*) Note angle on rim of instrument between arm A and tail of arrow.

(*k*) Move disc till tail of arrow makes double this angle with arm A.

Arrow head points to course to steer to rejoin the Fleet; line through pointer B parallel to arrow cuts arm A at the point at which course must be altered and distance indicated by pointer A divided by air speed gives time at which course must be altered.

Example.—Fleet steaming East at 20 knots. Wind N.E., 25 knots. Your speed 60 knots. You are ordered to scout on a bearing North and rejoin the Fleet in 4 hours.

(*a*) Work out course to steer by Problem II. 17°.

(*See* Figs. VIII. and IX.)

(*b*) Place arm and pointer A to West and 80.

(*c*) Place arm and pointer B to S.W. and 100.

(*d*) Revolve disc as in (*d*) arrow points to 65°. Distance between pointers—164′.

(*e*) Set arm and pointer A to 17° and 240 (*i.e.*, to 80, using convenient scale).

(*f*) Set arm and pointer B to 65° and 164 (*i.e.*, to 55).

(*g*) Set disc as in (*g*), angle between arm A and tail of arrow—43°.

(*k*) Set tail of arrow to 86° from arm A, *i.e.*, to 291°. Arrow head now points to 111°, the course to steer to return to Fleet.

Line through pointer B cuts arm A at 39′ (*i.e.*, 118), so time to alter is $\frac{118}{60}$ hours = hour 58 minutes after starting.

Scouting.

Problem VI.

You are ordered to scout in a given direction to find what course to steer to return to the Fleet at any moment.

Neither Fleet nor machine having altered course during the operation.

The allowance for wind should immediately be worked out by Problem II. so that your track is in the direction ordered.

The method now employed for keeping the positions of Fleet and yourself is simply using one arm and pointer to represent the Fleet's track and the other to represent your own (which will be track and speed *made good*). This is done as follows:—

(*a*) Set arm and pointer A to the direction in which you are ordered to scout and the distance you have made good.

(*b*) Set arm and pointer B to Fleet's course and distance gone.

(*c*) Resolve disc till same line on disc, parallel to arrow, passes through both pointers and arrow is towards the Fleet.

(*d*) Arrow points to bearing of Fleet and distance between the pointers is distance of Fleet.

Proceed as in Problem IV., case 2.

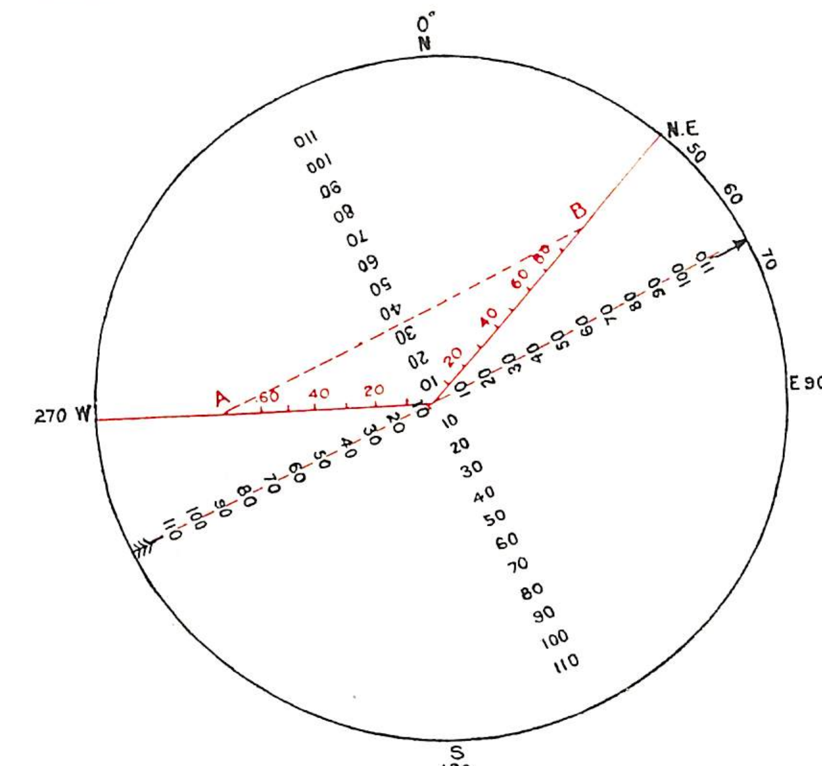

FIG. VIII.

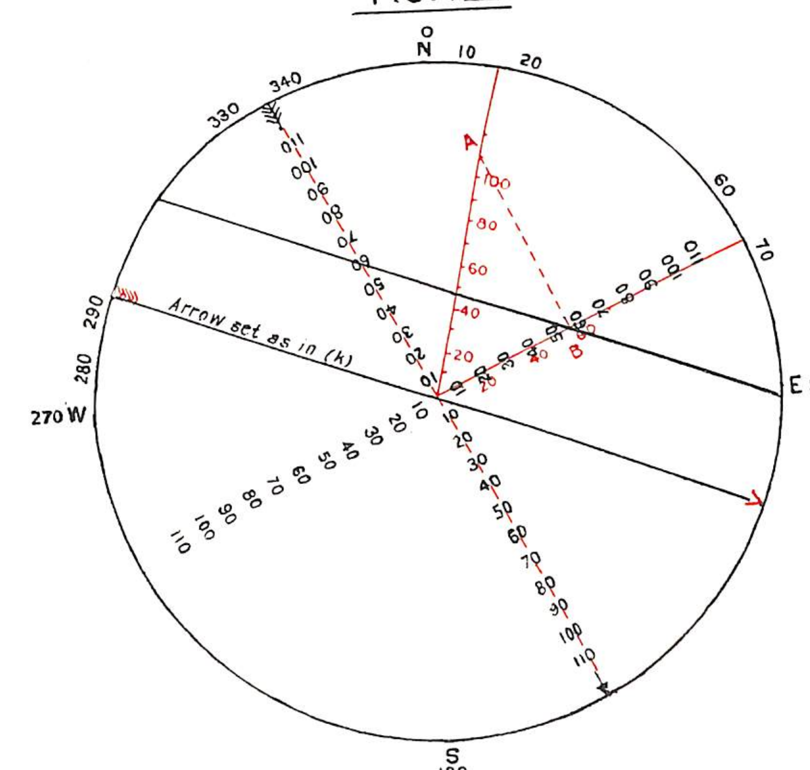

FIG. IX.

Problem VII.

Same as VI. Fleet or machine having altered course.

(*a*) Proceed as in Problem VI., obtaining bearing and distance of Fleet from you at moment of alteration.

(*b*) Put this bearing and distance on arm and pointer B.

(*c*) Move arm A to machine's new course.

(*d*) Set pointer A to distance gone since alteration of course.

(*e*) Revolve arrow to course of Fleet.

(*f*) Move arm *and pointer B* along course of Fleet on disc the distance Fleet has gone in this time.

(*g*) Revolve disc till the same line, parallel to arrow, passes through both pointers. Arrow points to bearing of Fleet. Distance between pointers is distance of Fleet.

Proceed as in Problem IV., case 2.

Problem VIII.

To determine the Course an Enemy's Fleet is steering.

This method only to be employed when Fleet is at a great distance.

Immediately on sighting Fleet course should be set to the bearing on which Fleet is sighted.

Maintaining this course, observe whether Fleet moves to left or right.

Having established this fact assume that Fleet is steering at right angles to bearing on which it was sighted, and assume a speed for the Fleet—

If battleships, 17 knots;
If cruisers, 23 knots;
If destroyers, 25 knots.

Course should now be set to close Fleet, preserving the bearing at this moment and allowing for wind as in Problem IV., case 2.

If bearing remains constant you have probably assumed the correct course and speed of Fleet.

N. B.—The word "probably" is used because an error in estimated speed might neutralise an error in course, but this would be negligible for a first report.

If bearing draws ahead, Fleet is steering more towards you than you have assumed and *vice versâ*. You have now established the course of the Fleet within eight points.

Now assume that Fleet is steering at 45° instead of 90° to first bearing.

Shape course, allowing for wind, to preserve your present bearing and observe as before.

This will establish the course of the Fleet within four points.

If it is desired to give the course of Fleet more accurately, the operation should be repeated until bearing remains constant.

Example on Problem VIII.

Fleet is sighted bearing East and estimated distant 60 miles (at this distance Fleet would probably be only just visible). Course of Fleet is S.S.W., speed 18 knots. Machine's speed 60. Wind North, 15 knots.

To find by above method course of Fleet:—

(*a*) Machine shapes course, allowing for wind, to make good track East and observes that bearing alters to the right.

Course of Fleet is therefore Southerly.

(*b*) You assume now that Fleet is steering South and now bears 95°.

(*c*) You shape course as above to preserve this bearing. By Problem IV., case 2, track to be made good, 112°. Course to steer, 99°.

Bearing of Fleet now draws ahead to 105°. You now know that Fleet is steering between South and West.

(*d*) You therefore assume Fleet to be steering S.W. and alter course as before to preserve the bearing; by Problem IV, case 2, this course to steer is 109°.

Bearing of Fleet now draws aft to 100°. You therefore know that course of Fleet is between S. and S.W.

(*e*) You assume it to be S.S.W. and shape course to preserve the bearing 100°; by Problem IV., case 2, this course to steer is 103° and bearing remains steady. Therefore course of Fleet is S.S.W.

CHAPTER V.

MAGNETISM AND DEVIATION OF THE COMPASS.

MAGNETISM.

Natural Magnets.—A certain iron ore or lodestone possessing the property of attracting and holding particles of iron.

A natural magnet, suspended horizontally, will always, if unaffected by local causes, lie with one end pointing nearly to the North Pole.

This end is called the north-seeking or red pole of the magnet; the other end is called the south-seeking or blue pole of the magnet.

Artificial Magnets are made of hard iron or steel, and possess the same properties as natural magnets. Iron and steel are divided into two classes, viz., hard and soft.

Hard iron is not easily magnetised, but when once magnetised retains its magnetism permanently.

Soft iron in a pure state becomes instantly magnetised when exposed to even small magnetic forces, but has no power of retaining its magnetism when these forces are removed.

Artificial magnets are made (1) by contact with a natural magnet; (2) by contact with other artificial magnets; (3) by contact with an electro magnet; (4) by percussion; (5) by passing the bar into a coil through which an electric current is passing.

No. (4) method influences the question of compass work, because by hammering, the steel parts of a machine when being built become themselves permanent magnets. No. (5) method is the one employed in making bar magnets, such as those used in compass adjustment. The bar is passed into an electric coil, through which a powerful direct current is passing, the polarity formed depending on the winding of the coil and the direction of the current. However magnetised, the bar or needle is said to be "saturated" when it cannot by any means be made any stronger.

(*See* FIG. I.)

The properties of magnets are shown in Fig. 1, where a small freely suspended magnetic needle is passed over a bar magnet. It will be found to take up the positions shown. Note that there are two points a short distance within the bar, where the needle stands vertical, and towards which the needle always points; these points are the "poles" of the magnet. Where the needle lies horizontal is called the neutral zone. The figure also shows that the blue pole of the bar magnet attracts the red pole of the needle, and *vice versâ*. From this we get the important rule that "like polarities repel, and unlike polarities attract." The bar magnets used for compass adjustment are painted half red and half blue, the red end denoting the north-seeking end and the blue end the south-seeking end. From this it is obvious that what we term, geographically, the North Pole of the Earth contains blue magnetism, and that red magnetism exists at the South Pole. The two polarities cannot be separated, *i. e.*, if a bar be broken, every piece will be found to possess a red and a blue pole.

Repulsions and attractions of magnetic poles vary inversely as the square of the distance, *i. e.*, if at a distance of 6 feet from the centre of a magnetic needle the pole of a magnet causes 2° of deflection, it will cause approximately 8° of deflection at a distance of 3 feet in the same direction. When both poles of a magnet are acting, as is always practically the case, the effect varies inversely as the cube of the distance, *i. e.*, if at a distance of 6 feet the effect is 2°, it will be 16° at 3 feet, since $2^3=8$.

A magnet, end on, has twice as much effect on a magnetic needle as when broadside on.

A magnet acts most powerfully when its direction is at right angles to the North and South line of the disturbed needle. Magnets diminish their power by rise of temperature, according to the temperature to which they are raised, ceasing to be magnetic when heated to a dull red heat. The properties of magnets are permanent in any part of the world, and in any direction in which they are placed, provided always that they are not stowed with like poles together, when they would tend to weaken each other's magnetism.

The power of magnets is reduced if the magnets become rusted, because magnetism lies on the surface.

Temporary Magnets and Induction.—We have seen that in magnets, like poles repel and unlike poles attract; we have seen also the varying direction that a freely suspended magnetic needle takes up if carried from end to end of a large fixed magnet. If now the same small magnet is made to vibrate, and the time of each vibration is noted, it will be found that the "period" of side-to-side oscillation is less when it is at the poles than at any other part of the magnet, always, of course, supposing the needle to be the same distance from the magnet; in fact, the faster the vibrations the greater the force. From this we observe that round every magnet there is a space in which magnetic force exists, which is strongest at the poles and gets weaker as the distance from the poles increases. This space is called the "field of the magnet."

(*See* Fig. II.)

If a bar magnet is placed under a sheet of paper and fine iron filings dusted on to the paper, these filings will be found to arrange themselves as shown in Fig. 2. Each particle of filings has become a temporary magnet, and they have arranged themselves so that their red and blue poles are in opposition to the blue and red poles of the magnet. The lines which the directions of the filings take up are known as "Lines of Force;" they are considered as issuing out of the red pole, curving round in wider and wider circuits until they enter the blue pole.

In the experiments just described, not only do the iron filings become magnets, but any soft iron placed in the field of a magnet will be found to be magnetised; in other words magnetism is "induced" in it.

(*See* Fig. III.)

In Fig. 3, if A is a magnet and B a soft iron rod, A will be found to have induced magnetism in B, so that the red pole

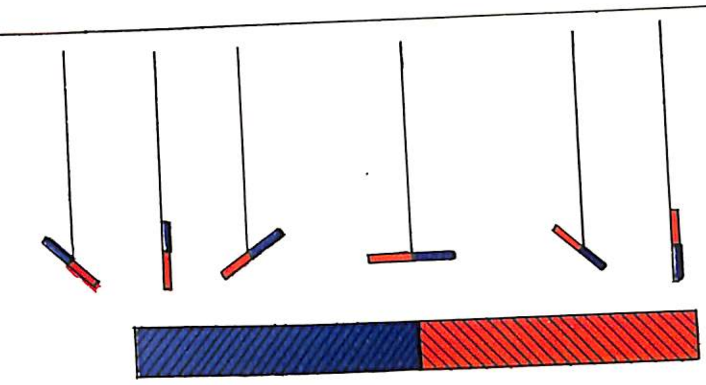

FIG. I.

FIG. II.

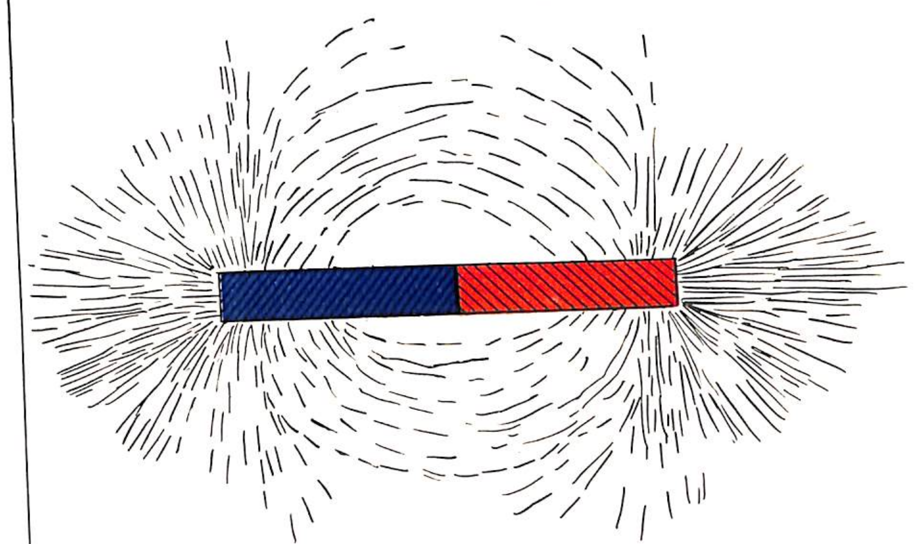

FIG. III.