AERIAL NAVIGATION

Part I. THE COMPASS
Part II. THE MAP

ISSUED BY THE

DIVISION OF MILITARY AERONAUTICS, U. S. ARMY

WASHINGTON, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1918

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PART I.

THE COMPASS.

INTRODUCTION,

When a pilot travels by airplane from his aerodrome to a point beyond the horizon, he has need of navigation by means of map and compass. The problem of passing from one point to another is evidently one of distance and direction. In both respects the pilot is liable to go wrong. Without proper care he may go many miles out of the way either by going too far or by taking the wrong course. He may even land within the German lines; he may mistake a German aerodrome for his own; he may land at his own aerodrome and think that he is lost. At any rate, without proper care he is apt not to accomplish his mission.

There are several sources of error which must be guarded against. For one thing, the influence of the wind; for another, the failure of the compass to point to true north; for another, failure on the part of the pilot to fly for a reasonable length of time. It is evident, for example, that a pilot proceeding on a course 30 miles in length at the rate of 90 m. p. h. in still air must not travel for anywhere near an hour. He must not go on and on in the hope of reaching his destination some time or other.

The influence of the wind is felt by an airplane exactly as the influence of a current of water is felt by a boat. If a man rows a boat across a river, pointing the boat straight across, he is drifted downstream. If the current is swift the downstream drift is considerable. So a wind is a stream or current of air which drifts the airplane in the direction it is blowing.

The extent of the error which may be caused by the wind is illustrated as follows:

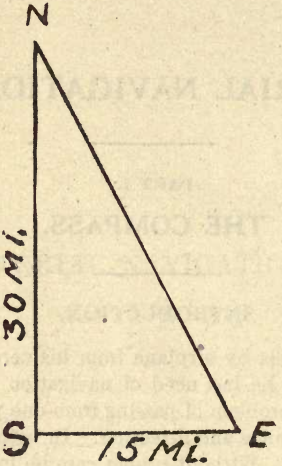

FIG. 1.

Suppose a ship has a speed of 60 m. p. h. and the desired course is true south, a distance of 30 miles. Suppose there is a west wind blowing at the rate of 30 m. p. h. If the pilot does not allow for this wind he will find himself, at the end of a half hour, 15 miles to the east of his destination and badly confused as to direction. If he tries to return to his own aerodrome by flying north, he will be 30 miles out of his way, supposing he has made no errors with respect to compass and watch.

On page 31, a problem will be worked out in detail showing how a pilot lays out his course so as to fly from his aerodrome to a given destination. If desired, it may be read in this connection or it may be read in its place after the general discussion. Following the discussion of this special problem will be found a paragraph showing how the pilot may check his course roughly for distance and direction and another showing how he may develop technique necessary for navigation. These paragraphs may be read when desired, either before or after the general discussion.

THE COMPASS.

The magnetic compass consists of three principal parts—a bowl, a needle, and a card.

The bowl is composed of nonmagnetic metal. In its center is a post or pivot, and on the top of this, which is jeweled to reduce friction to a minimum, is suspended a needle, or system of needles. These are attached to the lower side of a circular card. This card is free to rotate under the influence of the needles and take up a definite position with reference to the earth's magnetism. In aircraft compasses the bowl is filled with a nonfreezing liquid, generally alcohol or kerosene, which takes some of the weight of the needle and card

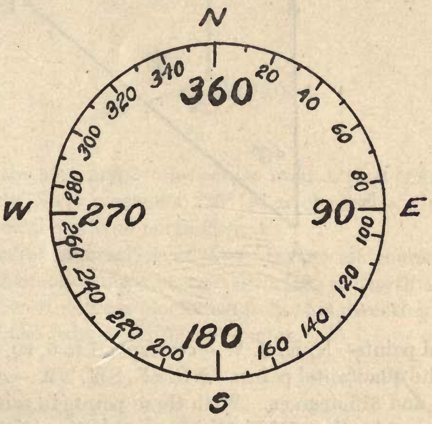

FIG. 2.

off the pivot and also serves to damp the oscillations and vibrations of the needle.

On its outer edge the card is marked off into 360 degrees. Starting with north as the zero point, the figuring runs clockwise through east, south, and west, to north again.

The value of the compass is that the needle gives us a fixed direction (compass north) from which to measure the direction our ship is taking. The needle does not follow the changes in direction of the ship. On the contrary, the ship turns around the needle. The direction of the machine is shown by the *lubber's line*, which is a small metal pointer fixed to the compass bowl or a line painted on the inside of the bowl. The lubber's line and the center of the compass give the direction of the fore and aft axis of the machine. Since the needle points north, the angle from the needle to the lubber's line represents the *course* of the machine. This angle is measured in degrees on the card in a clockwise direction from north. Thus, if the lubber's line is opposite 90, the compass course is east; if the lubber's line is opposite 45, the course is northeast, etc.

It is convenient to remember the number of degrees corresponding to each of the "cardinal" and "quadrantal" points of the compass.

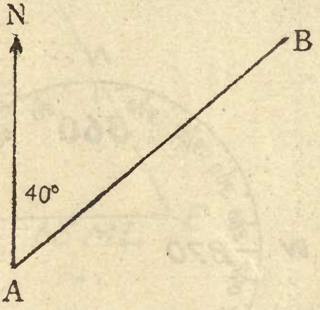

FIG. 3.

The cardinal points—N. E. S. W.—correspond to 0, 90, 180, and 270 degrees. The quadrantal points—NE. SE. SW. NW.—correspond to 45, 135, 225, and 315 degrees. With these points in mind, it is easy to see, for example, that 285° indicates a direction slightly north of west, and that 185° indicates a direction just west of south.

TRUE COURSES.

The problem of aerial navigation is to fly from one point to another. This may be divided into two problems—one of distance and one of direction. The problem of distance will be discussed later under "Map reading."

The direction of one point from another is fixed. In order to describe it in an exact way we must measure the angle which this direction makes with another direction that is known in advance. In navigation problems this known direction is taken as north.

The value of the angle which the given direction makes with north measuring clockwise from north is called the *course* from the point of departure to the destination.

For example, if A and B are two points on the map, the course from A to B is the number of degrees in the angle NAB, where the direction AN is the direction of the meridians on the map. In the figure, the course from A to B is 40°. Courses relative to the map are known as "true" courses.

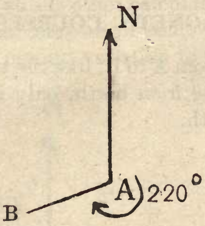

FIG. 4.

Similarly, the statement "the course from A to B is 220°" means that the angle NAB measures 220° in a clockwise direction and AN is the direction of true north from A.

It is advisable to practice at once, laying off courses from one point to another, choosing a certain direction as North and measuring the number of degrees clockwise from this direction in order to get an idea of the values of different angles.

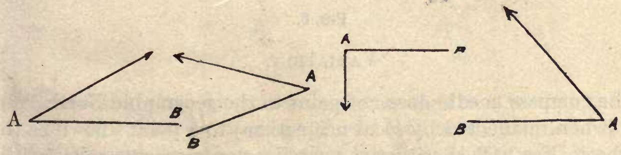

FIG. 5.

Example 1: If north is represented by the arrow, what is the course from A to B? Measure with protractor.[1]

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[1]A good protractor for this work is made by a transparent piece of celluloid 4 or 5 inches square on which is marked a circle graduated in degrees. At the center of the circle a silk thread is attached which when stretched taut will give the course from the center to any desired point relative to the line joining the center of the circle and the point marked zero or 360°. Practice with this protractor is valuable in giving a student a knowledge of the values of angles.

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Example 2: Choosing a certain direction as north, draw figures to represent the following: The course from A to B is 15°, 315°, 175°, 210°, 0°, 90°, 270°.

Example 3: From any map in your possession make up a number of examples to illustrate the course from one point to another and work them out. For example, given a map of the region about Paris, determine the true course from Nanteuil to Betz, from Nanteuil to Senlis, from Meaux to Coulommiers.

MAGNETIC COURSES.

The magnetic course from A to B, like the true course, is the angle NAB measured clockwise from north, only in this case AN is the direction of *magnetic* north.

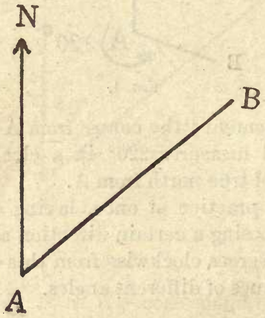


Fig. 6.

Variation.

The compass needle does not point to the geographic North Pole, but (when unaffected by local magnetism) to a point known as the magnetic North Pole, situated near the northern extremity of the American Continent. The difference between the two directions of magnetic and true north is known as *variation* or *declination.* It is described as easterly or westerly, according as the compass needle points to the east or west of true north. It is measured in degrees—15° west, 8° east, etc.

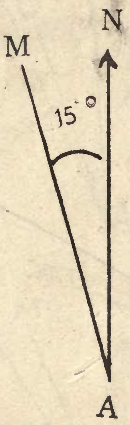
Variation on the east coast of the United States near Washington is about 8° west, and that in southern California is about 15° east. In northern France it is approximately 13° west. The variation as given on the Ypres sheet of the map of Belgium is 13° 34′, 1916.

The date of the variation is usually given, for the reason that the variation changes from year to year, though generally not by more than a few minutes.

RELATION BETWEEN TRUE AND MAGNETIC COURSES.

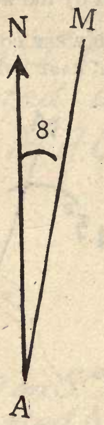
In northern France, at present, the magnetic courses differ from the "true" courses by something like 13°. If a pilot did not allow for this fact, he would be about 14 miles out of the way in a 60-mile flight, supposing that all his other calculations were correct.

The variation of the compass presents two problems: (1) Given the true course and a certain variation to find the magnetic course;



Variation 15°W

FIG. 7.



Variation 8°E

FIG. 8.

(2) given the magnetic course and the variation to find the true course. In either case the angle is read from north (magnetic or true) in a clockwise direction. From figure 7 it is evident that if the variation is 15° west, a clockwise reading from AM will be 15° greater than a clockwise reading from AN. Therefore if the variation is west and the true course is given, say 45°, to find the corresponding magnetic course, *add* 15°, getting 60° as a result. On the other hand, if the magnetic course is given, say 90°, to find the true course *subtract* 15°, getting 75° as a result.

If the variation is east, the reverse holds, namely, add the variation in passing from magnetic to true; subtract the variation passing from true to magnetic.

The difficulty in variation problems lies in the fact that they are so simple. It is necessary only to add *or* subtract a certain amount, but very frequently one adds this amount when he should subtract it, and vice versa. To reduce these errors to a minimum it is advisable to work out a large number of problems, taking care at the outset to make as few mistakes as possible in order that a correct habit may be formed and carrying on the practice over a long period of time.

It is advisable at the outset to draw a figure in every case. From the figures it will be apparent that if the variation is west, the magnetic reading is greater than the true; and if the variation is east, the magnetic reading will be less than the true. This relation may be remembered by the words—

Variation WEST COMPASS BEST.
Variation EAST COMPASS LEAST.

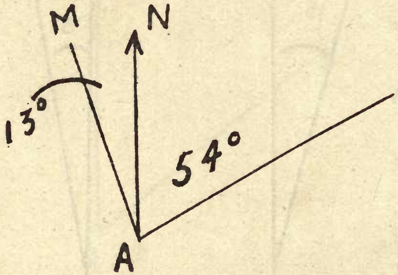


FIG. 9.

In remembering these phrases the word "variation" may be omitted if desired. The student should adopt that method of solving the problems which works best for him in practice. If possible he should visualize the angle NAM.

The following examples are given by way of illustration:

Example 1: The true course is 54° var. 13° W., then the magnetic course is 67°.

Example 2: Magnetic course is 300°, var. 8° E.; true course is 308°.

Example 3: True course 10°, var. 15° E.; magnetic course 355°.

Example 4: Magnetic course 15°, var. 10° W.; true course 5°.

COMPASS COURSES.

Deviation.

The compass in an airplane is affected by the iron and steel in the plane so that in general it does not point to magnetic north, but "deviates" from it slightly according to the course the airplane is heading. This means that the compass course, the angle the pilot must fly by, is different from both the true and magnetic courses.

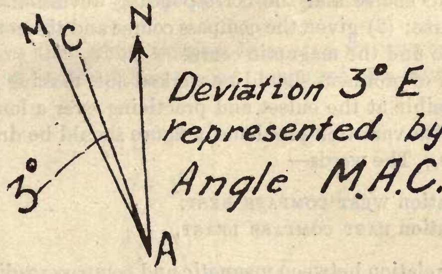


Fig. 10.

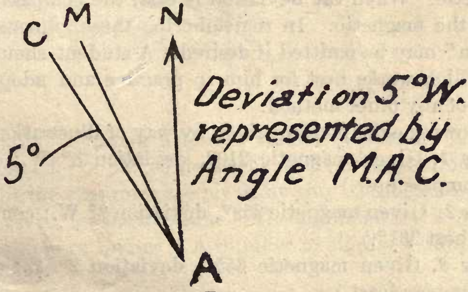


Fig. 11.

This deviation is similar to variation. As variation is divergence from true north, so deviation is divergence from magnetic north.

It is described in the same way as variation, 3° E., 5° W., etc. The deviation of an airplane compass varies, both in magnitude and direction, for different positions of the airplane. It must be corrected by means of magnets placed near the compass in such a manner as to counteract the local influence on the needle. All compasses have receptacles for these correcting magnets. This process is known as "swinging the compass" and will be described later in more detail under "Compass adjustment."

RELATION BETWEEN MAGNETIC AND COMPASS COURSES.

Let us suppose for the present that the deviation corresponding to a given course is known. Two problems are presented: (1) Given the magnetic course and the corresponding deviation to find the compass course; (2) given the compass course and the corresponding deviation to find the magnetic course.

A number of problems should be worked out, making as few mistakes as possible at the outset and practicing over a long period of time. As with variation problems, a figure should be drawn at first in each case. The words—

Deviation WEST COMPASS BEST,
Deviation EAST COMPASS LEAST,

express the relation between magnetic and compass readings. That is, when the deviation is west, the compass reading is greater than the magnetic. When the deviation is east, the compass reading is less than the magnetic. In remembering these phrases the word "deviation" may be omitted if desired. A student should find the method which works best for him in practice and adopt it to the exclusion of any other method.

The following examples are given by way of illustration:

Example 1. Given magnetic 210°, deviation 3° W.; compass is 213°. (Compass best.)

Example 2. Given magnetic 359°, deviation 2° W.; compass is 1°. (Compass best 361°.)

Example 3. Given magnetic 355°, deviation 2° E.; compass is 353°. (Compass least.)

Example 4. Given compass 5°, deviation 2° E.; magnetic is 7°. (Compass least.)

Example 5. Given compass 35°, deviation 3° W., magnetic is 32°. (Compass best.)

RELATION BETWEEN TRUE AND COMPASS COURSES.

ORDER OF PROCEDURE.

We have found the relation (1) between true and magnetic, (2) between magnetic and compass. A combination of these two enables us to find the relation (3) between true and compass. This relation between true and compass is determined by the relation which each bears to magnetic. Thus, magnetic is an auxiliary connecting true and compass. Whether we pass from compass to true or from true to compass, we must pass through magnetic. The order is either true, magnetic, compass; or compass, magnetic, true. There is no other order.

This means that when we pass from true to compass we apply variation first and deviation second; when we pass from compass to

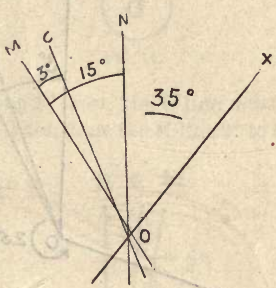


FIG. 12.

true we apply deviation first and variation second. A failure to observe this order of procedure might result in large errors.

The following examples are given by way of illustration with the deviation given for each course. The explanation is made quite full for the sake of review. A number of similar examples should be worked out.

Given true course 35°, variation 15° N., deviation 3° E., find compass.

The angle NOX, 35°, is the *true course* of the ship. It is evident that if we wish to obtain the *magnetic course* of the ship, which is MOX, we must *add* the 15° variation, the angle NOM. This gives us 50° magnetic course. Again, if we wish to obtain the *compass course* of the ship (that is, the angle its direction makes with the compass needle, the angle it must fly by), we must *subtract* from MOX the angle MOC, our 3° deviation, which gives us 47°, compass course.

It will also be clear that if the line OM lay to the right (east) of the line ON, that is, if our variation were 15° east instead of 15° west, we should have to *subtract* MON from NOX, in order to find MOX. In that case the result would be 20°, magnetic course. Similarly, if OC lay to the west of OM instead of to the east of it, we should have to *add* the angle COM to MOX in order to obtain COX, the compass bearing, which in that case would be 23°.

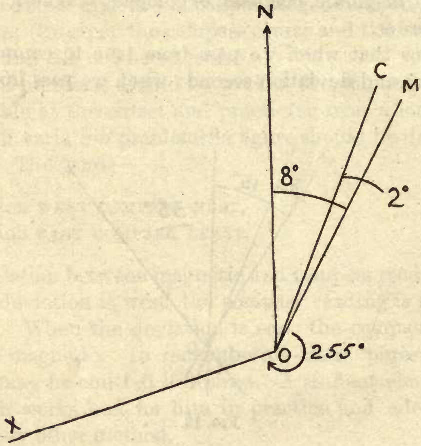


FIG. 13.

Suppose, with reference to above figure, the compass course, 47°, COX, is given us, and we wish to find the true course, NOX. In that case, we shall have to *add* our 3° easterly deviation to find the magnetic course, 50°, and then *subtract* our 15° westerly variation from that to get true course, which will be 35°.

Example. Given true course 255°, variation 8° E., deviation 2° W. To find compass course.

Until the thing is thoroughly understood, it is always well to draw a diagram.

NOX, our true course, is 255°. To find MOX we must subtract 8°, which gives us 247°, magnetic course. To find COX we must add 2°, which gives us 249°, compass course.

Example: Given compass course 357°, deviation 2° W., variation 5° E. To find true course.

Start out by drawing the angle we know, COX, 357°.

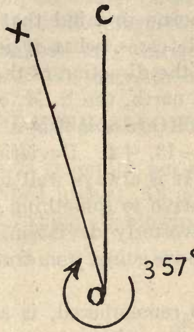


FIG. 14.

The deviation being 2° west, the C line must be 2° to the left, or west of the M line. Then draw the M line 2° to the east of the C line.

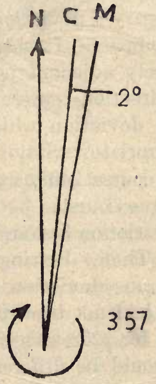


FIG 15.

To find magnetic course, MOX, subtract the 2° westerly deviation. This gives 355°, magnetic course.

But the variation being 5° east, the N line must be drawn in 5° to the left, or west, of the M line. This makes it identical with the

X line, the direction in which our ship is heading. In other words, we add 5° easterly variation and get 360°, true bearing. The ship is heading exactly true north, though according to the compass it is heading 3° to the west of north.

It should always be borne in mind that *a course is a clockwise angle from north.* In all cases, what it is desired to find is the angle which the X line, the direction of the ship, makes with one of the three lines around north, the N, M, or C lines.

Variation and deviation are sometimes referred to as plus or minus quantities, e. g., −13, +4. Deviation cards are frequently made out in this way. It is always well to beware of such signs, for their meaning is relative to something variable. Whether we should add or subtract westerly deviation, for example, depends entirely on which way we are going, from true to compass or compass to true.

Deviation, it must be remembered, is always considered with reference to magnetic, never with reference to true. We have no concern with the angle NOC.

Remember, therefore, when working from true to compass, to apply *variation first*, then deviation. Conversely, when working from compass to true, apply *deviation first*, then variation.

This would not be necessary if deviation were a constant quantity for every point of the compass. It actually varies considerably, often between quite closely adjacent points, so that a deviation correction applied to a direction representing a true course might differ radically from the deviation which should be applied for that course with the appropriate variation added or subtracted.

For example, compass course 240°, variation 15° W., deviation for 240°, 2° E. To find true course.

Suppose we correct for variation first and subtract our 15° westerly variation, getting 225°. Then, desiring to apply correction for deviation and looking at our deviation card, we might discover, especially if the compass had not been particularly well adjusted, that the proper deviation for 225° was 4° W., instead of 2° E. It is clear that the result would be different from that obtained by following the proper order. In the former case it would be 221°, in the latter 227°.

In the following examples the table, page 41, is used.

Example 1: Given true course equals 230°, variation 13° W. Find compass. Magnetic is 243°, corresponding deviation is 4° E. Compass is 239°.

Example 2: Given true 47°, variation 10° E. Find compass. Magnetic is 37°, corresponding deviation 4° W. Compass is 41°.

Working from compass to true we proceed as follows:

Example 3: Given compass 255°, variation 13° W. Find true. Corresponding deviation is 2° E., magnetic 257°. True 244°.

Example 4: Given compass 44°, variation 8° E. Find true. Corresponding deviation 4° W., magnetic 40°. True is 48°.

COURSE SETTING WITH ALLOWANCE FOR WIND.

In actual practice, it is generally not sufficient to set a course from the map as described above. It is necessary to make due allowance for the wind, which, if blowing with any considerable

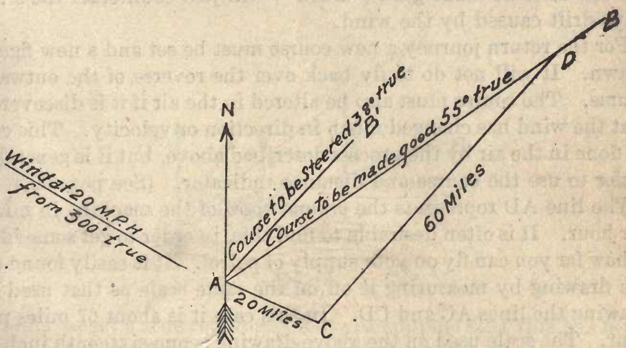


FIG. 16.

velocity, will deflect the airplane from its course and take it in a direction far from the desired one. The problem is difficult as the wind varies in velocity and direction with time and altitude. However, once the direction and velocity of the wind are known, it is not difficult to map out one's course so as to allow for its influence.

Suppose, for example, we wish to fly a course which we find to be 25° true, in a machine whose air speed is 60 m. p. h. The wind at the height at which we wish to fly is blowing at 20 m. p. h. from 300° true.

On the map itself, or on a separate sheet of paper, draw a line connecting the points of departure and destination, AB, at an angle of 55° from true north. Then from A, the point of departure, plot out a line directly *down wind*, proportionate in length to the number of miles the wind blows per hour, AC.

From C, swing a line equal in length to the air speed of the machine, in miles per hour, till it cuts the line AB. Mark this point D.

The line CD gives the course to be steered and air speed, AD gives the course to be made good ("track") and ground speed, while AC gives the speed and direction of the wind. The line AD is evidently the "resultant" of the "components" AC and CD.

From A draw a line parallel to CD, any convenient length, AB′. The direction of this line will give the course to be steered. In this case, it is 38° true. Then correct for variation and deviation, in the usual way.

The machine will fly over the course AB, but it will be headed ("crabbing") in the direction AB′. The divergence of this from the course to be made good ("track") will just counteract the sideways drift caused by the wind.

For the return journey a new course must be set and a new figure drawn. It will not do to fly back over the reverse of the outward course. The course must also be altered in the air if it is discovered that the wind has changed much in direction or velocity. This can be done in the air by the process described above, but it is generally easier to use the course and distance indicator. (See page 30.)

The line AD represents the *ground speed* of the machine in miles per hour. It is often desirable to find this, in order to get some idea of how far you can fly on your supply of petrol. It is easily found on the drawing by measuring it off on the same scale as that used in drawing the lines AC and CD. In this case it is about 67 miles per hour. The scale used on the above drawing is one-sixteenth inch to a mile, or sixteen miles to an inch; this will be found to be a convenient scale when working in miles. When working under the metric system, the scale of 1 millimeter to a mile is convenient.

It will be noted that in the above drawing the ground speed is greater than the air speed. This is because the wind is blowing more from behind the machine than from in front of it, and is consequently pushing it forward rather than back. If the wind tends to blow the machine back, the ground speed line will of course be shorter than the air speed line.

TO FIND DIRECTION AND VELOCITY OF WIND.

In the foregoing problem it is assumed that the force and direction of the wind are known. In practice these data are often furnished to the airdrome by an adjacent meteorological station, but this is not always the case. It is sometimes necessary for a pilot to go up, fly over a short known course, and from the data thereby obtained work out on paper the desired information. This is done by a process similar, or rather converse to, the one just described.

AB represents the bearing between the two known points, such as two prominent buildings, for example; if the course is flown at night, two searchlights are used. The bearing AB is 55° true. Starting over A and keeping the point B always in sight, the pilot flies toward it in as straight a line as possible. If there is a wind blowing, he will find himself "crabbing;" that is, in order to fly over the prescribed track, he will have to alter the direction or course of his machine. In this case we will call the course AC, 38° true. Naturally the pilot can not take true readings from his compass, but will have to correct his compass reading for deviation and variation

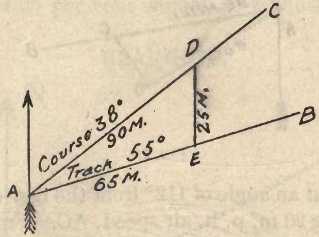


FIG. 17.

in order to get a true reading. We will suppose that this has been done, and that the true course thus found is 38°.

It is also necessary to have the air speed and ground speed of the machine. The air speed is read from the air speed meter; suppose in this case it is 80 m. p. h. For obtaining the ground speed a stop watch is necessary. By it the pilot discovers the number of seconds it takes him to fly a known distance on his track. Suppose he traverses 1 mile in 55 seconds. To turn this into miles per hour, it is only necessary to divide 3,600 (the number of seconds in an hour) by 55. This gives 65 and a fraction.

Now the pilot lays off a unit of length proportional to his *air speed* on his *course*, and a corresponding unit representing his *ground speed* on his *track*. A line joining the two will give the direction and velocity of the wind, in miles per hour.

This is the line DE, which on being measured is found to be proportional to 25 miles in length, with a true bearing of 350°.

(The measurements in the diagram are on a scale ¼ inch equals 10 miles. Any scale will do, regardless of the length we draw AB, so long as the same scale is used for all measurements concerned.)

Remember that the direction of a wind is always given as true; also that its "direction" means the direction it *blows from.*

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

For example: Course 112° true; wind, 20 m. p. h. from 60° true; air speed 90 m. p. h., find track and ground speed.

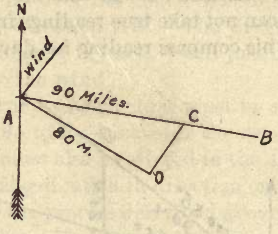


FIG. 18.

On AB, drawn at an angle of 112° from the meridian, lay off a distance representing 90 m. p. h. air speed, AC. From C lay off, *down wind*, at an angle of 60° from the meridian, a distance equal to 20 miles, on the same scale. Join A and D; measure the distance between them and the angle AD makes with the meridian, and you have the ground speed of the machine and the true bearing of the track. In this case they are 80 m. p. h. and 125°

RADIUS OF ACTION IN A GIVEN DIRECTION.

The supply of fuel in an airplane is necessarily limited. A certain amount of gasoline will supply the plane with fuel for a certain time. In making a long trip in a certain direction, it is desirable to consider in advance whether the objective falls within the plane's "radius of action." The radius of action in a given direction is the distance that a plane can fly in that direction and still return, using a certain amount of fuel—that is, flying for a certain time. The radius of action may be found as follows:

Given the air speed of the machine, the direction and speed of the wind, and the number of hours' flight possible with the supply of gasoline known:

(1) Compute the ground speed out and the ground speed in as heretofore.

(2) With these values known, the radius of action will be the number of hours times the product of the ground speeds, divided by the sum of the ground speeds.

For example, if the ground speed out is 50 m. p. h. and the ground speed in is 64 m. p. h. and the number of hours' flight possible with a given supply of fuel is 5 hours, the radius of action is

$$5 \times \frac{50 \times 64}{50+64} = 140 \text{ miles.}$$

The proof for finding the radius of action is not given.

For one hour's flight the radius of action is the product of the ground speeds divided by the sum of the ground speeds.

An allowance of 25 per cent should be made for changes in the wind, etc.

BEARINGS.

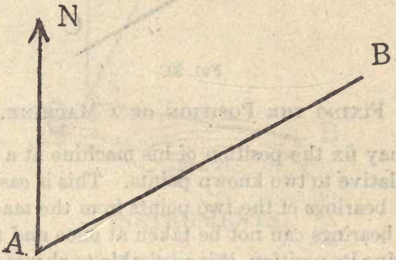


FIG. 19.

DEFINITION.

The *bearing* of a point B from a point A means the angle NAB measured clockwise from north. Thus the true bearing of B from A is the same as the true course from A to B, the magnetic bearing of B from A is the same as the magnetic course from A to B. The compass bearing of B from A, however, requires special consideration.

When the airplane is in flight steering a given course, the compass bearing of points along the course is the same as the compass course steered. It is often useful, however, for the sake of fixing one's position to take bearings of points *off* the course that one is flying, say, the bearing of B from A when the course is AC. When reckoned from the course AC the compass bearing of B from A is not the same as the compass course from A to B. The reason is that deviation depends on the direction that the airplane is heading and not on the direction that the pilot is looking. The deviation corresponding to the bearing above is the deviation for course AC and not for course AB.

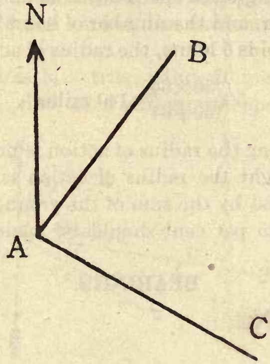


FIG. 20.

FIXING THE POSITION OF A MACHINE.

The pilot may fix the position of his machine at a given time by its position relative to two known points. This is easily established by taking the bearings of the two points from the machine.

Since both bearings can not be taken at once and the machine is rapidly changing its position, it is advisable to choose the first object well on the bow and as far away as possible in order that its bearing may change as little as possible before the bearing of the second object is taken. The time of the observation is the time when the second bearing is taken. If the objects are chosen in this manner the "fix" of the machine is accurate enough for most purposes. The course of the machine must remain unchanged during this process.

To illustrate, suppose for convenience that the machine is flying north. At 2 o'clock take the bearing of a distant object A well on the bow, bearing 15° say, and at 2.01 take the bearing of a nearer object B, bearing 100° say. Then the position of the airplane at 2.01 is found by the intersection of two lines bearing 195° from A and 280° from B. These last bearings may be found, if desired, by drawing from A and B lines parallel to ON to represent north at these points.

In general, given the bearing of B from A, the bearing of A from B is found by adding 180°. In case the resulting angle is more than 360°, subtract 360° from it. For example, the bearing of B from A is 350°. Then the bearing of A from B is 530°, which is the same as 170°. This gives the same result as if one had subtracted 180° from the first bearing and so one might follow the rule to add 180° to the first bearing, unless the result is greater than 360°, and if this is the case, subtract 180° from the first bearing.

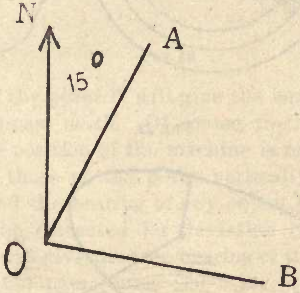


FIG. 21.

INSTRUMENTS.

BEARING PLATE.

The bearing of an object from the machine is taken conveniently by means of the bearing plate, a description of which follows.

This instrument consists of a fixed plate open in the center with two arrows arranged so that it can be set in the fore and aft line of the machine.

On this is set a movable flat ring marked off for each 5° from 0° to 360° in a clockwise direction with numbers placed at the marks 10°, 20°, etc. (fig. 22). Fixed to the outer plate is a movable framework with wires stretched across and capable of being rotated around the plate. At either end of this framework are placed upright pointers to facilitate sighting.

The chief use of the instrument is to take the compass bearing of an object.

To do this, read the compass course of the machine and set the movable ring so that the number opposite the forward arrow is exactly the same as the compass course. We see from the figure

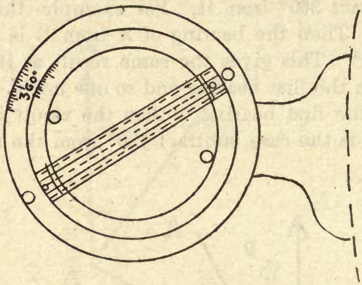


FIG. 22.

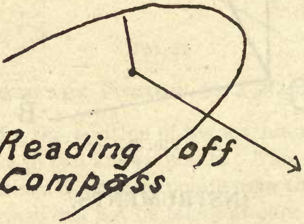


FIG. 23.

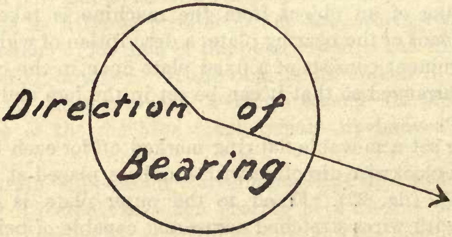


FIG. 24.

that the bearing plate will then have its zero mark in exactly the same direction as the compass north, and, as long as the course remains the same it can be used as the compass for observing the direction of any object. The compass itself can seldom be used for this purpose as the field of view around it is often restricted. The movable framework can be placed so that the sights or pointers and center drift wires (the wires being called drift wires, as will be seen later) are aligned on the object.

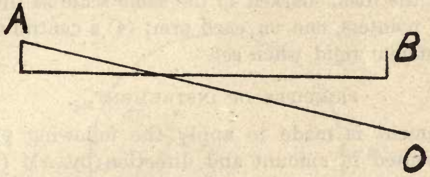


FIG. 25.

The reading of the point B will give the bearing of the object O as read from compass north. Of course, the horizontal bearing is given, but as the position of the machine is relative to the ground all bearings are those of the point vertically above the object. Now, having found the bearing of any object from the compass, it will require to be corrected for deviation from the course and variation. This will give the true bearing of the object.

For example: Compass course 200°, var. 13° W., dev. 7° E., compass bearing of an object is 120°. Find its true bearing.

CB	120°	
Dev.	7° E	taken from the compass course.
MB	127°	
Var.	13° W	
TB	114°	

This gives the true bearing of the object from the machine to be 114°, and therefore the bearing or direction of the machine from the object is 180° plus 114° equals 294°.

AIRCRAFT COURSE AND DISTANCE INDICATOR.

The aircraft course and distance indicator (C. D. I.) makes possible the solution of certain problems during flight without the use of pencil, parallel rulers, dividers, etc.

DESCRIPTION.

This instrument consists of (1) an outer ring marked every 5° from 0° to 360°; (2) a central rotating disk whose radius is marked to represent 120 miles, the disk itself being squared, each side of a square representing 10 miles; (3) two arms A and B pivoted at the center of the disk, marked to the same scale as the disk with two movable pointers, one on each arm; (4) a central clamp holding the instrument rigid when set.

PRINCIPLE OF INSTRUMENT.

The instrument is made to apply the following principle: A force[1] represented in amount and direction by AM (equals CD) plus a force represented (in amount and direction) by MB is equal to the force represented (in amount and direction) by AB. In this case AB is called the "resultant" of the two "component" forces AM and MB.

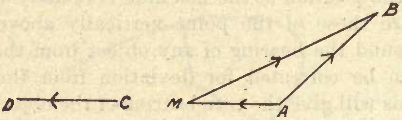


FIG. 26.

For example, if the line AM is 1 inch in length, and represents a wind of 40 m. p. h. blowing from A, and the line MB is 2 inches in length and represents an air speed of 80 m. p. h. in the direction MB, the resultant speed is about 60 m. p. h. in the direction AB.

In the following problems we shall have to do with these quantities:

(1) Speed and direction of the wind.

(2) Ground speed and track (course to be made good).

(3) Air speed and course (true).

It may be noted that the ground speed is always along the track, and the air speed is always along the course (here taken as "true").

The direction of the wind is given relative to true north, and represents the direction from which the wind blows; for example, a north wind is blowing from the north.

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] Or a velocity.

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

(2) Always keep the general lines of the situation in your head.

(3) Check each example by the idea *more or less;* for example, the ground speed will evidently be greater than the air speed if the wind favors the pilot on his course.

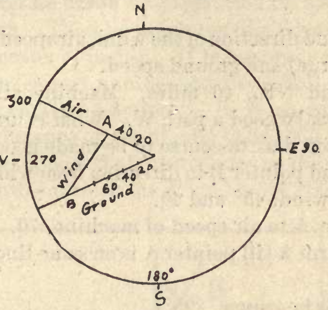


FIG. 27.

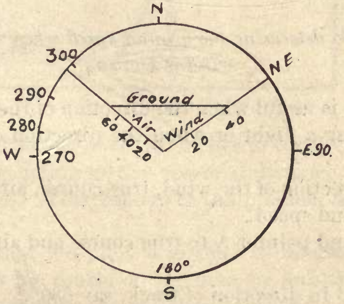


FIG. 28.

Problem I: To find the speed and direction of the wind, given the track and ground speed, course (true) and air speed.

Examples: Machine steers 300° at 50 miles. Track observed to be 260° at 70 miles. Find the speed and direction of wind.

(*a*) Set arm and pointer A to course steered (true) and air speed 300° and 50.

(*b*) Set arm and pointer B to course made good and ground speed 260° and 70.

(*c*) Set disk so that arrow is parallel to line AB.

Arrow points to direction in which wind is blowing, 215°, therefore wind blows from 35°. Length of AB is speed of wind, 44 m. p. h.

Problem II: To find what "allowance to make for a wind."

Given speed and direction of the wind, air speed, and track desired, to find course (true) and ground speed.

Example: Wind NE., 40 miles. Machine air speed, 70 miles. Pilot wishes to make good a path W. What course must he steer?

(*a*) Set arrow on disk to course to be made good (track), 270°.

(*b*) Set arm and pointer B to direction from which wind is blowing and to speed of wind, 45° and 40.

(*c*) Set pointer A to air speed of machine, 70.

(*d*) Revolve arm A till pointer A is on same line (parallel to arrow) as pointer B.

Arm points to the course, 295°.

The distance between pointers A and B will be ground speed, 91. (See fig. 28.)

Problem III: To determine the ground speed when the direction of the wind is known.

This problem is useful when the direction of the wind is observed to change during a flight or when the direction of the machine is changed.

Given the direction of the wind, true course, air speed, and track, to find the ground speed.

(*a*) Set arm and pointer A to true course and air speed, say north and 80 m. p. h.

(*b*) Set arm B in direction of track, say 330°.

(*c*) Move disk until arrow shows the direction of the wind, say 60°.

(*d*) Set pointer B where parallel to arrow from A cuts arm B. This will give the ground speed along the track. 69 m. p. h.

The conditions given in this problem allow us also to read from the indicator the speed of the wind. In this case it is 40 m. p. h.

In case it were desired to fly directly up (or down) wind, the wind speed might be computed as above and then subtracted (or added) to give the ground speed.

ILLUSTRATIVE PROBLEM.

(This problem is given to apply some of the foregoing principles in succession to a particular case. The explanation is made quite full in order that, if desired, the problem may be read in connection with the Introduction, page 6.)

By means of map and compass the pilot proceeds as follows to lay out his course. First he draws a straight line on his map from aerodrome to destination. Then he measures this distance on the map. This distance is a matter of inches. It is necessary to fly a matter of miles. He finds the correct number of miles as follows: On his map is printed a "representative fraction." R. F. equals 1/200,000, say. This means that a distance on the ground is 200,000 times as great as on the map. Let us suppose that the distance on the map is 14 inches. This means that the distance on the ground is 200,000 times 14 inches.

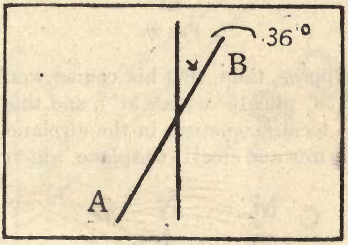


FIG. 29.

Since there are 5,280 feet or 63,360 inches in a mile, the distance on the ground corresponding to the observed distance of 14 inches on the map is 44 miles. This disposes of the problem as far as distance is concerned.

The direction that the pilot is to steer is determined as follows: First he measures his course on the map by means of a protractor, measuring the angle from the meridian indicated on the map to the straight line along which he is to fly. It is not always advisable to fly a straight course, but we will suppose it to be so in this case. He finds this angle to be 36° say, and therefore his "true" course is 36°.

This, however, is not the course which he will steer when using his compass, because the compass does not point true north. In France a compass unaffected by local magnetism points from 10° to 15° to the west of true north, toward the *magnetic pole* of the earth.

The amount by which the compass differs from true north is known as its *variation* and is said to be easterly or westerly according as the compass points east or west of true north. Let us suppose that the variation of the compass at the pilot's aerodrome is 15° west.

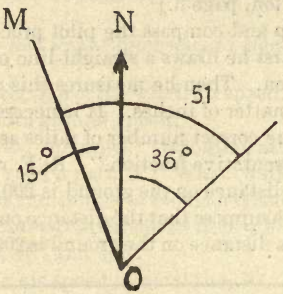


FIG. 30.

One might suppose, then, that his course would be his "true" course plus 15° (36° plus 15° equals 51°), and this would be the case if there were no local magnetism in the airplane, but the compass is affected by the iron and steel in the plane, which deflect the needle

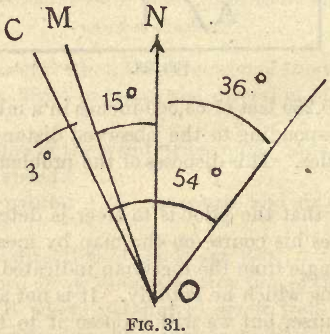


FIG. 31.

a little this way or that, according to the way the ship is headed. It must be borne in mind that the compass needle tends to point to "magnetic" north regardless of the direction of the ship, and as the machine changes direction different bodies affect the compass needle; for example, when the ship is flying east, magnetism in the engine may pull the compass needle toward the east, and when flying west, to the west. It has been found necessary in practice to correct the compass reading for this "deviation" at the points north, east, south, west, and the points halfway between them. The deviation for other points may be computed from these. (See page 41.)

Let us suppose that the deviation corresponding to the pilot's "magnetic" course of 51° is 3° west. This means that the "compass" course is 3° plus 51°, or 54°, and this is the course which the pilot will have to steer—or, rather, it is the course which he would steer if there were no wind.

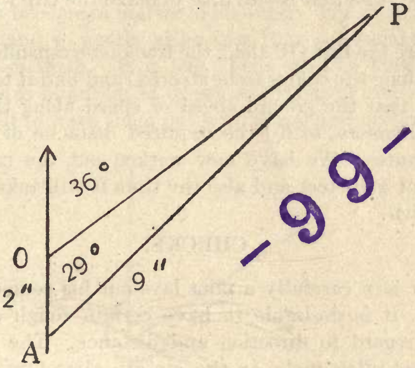


FIG. 32.

Let us suppose now that there is a wind from true north blowing 20 miles an hour. This means that no matter in what direction the airplane steers it is going to be carried in a southerly direction at the rate of 20 miles per hour. It is evident, therefore, that if the pilot wishes to reach a certain destination he must steer to the north of it by a certain amount.

Let us compute this amount graphically by protractor and ruler. A wind blowing from the north will deflect the machine in a southerly direction by an amount proportional to 20. From the aerodrome O let us draw a line OA in the direction of true south, say 2 inches in length. This will represent the amount that the wind deflects the ship. Our problem is to steer a course from A which will keep us on the desired track. With A as a center and a radius of 9 inches proportional to the speed of the ship, let us cut the track at the point P. Then AP is the direction to be steered by a plane going 90 miles an hour to stay on the track in spite of a north wind blowing 20 m. p. h. If we measure the angle OAP with a protractor, we find it to be 29°. This angle represents the true course, allowing for wind.

From the true course we may find the compass course to be steered by applying the proper variation and deviation getting as a result 29° plus 15° plus 3° (supposing the deviation corresponding to magnetic 44° to be the same as for magnetic 51°, although this would not always be the case) equals 47°, the compass course to be steered.

To find the time that it will take to make the trip we may proceed as follows:

We measure the line OP along the track (corresponding to a length of 9 inches along the course to be steered) and find it to be 7½ inches. This means that the ground speed or speed along the track is 75 m. p. h. Therefore, to fly the required distance of 44 miles will take 35 minutes. We have now worked out the compass course that the pilot will steer and also the time it will take him to reach his destination.

CHECKS.

No matter how carefully a pilot lays out his course and uses his instruments, it is desirable to have certain rough checks on his flight with regard to direction and distance. The mistakes that inexperienced pilots make in the air are almost incredible—such mistakes as, for example, getting 30 miles out of the way on a 10-mile flight.

With respect to direction a pilot may check his flight by means of the sun and the map. On most flying days the direction of the sun may be observed, and if the course is known the sun ought to be in *about* such a position relative to the direction of the plane. While the compass and the calculated course are the chief things of importance, an occasional observation of the sun will prevent a pilot from making *large* errors in direction. Such errors will also be prevented by careful observation of the country over which he is traveling and comparison with his map.

Observation of the country and the map will also prevent large errors with respect to distance. These errors may also be prevented by a knowledge of the time required to make the trip. Such a check on his flight would prevent the pilot from being 30 miles out of the way on a 10 mile trip, for if he flew for the proper length of time (in still air) so large an error would be physically impossible no matter what direction was taken.

TECHNIQUE.

In order to take navigation out of the realm of theory and make it a practical matter it is necessary for the pilot to develop his technique in certain respects to a high degree of proficiency. It is necessary to develop (1) a sense of direction; (2) a sense of distance; (3) a sense of quantity (proportion). In each of these respects the pilot should train himself by numerous exercises over a long period of time until accuracy becomes a matter of instinct. The exercises required are so simple and so nearly alike that it is not feasible to print a large number of them. It is left to the pilot to make up a large number, perhaps hundreds of exercises similar to each of these, and to train himself to work them out with speed and certainty.

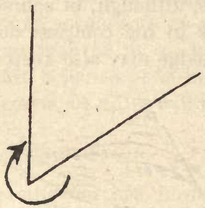


FIG. 33.

DIRECTION.

The *first exercise* consists in drawing angles between 0° and 360°, guessing at their size and checking by protractor until the guesses are fairly accurate. For example, how many degrees is a certain angle.

Check by protractor. This angle is about 320°.

Second exercise: The line OP from O to P bears 300° by compass (fig. 34). Draw a line (a) bearing north (fig. 35), (b) bearing 150° (fig. 36).

Third exercise: The following exercise is for the purpose of preventing the pilot from making large errors in direction. The direction of the sun may be observed approximately on most flying days. At 12 o'clock noon this direction is *about* south regardless of the season of the year. At 6 p. m. it is about west; at 6 a. m. about east, etc. Thus knowledge of the direction of the sun at any hour of the day will give the pilot an idea of where to expect north and

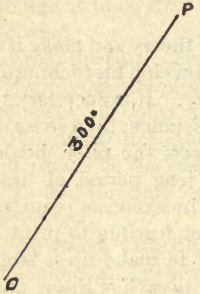


FIG. 34.

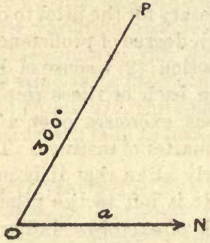


FIG. 35.

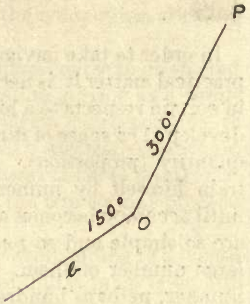


FIG. 36.

all the other directions, although, of course, it will not enable him to correct small errors in his compass nor get along without his compass. Such knowledge may also keep him from being confused

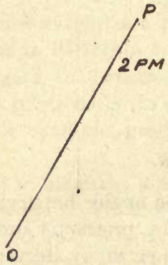


FIG. 37.

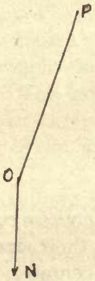


FIG. 38.

at moments when the compass is unreliable, say, after a steep bank or after emerging from a cloud. From O the sun is in the direction OP at 2 p. m. Find the direction of north from O. (Fig. 38.)

DISTANCE.

First exercise: How long does it take to go 12 miles at 80 m. p. h.? This exercise should be worked out mentally so as to be approximately correct, as follows: At 60 m. p. h. it would take 12 minutes.

At 80 m. p. h. it would take less than 12 minutes, perhaps 9. The guess should be checked as follows: Since the time is *inversely* proportional to the speed, it would take sixty-eightieths of 12 minutes, equals 9 minutes. Usually the guess will be somewhat out of the way, but the pilot should practice the exercise until his guess is approximately correct.

Second exercise: Two vertical searchlights are 5 miles apart. It takes 4 minutes 10 seconds to traverse the distance between them. Required the ground speed. The plane is evidently going more than 60 m. p. h., say 70, for a guess. To check the guess proceed as follows: 4 minutes 10 seconds is 250 seconds. Five miles in 250 seconds is 1 mile in 50 seconds. There are 3,600 seconds in an hour. One mile in 50 seconds means 72 miles in an hour, thereby checking the guess.

Third exercise: How far can one go in 10 minutes at 90 m. p. h.? The guess is 15 miles and may be made correctly at once since 10 minutes is one-sixth of an hour, and one-sixth of 90 is 15.

Fourth exercise: It takes 55 seconds to go a mile. Required the speed. The speed is more than 60 m. p. h., say 70, for a guess. Check as follows: There are 3,600 seconds in an hour; therefore, if 1 mile is traveled in 55 seconds, 65 miles will be traveled in an hour.

Proportion.

Certain exercises in proportion are implied in the foregoing. Certain others are required when laying out a course to allow for wind, as follows:

First exercise: An air speed of 70 is represented by a line 2 inches in length. What line represents a wind of 20? Answer: Two-sevenths of 2 inches.

Second exercise: A wind of 15 is represented by a line 1 inch in length. What line represents an air speed of 90? Answer: Six inches.

Third exercise: Ground speed 65 is represented by a line 3 inches in length. What line represents an air speed of 75? Answer: Seventy-five sixty-fifths of 3 inches.

Note.—In solving these examples in proportion it is first desirable to decide the general question "more or less." Thus, in the preceding exercise it is first desirable to realize that the line representing 75 will be *more* than 3 inches in length before working out exactly how much more. In the first exercise the line would be *less*, and about one-third of 2 inches.

Fourth exercise: Free-hand drawing of lines in different directions proportional to different numbers. Check by means of ruler and protractor. For example, draw two lines making the angles 30° and 230°, respectively, with a given line and proportional, respectively, to the numbers 5 and 2.

The pilot should also have facility with a time scale, described under "Map reading."

COMPASS ADJUSTMENT.

Compass adjustment is the process of eliminating, as far as possible, errors of the compass caused by the magnetic material in the ship. This adjustment is effected by swinging the compass on a temporary or permanent swinging base, which is essentially a central point with the magnetic cardinal and quadrantal points laid off around it. The process of swinging consists in bringing the plane with the compass in it to the base and successively heading it on each point.

A temporary swinging base, such as is constructed at an aerodrome near the fighting line, is located out in the field, at least 50 yards away from any magnetic material. The center is marked with a peg. By means of a prismatic compass (or any other type with sighting attachments) set up over this central peg, the positions of the eight points are determined and marked with pegs or stakes. (It takes two men to do this, one to sight and one to peg.) When established, each stake should be joined to the central peg by a taut cord.

The permanent swinging base, such as is used at factories, schools, and permanent aerodromes, is made by digging a circular basin 20 yards in diameter and about 1 foot deep, and filling it with concrete. When leveled and set, the platform thus formed is marked off with the cardinal and quadrantal points as above, the lines being marked with black paint instead of cords and pegs.

Before the machine and compass are taken to the swinging base for the adjustment, the compass must be carefully inspected for its mechanical condition. Three points are particularly to be observed:

1. Large bubbles should be eliminated.
2. The card should hang evenly on its pivot.
3. There should be no friction in the bearing.

The test for the last is to deflect the needle with a magnet and release it. If it does not come back promptly to the reading that it had before the deflection, there is friction, and the compass must be replaced.

The position of the compass in the machine has been worked out and standardized for each type of machine in order to secure the greatest ease of reading by the pilot, the greatest convenience of adjustment, and the least unbalanced influence from the magnetic material in the ship. It follows that the compass must be in the authorized position for the given type of machine, and in no other.

The compass being properly placed and in good working order the machine is set up on the center of the flying base, tail raised to flying position by means of a trestle. A plumb line is dropped from the boss of the propeller and another from the tail skid or the center line of the tail. Now, by sighting along these and the N. line, one can point the machine's nose due north (magnetic) and observe the compass reading. If this is not zero, magnets can be set athwartship in holes provided in the compass case, in such a manner that the deflection will be neutralized. This is called *compensation.*

Next the machine is turned so as to head exactly east, being sighted along the plumb lines and the stake or ground line as before, and the compass reading is again taken. In this position the error will be much greater than in the N.–S. position, for the needle is lying transverse to the lines of force from the chief source of magnetic attraction, the engine, which is always in the fore-and-aft line in any single-motor type of ship. Hence more compensating magnets are required for correcting on the E.–W. axis than on the N.–S. axis. These magnets are placed fore and aft in the compass case in order to act at right angles to the needle, which is pointing in the general direction of north; that is, athwartship, the ship having been turned one-quarter turn to the right or east.

The deviation being corrected on N. and E., the machine is sighted on S. and W. in turn. If the deviation in these positions is no greater than 3°, it is best not to compensate for it, since to do so would only throw out the already correct reading on N. and E. If, however, the error is greater than 3°, it is best to compensate half the error Since the deviation on E. has already been corrected by fore-and-aft needles, alteration of those needles to correct the deviation on W. will create an error on E. approximately equal to the correction on W. Hence, by halving the error on W, we distribute it equally between E. and W., giving each a small amount.

This compensation on the *cardinal* points as explained serves to neutralize the effect of the *permanent* magnetism in the ship, i. e., that resident in those hard iron and steel parts which acquired magnetism in the process of manufacture and assembly. In addition to these errors there will still be errors on the *quadrantal* points, due to *induced* magnetism in the soft iron of the ship. In the ordinary aero compass these can not be compensated for. What is done is to swing the ship to all these points and note the error on each, along with any uncompensated error on the cardinal points on the deviation card.

The deviation card is then prepared and placed conveniently near the compass, so that both may be read by the pilot at the same time.

DEVIATION CARD.

The deviation card represents the minimum to which the deviation of a particular compass in a particular machine can be reduced by properly placed magnets. A common form of deviation card follows:

Magnetic course.		Deviation.
N.	0°	0
NE.	45°	4 W.
E.	90°	1 W.
SE.	135°	5 E.
S.	180°	2 E.
SW.	225°	7 E.
W.	270°	2 W.
NW.	315°	3 E.
Compass checked by ———		Date ———

When the compass reading has been corrected as above for the points 0°, 45°, etc., an approximate correction for points 10°, 20°, 30°, etc., is made by interpolation, assuming that the amount of deviation changes regularly from point to point. To illustrate this process, the following table is made out from the deviation card given above, giving the readings from 0° to 90°, and from 230° to 270°. The completion of this table is left as an exercise.

TABLE.

Magnetic course.	Deviation.
10°	1° W.
20°	2° W.
30°	3° W.
40°	4° W.
50°	4° W.
60°	3° W.
70°	2° W.
80°	2° W.
90°	1° W.
230°	6° E.
240°	4° E.
250°	2° E.
260°	0°
270°	2° W.

This form is being supplanted in the United States Air Service by another which is purely visual and saves labor of calculation. It consists of two concentric circles, marked off in degrees like the compass card. The inner circle represents magnetic readings, the outer circle compass readings, and lines are drawn in by the compass officer connecting the two, to indicate the appropriate amount of deviation.

It is desirable, however, to have great facility in working out problems from a deviation card. It is not necessary to interpolate for angles which are not multiples of 10°. The deviation corresponding to these angles may be taken as the deviation corresponding to the nearest multiple of 10°. For example, using the table, the deviation for 42° is taken as the deviation for 40° (4° W.) and the deviation for 87° is taken as the deviation for 90° (1° W.), etc. The card and table just given will be used in the following examples:

Example 1: The compass reading corresponding to magnetic 32° is 35°.

Example 2: Corresponding to magnetic 235° we have compass 229°.

It may also be assumed without large error that the deviation corresponding to compass 50° is the same as for magnetic 50°, etc. With this assumption the table may be used as follows to pass from compass to magnetic readings.

Example 3: Corresponding to compass 232° is magnetic 233°.

Example 4: Corresponding to compass 266° is magnetic 264°.

Given variation 13° W. and the deviation card and table above:

Example 5: Find the compass readings corresponding to the true reading 0°, 340°, 5°, 350°, 175°.

Example 6: Find the true readings corresponding to the following compass readings: 0°, 10°, 190°, 350°, 13°.

Example 7: Given course 250°, compass bearing 45°, find true bearing.

Example 8: Given course 54°, compass bearing 72°, find true bearing.

Example 9: Given course 232°, compass bearing 21°, find true bearing.

AERIAL NAVIGATION.

PART II.

THE MAP.

INTRODUCTION.

In our study of aerial navigation so far, we have been concerned primarily with the compass. This instrument helps us to find our objective, once we know the track, but it can not determine the track.

The map, on the other hand, not only helps us to stay on the track as we go along, but shows us what track to take in order to arrive at a desired point. The plan for a flight must be made from the map. On the map the flight is taken in theory. The pilot with his plane, engine, and compass turns this theory into practice, but he must have exact knowledge of the course to be made good. If it were known only in a general way that Bruges lies somewhere north of Ypres, Bruges would have no fear of bombing raids.

Without maps, long-distance flying would be a hit-or-miss performance of the worst sort. Every voyage would be a voyage of discovery and there would be no such thing as proceeding in short order to a point determined in advance unless, of course, one were familiar with the route. Without maps the military value of aviation would be little or nothing.

The chief characteristics of the map are as follows:

I. Points on the map represent points on the ground and vice versa.

At once two problems are presented to the aviator:

(1) Given a point on the ground to locate it on the map.

(2) Given a point on the map to locate it on the ground.

If a point on the ground which we wish to study in its relation to other points (to a battery of 155's, say) is not on the map already, the aviator must put it on the map. He has three means of doing this:

(1) By marking his map.[1]

(2) By making a rough sketch showing this new point in relation to points already known. (Not common.)

(3) By taking a photograph.

The last is the best and most common means of putting points on the map, but it can not be treated here as the subject is too large. Since this is the case, we shall consider only the problem of finding a point on the ground that is given on the map. This division of our subject will be called LOCATION OF POINTS.

II. A map is drawn "to scale." Distances and dimensions on the ground are reduced in a certain proportion as with building plans and working drawings. It follows that map distances must be translated into ground distances and vice versa according to the given proportion. This gives the aviator two problems:

(1) Given a distance on the ground to find the corresponding distance on the map.

(2) Given a distance on the map to find the corresponding distance on the ground.

The first of these is more important when we are making a map; the second when we are using a map already made. Therefore, the second problem will be emphasized when we treat of SCALES.

III. It must be remembered that objects on the ground are shown on the map as if viewed from directly above. Distance between two points on the map means horizontal distance and not distance along the slopes of the ground. So a plan of a gable roof represents the horizontal distance between the eaves and not distance along the roof from eaves to ridgepole and down the other side.

But how are elevations and depressions to be represented on a map? Evidently they can not be given by distances because all distances that can appear on the map are accounted for already as horizontal distances. Therefore, irregularities of elevation (hills, plateaus, watercourses) are represented by symbols called CONTOURS, which show the elevation of certain points and lines above mean sea level, and enable us from these to estimate the elevation of other points. From contours we are able to tell whether a slope is going up or down, whether it is gentle or steep, whether a certain neighborhood is a plain or a rolling country or whatnot with respect to elevation.

[1] This is the same problem as fixing the position of the machine, Part I, page 24.

IV. But there are many other objects on the ground besides elevations and depressions which have to be represented, if at all, by symbols. Map position shows where a thing is, but not what it is. For military purposes it is convenient to have certain other CONVENTIONAL SIGNS, as well as contours. Thus we may represent the forest of Villers-Cotterets by a green patch on the map; we may surround Dickebusch Lake by a blue line; we may represent barbed-wire entanglements by XXXX; machine-gun emplacements by M. G., and so on.

Orientation.—When using a map in connection with the ground which it represents, it is best to "orient" the map. This means to place it "square with the world"; that is, so that any line on the map which represents a certain direction on the ground is actually pointing in that direction. The line most commonly used to orient a map is the north and south line, either true or magnetic, although any line may be utilized. One very common error made in orientation is that of comparing true north on the map with magnetic north on the ground, or vice versa. Care must be taken to compare true north with true north only, and magnetic north with magnetic north only, unless the proper correction has been made to work from one to the other. Maps which have no north line marked upon them may be assumed to be drawn with the direction of true north parallel the side of the map and pointing toward the top.

The pilot usually orients his map by means of the bearing plate. The bearing plate is set so that its zero mark coincides with the direction of compass north. Deviation of the compass is determined from the deviation card according to the compass course of the ship. The problem may then be stated: Given compass north; find the compass bearing of true north [1] (or magnetic north). This has been treated in Part I under the heading "Bearing plate." When the compass bearing of true north is found, it is necessary only to set the drift wires of the bearing plate in this direction and to make the meridians on the map take the direction of the wires.

The four general divisions of our subject that have been indicated above will be treated in the order scales, conventional signs, contours, location of points, as follows:

[1] For example, if the compass needle allowing for variation and deviation points 10° to the west of true north, then true north bears 10° to the east of compass north; that is, the compass bearing of true north is 10°.

SCALES.

Every map should have in some form or other a scale or statement of the proportion between distance on the map and distance on the ground. A scale should be the first thing that the pilot looks for as he starts to read a map. It may be indicated in three ways:

(1) By equation: 1 inch equals 3 miles; 1 mile equals 3 inches.

(2) By graphical representation: Laying off on a straight line distances that correspond to a certain number of miles or kilometers.

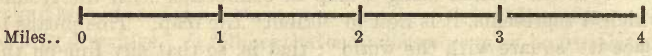


FIG. 1.

(3) By representative fraction (R. F.), for example, 1/200,000. This means that a distance of 1 inch on the map represents a distance of 200,000 inches on the ground. So 1/20,000 means that 1 inch on the map stands for 20,000 inches on the ground. Evidently the dimensions of an object on the second map are ten times as great as on the first.

Relation between scales.—The special advantage of the R. F. is that it is equally significant whether we are dealing with British maps which speak of miles and inches or French maps, which speak of kilometers and centimeters. It is often convenient, however, for the aviator to think in terms of so many miles to an inch or so many inches to a mile. If he is using a French map, these forms of the scale will not appear and he will have to construct them. He may proceed as follows: There are 63,360 inches in a mile. Therefore the fraction 1/63,360 stands for 1 inch to a mile or 1 mile to an inch. To solve the problem in inches to a mile for a given representative fraction, we must answer the question, "Will there be *more or less* than 1 inch (to a mile), and how much?" Since 1 inch on the map corresponds to 200,000 inches on the ground, the map will evidently have *less* than 1 inch to a mile, and exactly 63,360 divided by 200,000 equals 0.32 inch to a mile.

By the same reasoning it appears that on this map there will be *more* than 1 mile to an inch, and exactly 200,000 divided by 63,360 equals 3.16 miles to an inch.

Therefore, to determine the number of inches to a mile or miles to an inch corresponding to a given representative fraction, we either divide into 63,360 or divide by it according to the idea "more or less." As a check on the correctness of our work we may notice that 3 miles to an inch is about 190,000 inches to an inch, proving at a glance that we are not far out of the way.

If it is desired to lay off accurately the scale 0.32 inch to a mile and our foot rule is graded to sixteenths, we may get a reasonable degree of accuracy by using the scale of numbers—

$$\tfrac{1}{4}=0.25 \qquad \tfrac{1}{16}=0.0625$$
$$\tfrac{1}{8}=0.125 \qquad \tfrac{1}{32}=0.0313$$

from which it appears that 0.32 is about $\frac{1}{4}$ plus $\frac{1}{16}$ or $\frac{5}{16}$ of an inch. (Evidently 0.32 is more than 0.25 and less than 0.50. It is less than $0.25+0.125=0.375$. It is about $0.25+0.0625=0.3125$.) The error is 75/10,000 of an inch, which in this connection is small. This will give as accurate a scale as a pilot will probably need, for short distances.

For long distances the corresponding scale would be 3.2 inches equals 10 miles. With a foot rule this might be laid off as $3\frac{3}{16}$ inches equals 10 miles, the error on the ground amounting to only 200 yards or so in 10 miles, and in air work this error is considered small. For still closer approximation, using thirty-seconds of an inch (taking points midway between sixteenths) the error could be further reduced to about 1 mile in 1,000.

There is also a simple geometrical method for solving this problem, but it will not be given here, since without good instruments it is not as accurate as the arithmetical method and the arithmetic scale if forgotten can be readily found through successive divisions by 2.

Time Scales.

(In the following it must be borne in mind that speed and m. p. h. refer to ground speed and not air speed.)

We have seen that map scales show relations between distances on the ground and distances on the map. It is also desirable for the pilot to have a scale of map distances in terms of the *time* it takes to fly them at different ground speeds. The value of this scale is that it enables the pilot to measure on his map the time it takes to fly from point to point without computing the number of miles traveled. If the time is known and the pilot has a supply of fuel for a certain number of hours, the number of miles in the trip makes no difference.

The time scale is constructed by choosing a convenient time unit, for example, 10 minutes, and laying off the distances which may be traveled in this time at different ground speeds. Suppose the R. F. of the map is 1/200,000. This amounts to 0.32 inch to the mile, or 3.2 inches for 10 miles, or 3.2 inches for 10 minutes at 60 m. p. h. ground speed. At 70 m. p. h. ground speed we are going $\frac{7}{6}$ as fast as before, and so for 10 minutes the map distance will be $\frac{7}{6}\times3.2=3\frac{3}{4}$ inches (about). At 80 m. p. h. ground speed we are going $\frac{8}{6}$ as fast as at 60 m. p. h, and the corresponding map distance for 10 minutes will be $4\frac{1}{4}$ inches. At 90 m. p. h. ground speed the map distance is 4.8 inches, and so on. The completed scale is on page 49.

It must be remembered that *the length on the scale from zero to a certain ground speed is the map distance traveled in 10 minutes at that speed;* for example, referring to the map of Paris, a plane going at the rate of 70 m. p. h. ground speed could fly in 10 minutes from Notre Dame, in Paris, to St. Germain, about $3\frac{3}{4}$ inches, regardless of the number of miles traveled over the ground.

So in 20 minutes at the same ground speed $7\frac{1}{2}$ inches map distance might be covered; for example, from Chateau-Thierry to Soissons.

To find the time required to fly from Paris to Soissons at 90 m. p. h. ground speed, find the number of times that the distance from 0 to 90 on the scale will be contained in the given map distance. This number of times turns out to be 4. Therefore at 90 m. p. h. ground speed, it will take about 4$\times$10 minutes for the flight.

To fly from Paris to Meaux, a map distance of 8 inches at 90 m. p. h. ground speed will take, applying the time scale, about $2\frac{1}{3}\times10$ minutes, equals 23 minutes.

These examples may be worked out to whatever degree of accuracy is required by the circumstances; for example, in the foregoing, 23 minutes would be a sufficient degree of accuracy.

On the time scale it will be found that 60 is twice as far from 0 as 30 and that 120 is twice as far from 0 as 60, etc.; that is, the rate represented is proportional to the distance from 0 on the scale. For this reason interpolation may be easily applied; for example, 55 would lie half way between 50 and 60, and so on.

If desired, any other convenient unit of time might be used instead of 10 minutes; for example, 12 minutes. If the scale is graduated for 10 minutes on one edge and for 12 minutes on the other, it will be easy to compute the ground speed for any short distance since any one of the numbers, 2, 3, 4, 5, 6 is contained either in 10 or 12. For example, a pilot finds that he has covered a certain map distance in 6 minutes. Using the 12-minute scale he

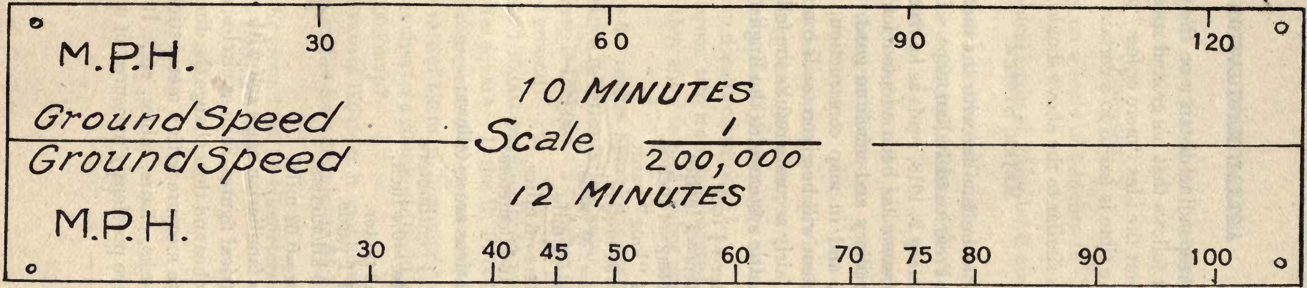

M.P.H.
30
60
90
120
10 MINUTES
Ground Speed
Scale 1/200,000
Ground Speed
12 MINUTES
M.P.H.
30
40
45
50
60
70
75
80
90
100

Fig. .

finds that the corresponding distance on the scale shows the speed of 65 m. p. h. It follows that his ground speed is 130 m. p. h. In examples of this sort the idea "more or less" must be kept in mind; for example, if the time is *less* to go a certain distance, the speed is *more*, and so on.

Other examples similar to the above should be worked out.

Metric System.

An aviator should be familiar with the metric system, since this system is used on French and Italian maps. Paragraph 2 of General Orders No. 1, January 2, 1918, reads as follows:

"The metric system has been adopted for use in France for all firing data for artillery and machine guns, in the preparation of operation orders, and in map construction. * * * Instruction in the metric system will be given to all concerned * * *."

For quick and fairly accurate results the following relations suffice to connect the metric system with the English:

1 centimeter=$\frac{2}{5}$ inch.
5 centimeters=2 inches.
10 centimeters=4 inches.
1 meter=1 "long" yard.
100 yards=90 meters.
200 meters=220 yards.
1 kilometer=$\frac{3}{5}$ mile.
10 kilometers=6 miles.
10 miles=16 kilometers.

More exact relations are as follows:

1 inch=2.54 centimeters.
1 centimeter=0.4 inch.
1 yard=0.9 meter.
1 meter=1.1 yards.
1 mile=1.6 kilometers.
1 kilometer=0.62 mile.

A good way to familiarize one's self with the metric system is to construct geometrical figures, such as circles, squares, etc., of known dimensions in inches and then change the dimensions to centimeters. Another way is to measure with a meter stick ordinary objects in a room, such as desks, chairs, tables, etc. It is often useful also to pace off a distance previously measured in meters.

The following examples are given for practice on scales with English and metric systems:

Examples.

(1) If a map is made on a scale of 6 inches to the mile, give the R. F. of the map.

(2) Construct a graphical scale of miles for a map whose R. F. is 1/200,000.

(3) The distance between two towers on the map is 10 inches. If the R. F. of the map is 1/200,000, what is the actual distance in kilometers on the ground?

(4) Two points on the ground are 10.5 kilometers apart. What is the distance between them in inches on a map whose R. F. is 1/100,000?

(5) Two points are 6 inches apart on a map whose R. F. is 1/40,000. Give the distance on the ground in miles.

(6) (*a*) The scale of a map is 3 inches to the mile. Give its R. F. (*b*) To what French map does it correspond?

(7) The distance between two trees is measured and found to be 500 yards; on the map they show to be 2 inches apart. What is the R. F. of the map?

(8) If two points are 6.7 inches apart on a map whose R. F. is 1/100,000, find the distance in miles (kilometers).

(9) The scale of the map is 1/20,000. 2.7 inches on that map equal how many miles on the ground?

(10) Express the scale 1/10,000 graphically in terms of yards.

(11) A map is 48 inches square. If the R. F. is 1/200,000, what is the area of the country represented in square miles?

(12) Traveling at the rate of 150 m. p. h. ground speed, what would be the map distance in inches for a 20-minute flight given a 10-minute time scale and a 1/200,000 map?

(13) Traveling at the rate of 120 m. p. h. ground speed, what would be the map distance in inches for a 20-minute flight and a 1/200,000 map?

(14) Two points on the ground are 10 kilometers apart. Find the distance in inches on a 1/200,000 map.

CONVENTIONAL SIGNS.

Conventional signs should fulfill two requirements: (1) They should be as simple as possible; (2) they should suggest the objects represented.

The number of these signs in use is large; a few of the most important ones appearing on military maps are presented here. Practice with the map should be given until the student is perfectly familiar with them.

Standard abbreviations of letters or groups of letters are often used in connection with conventional signs. No attempt will be made to present these here, as the student will soon be accustomed to those in use upon the maps with which he is working.

It should be remembered that the list of conventional signs given below is general, and that any particular map must be studied carefully with a view to the signs which appear on that map.

CONTOURS.

The earth looks quite flat to an aviator at any considerable distance above it. He is unable to tell whether it is sloping up or down or whether he is passing over a hill or a valley or level country. For this reason the contour lines on his map are of special value.

Contours are lines obtained by cutting the earth's surface by horizontal planes at certain distances from each other. These distances are taken at convenience. The contours are marked on the map to show their distances above a certain plane of reference (datum) usually taken as mean sea level. A system of contours may be illustrated by considering an island in the center of a body of water. (See figs. 3 and 4.) The shore line is a contour. Imagine the surface of the water to be raised a distance of 10 feet. The shore line thus formed is a contour whose elevation is 10 feet above the first. Successive contours representing equal increases in elevation can be secured in a similar manner. These contours when projected upon a single plane represent a contour map. (See figs. 5 and 6.) The vertical distance between the successive elevations is known as the contour or vertical interval (abbreviated to V. I.). The distance measured on the map between two successive contours is called the map distance.

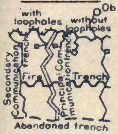
CONVENTIONAL SIGNS
BRITISH

- Any trench organized for fire
- Approximate line, reported by observers and not yet confirmed by photographs
- Wire entanglements
- Ground cut up by artillery fire
- Enemy tracks
- Buried pipe line or cable
- Air line
- Supply depot
- Observation post
- Dugout
- Earthwork
- or M.G. — Machine gun emplacement
- or T.M. — Trench mortar emplacement
- L or L.P. — Listening post
- Mine crater, unfortified
- Mine crater, fortified
- Organized shell holes
- Anti-aircraft gun
- Hutments
- Aerodrome
- Airship shed
- Balloon
- Barge
- F — Fire
- Railhead
- Mechanical transport, moving
- Mechanical transport, stationary
- Horse transport, moving
- Horse transport, stationary

- Infantry, moving in column of route
- Cavalry, moving in column of route
- Artillery, moving in column of route
- Post
- Patrol
- Holding line in action
- Gun emplacements
- 3 — Battery of guns, inactive
- Single guns, inactive
- Battery of howitzers, active
- Single howitzers, active
- Doubtful battery, active
- Doubtful guns or howitzers, active
- Hedge, fence, or ditch
- 5'W 6'D — Ditch, permanent water
- Woods
- Orchard
- Brushwood or undergrowth
- Faults in chalk country
- Embankment
- Cutting
- Church
- Wind mill
- Water mill
- Houses, standing
- Houses, ruined
- Fenced / Unfenced — Roads, 1st class
- Roads, 2d class
- Roads, 3d class
- Railways, double
- Sta — Railways, single
- Narrow gage railway
- Trench railway
- Ferry — Ferry
- Railway over river
- Marsh

CONVENTIONAL SIGNS
FRENCH

German



Trenches

Trenches, from report
Trenches, abandoned

1 to 4 pieces
Isolated strong point
Batteries

Anti-aircraft gun

Camps
Park
Camps, Wagon parks
Munition depots

Works

X X X X X X Wire entanglements

Abatis

Shelters

Screened gun pits

O Ob. ▭ P.C. Observation, post commanders

Shell or mine craters

M B Machine guns, bombthrowers

C.R. Revolving cannon

Standard gage, R. R.

Narrow gage, R. R.

French

Advanced line

Infantry

Cavalry squadron

Cavalry regiment

Field battery, occupied

Field battery, prepared

Aero squadron

Aero park

Balloon

Automobile service

National road

Departmental road

Road passable in dry weather

Dirt road

Path, cleared line

Standard gage single track R.R.

Standard gage double track R. R.

Narrow gage R. R.

Bridge
Foot bridge
Large stream

Ford
Small stream

Fort
Lock
Towpath
Canal

Pond

Spring

Well

Deep Water
Inundated land

Wall

Hedge

Wooden fence,

Iron wire fence

Ditch

Earth embankment or fill

Ruins
Houses
Village

Steeple

Wayside cross

Chapel

Cemetery

Wind mill

Water mill

Smokestack

Vines

Gardens and orchards

Woods

Fir or pine thicket

Brush

Isolated trees

Marsh or swamp

166
Contours and elevations

Sand dunes

Quarry

Steep slopes

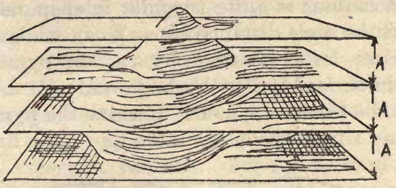


FIG. 3.

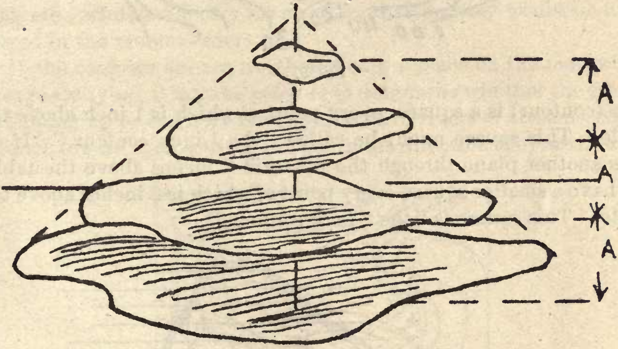


FIG. 4.

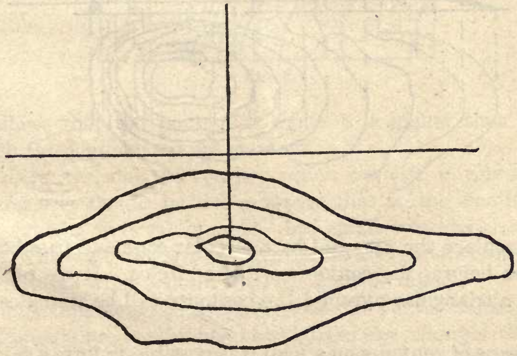


FIG. 5.

In general, a contour is quite irregular in shape although every point of it is at the same distance above mean sea level. To make the matter clearer, let us illustrate by a square pyramid placed on a table. Let the surface of the table be the datum. Let the vertical interval, V. I., be taken as 1 inch. Imagine the pyramid cut by a horizontal plane 1 inch above the table top. The line of intersec-

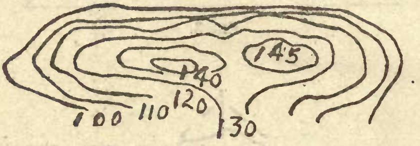


FIG. 6.

tion (contour) is a square, every point of which is 1 inch above the table. This square might be called "the 1-inch contour." If we pass another plane through the pyramid 2 inches above the table, we have a smaller square every point of which is 2 inches above the table. This square is "the 2-inch contour."

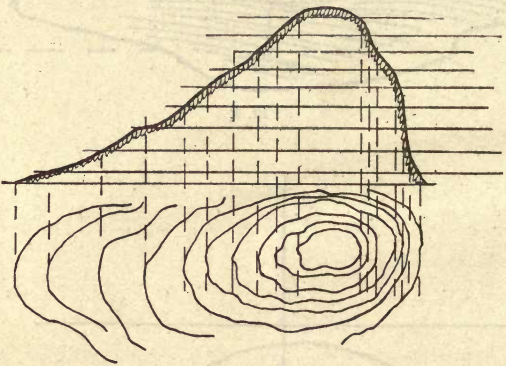


FIG. 7.

If we replace the pyramid by a circular cone and pass horizontal planes as before, the contours will be circles. If we replace the cone by a triangular pyramid the contours will be triangles, and so on.

By means of contours on a map it is possible to form a fair idea of the general appearance of ground we have never seen. For example, we can tell that one object must be higher than another because it is on a higher contour. We can tell that a slope is steep because the contours are close together, or that it is gentle because the contours are far apart, or that there is very little change in elevation on the ground because the contours are not a prominent feature of the map.

So far we have been considering elevations. Contours serve equally well to show depressions. For a downward slope proceeding in a certain direction the elevation of the contours becomes less and less as we go along. For example, if the vertical interval is 10 meters, the contours along the slope might be numbered 150, 140, 130, etc., while evidently for an upward slope they would be numbered in the reverse order.

If the contours are not numbered at the place on the map which we are studying, it may be possible to determine whether the ground is sloping up or down by the appearance of rivers or streams, which branch toward their sources and not in the direction they are flowing.

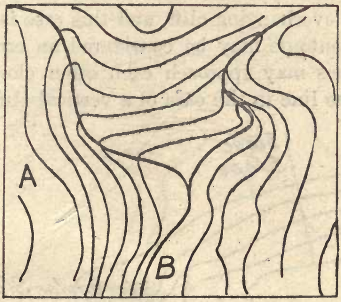


FIG. 8.

It follows that the point A in figure 8 is higher than point B, although the contours are not marked.

The more irregular the country which we wish to represent, the closer together should be the contours; that is, the smaller should be the contour interval in order that small irregularities may be shown. The scale and size of the map are also factors of importance in determining what contour interval shall be taken.

The following facts about contours should be well noted:

(1) Contours are continuous closed lines (for example the circles, squares, and triangles referred to above). If a contour does not close upon itself within the limits of the map, it means that the map is not large enough to show the entire contour.

(2) All points on a contour are at the same elevation, because the contour lies in a horizontal plane.

(3) Contour lines do not branch. A branch or spur projecting from a contour would indicate a ridge the top of which is an absolutely level "knife-edge." This, of course, is never found in nature.

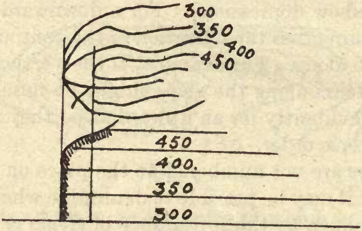


FIG. 9.

(4) Contours of different elevations do not cross each other except in the case of an overhanging cliff, and this case is so rare that any case of crossed contours may be considered an error. Contours at different elevations may approach each other closely, and in fact may appear as one line in the case of a vertical cliff.

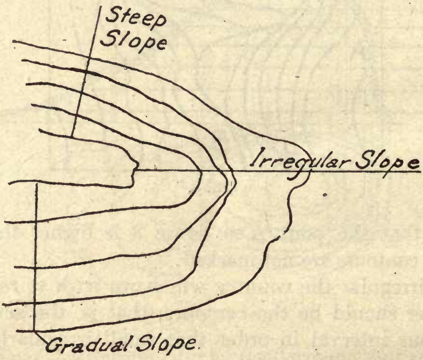


FIG. 10.

(5) When the contour interval is constant (as it is on most maps) the spacing of the contour lines indicates the degree of the slope; that is, the nearer together the contours, the steeper the slope; the farther apart, the gentler the slope; if the contour lines are equally distant the slope is regular.

(6) Contours are usually drawn as brown lines.

(7) Dotted contours are sometimes inserted at odd elevations to show special features of the country; for instance, a 33-foot contour dotted might be inserted between the 30-foot and the 40-foot contour.

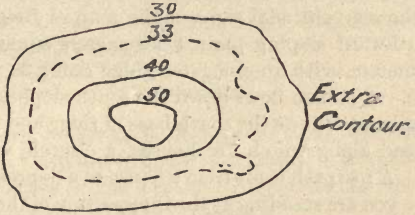


FIG. 11.

(8) It is customary to break contours when crossing roads, railroads, etc., continuing them on the other side.

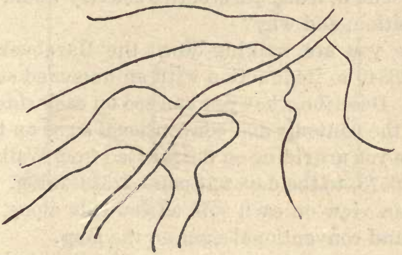


FIG. 12.

Examples.

The following examples are given to illustrate the principles of conventional signs and contours:

(1) Illustrate by means of 10-foot contours: (*a*) A hill of 75 feet elevation, rising for the first 30 feet gradually and being very steep for the last 45 feet; (*b*) a hill of the same elevation rising steeply for the first 30 feet, gently the last 45 feet; indicate a stream on the last hill.

(2) Would you expect to find a small contour interval or a large contour interval on a map of a very rugged country? Give your reasons.

(3) Represent the following by contour sketches: Valley, hill, depression, ridge, steep slope, flat slope, gorge.

(4) Make a sketch showing two streams joining, a ridge between the streams and rising from them, steep ground on one side, gently sloping ground on the other.

(5) Using the conventional signs of the map of Belgium, draw a map of a southward sloping plain 5 kilometers square, maximum elevation 20 meters, with an elongated ridge rising 30 meters above its north edge. A stream flows down the south slope to the sea. A single-track railroad follows the south base of ridge and crosses under a first-class road along which are houses, a church, windmill, and several trees. A footpath leads from a house to a depression near by.

(6) Imagine you are standing at the intersection of the roads shown at point 21395–29410, map of Belgium. Describe briefly the topography of the surrounding country within a circle of radius 2 kilometers with your position as the center, the description to be based upon the contours and conventional signs shown within the territory mentioned. Which, if any parts of this country would not be visible from your position, and why?

(7) Imagine you are walking down the Hazebeek stream from point 21350–28840 to its junction with an unnamed stream at point 21522–29130. Describe what you can see on each side as you walk, judging from the contours and conventional signs on the map.

(8) Imagine you are riding on the railroad from Walkrantz station, point 22285–29575, to the depot at point 22323–29160. Describe the country within view on each side as you ride along, judging from the contours and conventional signs on the map.

(9) Imagine you are flying in a straight line from the town of Dickebusch to the town of Elverdinghe. Describe the country over which you fly, judging from the conventional signs and contours as shown on the map.

LOCATION OF POINTS.

It is not only in long flights that accurate navigation is necessary. Short flights often require special precision because of the nature of the objective. A machine-gun emplacement or an ammunition dump carefully camouflaged is invisible from the air unless the aviator knows in advance exactly where to look for it. This precise knowledge is furnished him on maps drawn to a larger scale than those used for cross-country flights, bombing raids, and the like.

But no matter what map is used the principle of locating a point is the same. It consists of inclosing the point first, within a large square designated by a number or a letter; then (British system) within a smaller square inclosed by the first, and so on. Finally there comes a time when this method of inclosure within squares has been carried as far as it is practical. The British use three inclosing squares; the French only one.

Coordinates.

The last square, however, be it large or small, represents an area and not a point. A point is fixed by its relation to the western and southern boundaries of the square. Perpendicular distances from these boundaries will fix the point exactly.

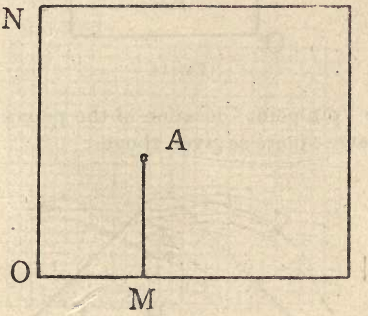


Fig. 13.

Suppose, for example, that the square given in the figure is 10 units on a side and that ON gives the direction of north. The point A is 3 units to the east of the western boundary and 5 units to the north of the southern boundary. These distances are called the coordinates of the point A.

Instead of fixing the position of the point by distances from the boundaries, we may fix it by distances *along* the boundaries measured from the southwest corner of the square as a point of reference. For example, the point A might be fixed by (1) the distance along the southern boundary from O to a point M directly south of A (in this case 3 units), and (2) the distance from M to A (equal to the distance along the western boundary from O to a point directly west of A, in this case 5 units).

When stating these distances it has become conventional to state *first* the distance along the southern boundary (*from* the western boundary) and to state *second* the distance along the western boundary (from the southern boundary), just as in geometry we always state the x coordinate first and the y coordinate second when locating a point.

Exercises.

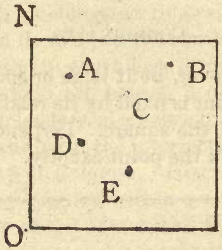


FIG. 14.

(1) Give the "pin-point" location of the points A, B, C, D, E, assuming the same square as given above.

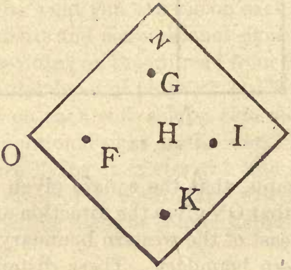


FIG. 15.

(2) Without changing the position of the page "pin-point" F, G, H, I, K.

(3) Drawing a certain square and taking points O and N as above, locate the points whose coordinates are 5–5, 3–3, 0–0, 6–4, 9–2, 1–9.

It is conventional never to use the coordinate 10 because a perpendicular distance of 10 from the boundary of one square carries us to the boundary of another square. For example, the northeast corner of a given square would not be located as 10–10 with reference to that square, but as 0–0 with reference to an adjacent square lying northeast of the first.

BRITISH MAPS.

Let us take the ordnance map of Belgium, 1/20,000 as an example of British maps. This map, which is part of a system of maps, represents a section 13,500 yards in width by 11,000 yards in height. For convenience in locating points the maps in the system are divided into a series of squares, the first row being lettered A, B, C, D, E, F; the second row being lettered G, H, I, J, K, L, with G under A, H under B, etc. On this map only the squares A, B, G, H are found. On the adjoining map to the east we should find square C matching up with B and I with H.

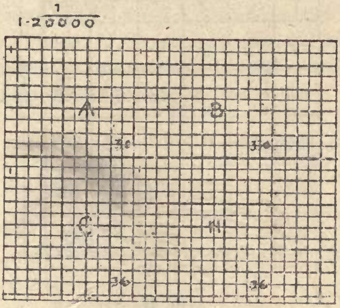


FIG. 16.

Each lettered square is subdivided into 30 or 36 smaller squares. Always there are six squares from west to east and five or six squares from north to south.[1] The large squares lettered A, B, C, etc., are 6,000 yards wide and 5,000 or 6,000 yards high. The smaller squares which make up the large squares are numbered from 1 to 30 or 36 (fig. 17). Each small square is 1,000 yards in width and in height. These numbered squares are divided into four minor squares whose sides measure 500 yards. These minor squares are considered as lettered a, b, c, d, but only squares numbered 6 are actually so lettered, to avoid unnecessary confusion on the map.

[1] In converting the French and Belgian maps, laid out according to the metric measurements, to the English system of map squaring in yards, etc., the grid lines do not coincide, and this discrepancy in the English map is compensated for by making some lettered squares contain 30 squares and others 36.

To locate a point within a small square, consider the sides divided into 10 parts (fig. 18) and define the point by taking so many tenths from west to east along the southern side first, and then so many tenths from south to north, the southwest corner always being taken as the origin. If square c belongs to square 14 in big lettered square H (fig. 18), then the designated points would be located as follows

J at H14c60.
K at H14d05.
L at H14c05.
N at H14c00.
R at H14c67.

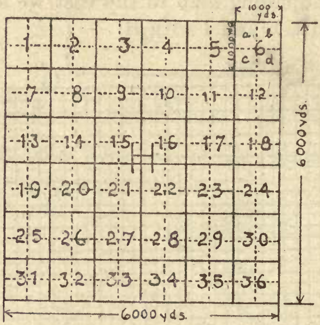


FIG. 17.

It will be noted that a point is not designated as 10, since 10 is the 0 of the next square. If a point is on the upper horizontal line of the square, it is zero of the square above, and if the point occurs on the right line of the square it is zero of the square to the right. Thus the point Z would be located as H14a40, Q would be H14b00, and K would be H14d05. Since each small square represents 500 yards, more accurate locations may sometimes be desired, and in such cases the sides of the small lettered squares may, in imagination, be divided into 100 parts instead of 10 parts. This would necessitate the use of four figures instead of two as before. Thus point G would be located at H14c3565 and X would be located at H14c0847, denoting 08 parts east and 47 parts north of origin. Use 0, but not 10; use either two or four figures, but do not use fractions, as $8\frac{1}{2}$, $4\frac{1}{4}$, etc.

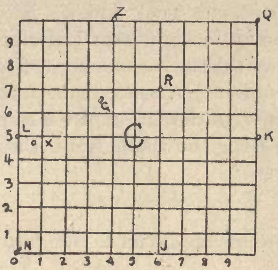


FIG. 18.

FRENCH MAPS.

The method of locating a point on a French military map is by reference to grid lines, which are 1 kilometer apart each way. These lines are approximately N.–S. and E.–W., though not exactly so. They are designated by numbers reading from west to east and from south to north, as in the following figure.

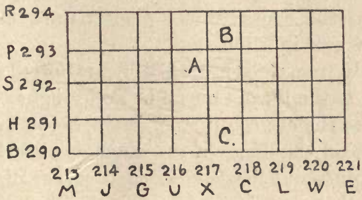


FIG. 19.

Assuming each of these squares divided into 10 spaces from west to east and 10 spaces from south to north, the point A, figure 19, would be designated as 2165–2925, point B as 2173–2931, and point C as 2178–2904.

Under certain circumstances there is no confusion caused by dropping the first two figures, making the location of point A read 65–25, point B 73–31, and point C 78–04. It must be remembered, however, if the first two numerals are dropped, that every 10 kilometers north, south, east, and west, there will be points designated by the same numbers. Whenever there is danger of confusion three figures are used, as 165–925.

In actual work on the front the lines of the grid are given letter designations, which may be changed from week to week. Point A might be called U5–S5 one week and Q5–K5 the following week. In this way the enemy is kept from knowing the zone to which wireless messages may refer. Various keys of letters are in use, and from time to time orders are issued substituting one for another. In using this letter system repetition of the same letter would occur every 25 kilometers along the whole front (the number of letters in the French alphabet).

Exercises.

The following exercises are given to illustrate the practical use of compass and map:

Example 1: Fly from the church in Elverdinghe to the church in Boesinghe, to the church in Brielen, and back to the starting point. Make a diagram of the course, giving the magnetic bearings and the names of the places with the pin-point location under them. Let an arrow indicate the direction of each flight.

Example 2: Fly from the church in Ypres to the church in Voormezeele, to the church in Dickebusch, to the church in Vlamertinghe, and back to starting point. This will make a four-sided diagram. State the magnetic bearing of each line, give the pin-point location of the corners of the course under their names, and estimate the length of each course in kilometers.

Example 3: Fly from Goed Moet Mill near Ouderdom to the church in Reninghelst, to the lower church in Poperinghe, to the crossroads in Busseboom, to the church in Vlamertinghe, and back to starting point. Indicate on the diagram the magnetic bearing of each line, the name and pin-point location of each corner of the course, and the length of each course in kilometers.

Example 4: From your aerodrome at 2175–2885 course 45° (mag. bearing) fly to a point 4.5 kilometers away. Give pin-point of the end of the course.

Example 5: From your aerodrome at 2175–2885 fly 3.5 kilometers course 60° (mag. bearing), then 4 kilometers course 300°, then back to starting point. What is the length and magnetic bearing of the last course? Pin-point the other two corners of the course.

Example 6: From church in Reninghelst course 10° 33′ fly for a distance of 3.5 kilometers and from there fly to church in Vlamertinghe. From that point fly back to starting point. Make diagram showing all magnetic bearings, pin-point corners of course to five places, let arrows indicate direction of flight, and give distance in kilometers from corner to corner of course.

O