

MAP READING

NOTES AND EXERCISES

This section is made up of facts and definitions, with explanations sufficient for a good grounding in the subject. The Manual of Military Map Reading issued by the War Office should be available for reference, and of course, copies of the maps should be in the hands of the pupils, preferably maps of their own locality. With this in mind many of the exercise problems have been purposely made suggestive rather than definite, so that they may be fitted to any locality or map.

The order of treatment differs somewhat from that of the course of study, but will be found to be a logical sequence for teaching purposes.

PART I

MILITARY MAP READING

1. **Scales.** The scale to which a map is drawn is expressed either in words (so many inches to the mile, or centimetres per kilometre), or by a fraction known as the Representative Fraction or R.F. This fraction always has a numerator 1 (one inch) and a denominator showing the number of inches on the ground actually represented by one inch on the map. Instead of the fraction this may be expressed at a ratio (E.g. $\frac{1}{100,000}$ or 1:100,000).

Common scales for Canadian military maps are:— 1:63,360 or one inch per mile; 1:31,680 or two inches per mile; 1:25,000 or approximately $2\frac{1}{2}$ inches per mile. Maps of smaller scale than these, that is, maps showing more miles per inch, are sometimes useful for long distance operations, but cannot show much detail. The larger the scale of the map the greater the amount of information it can provide. For aerial navigation the maps used are of relatively small scale, four miles per inch and eight miles per inch, and the amount of detail shown is less than in the military maps.

In addition to these statements of scale, the map usually carries at the bottom a printed line scale showing miles and tenths of miles as well as yards in thousands and hundreds. If this should be missing from the map it can be found on a military protractor which carries line scales corresponding to nearly all map scales, or a line scale can be constructed.

2. **Constructing a scale.** Where the scale or R.F. of a map is known, but no line scale is provided, a simple calculation and a familiar geometrical construction will produce the scale. Suppose it is required to draw a line scale for a 1:25,000 map to show miles and tenths. One mile is represented by $\frac{1}{25,000}$ mile or $\frac{1}{25,000}$ of 63,360 inches which is 2.53 inches. A line to show five miles would be 12.65 inches long. Draw this line and use the construction which enables you to divide a given straight line into any number of equal parts, to divide it into five. Use the same construction if necessary to divide one section into tenths.

Exercise

1. Construct a line scale for a two inch per mile map, showing miles and tenths.
2. Construct a line scale in thousands and hundreds of yards for a 1:10,000 map.

3. **Conversion.** It may sometimes be necessary to use maps which have the scale expressed in units of the Metric system. The following conversion factors are valuable.

1 metre=39.37 inches.

1 kilometre=39370 inches= $\frac{39370}{63360}$ miles=.6212 miles.

For an approximation 8Km=5 miles.

The R.F. may also be used in making the conversion. A scale of 1 cm. per Km. is 1/100,000. On the protractor, this scale can be found with values in yards or miles. Or, by calculation 1 inch in 100,000 inches is 1 inch in $\frac{100,000}{63360}$ miles or 1 inch in 1.58 miles.

4. **Measuring distances.** Distances between two points on a map may be measured with a ruler, but can be found

with greater accuracy using the dividers found in a set of geometry instruments. Set the dividers with one leg on each of the points. Then move the dividers without alteration to the line scale at the bottom of the map (or

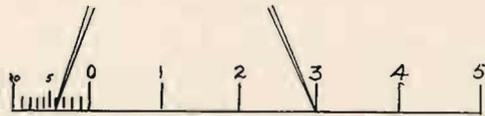


Fig. 1.

the appropriate scale on the military protractor). The zero point on the scale may be used at first to get an approximate value. Then set the right leg of the divider on the nearest whole number of miles and read the fraction shown by the left leg. Note that the fractions are numbered *left* from the zero point, so that the reading above is 3.4 miles.

Exercise

1. Select a number of pairs of points on the map and measure distances in miles (to the nearest tenth) and in yards.
2. Measure the distance between the main crossroads of two villages on your map.
3. Select two villages which are not on the same straight road. Measure the distance between them (a) by airline, (b) by several different roads, (c) by a cross-country route if a certain bridge must be used to cross a river. Compare the results.
4. Devise a method of measuring the length of a section of a winding river or road or shoreline.
5. Convert the answer to question 2, to kilometres.

5. **Bearings.** "A bearing is the angle, measured clockwise, from a certain fixed line to any line in question." Directions on a map or on the ground could be measured

by compass directions such as N.E., S.S.W., or S.E. by E., but for military purposes directions are always expressed as bearings.

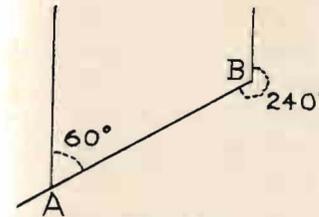


Fig. 2.

From A the bearing of B is 60° .* From B the bearing of A is 240° . (This latter is sometimes called the back-bearing. Note that the back-bearing is always the bearing angle $+ 180^\circ$).

The bearing angle may be any number from 0 to 360 and is always measured *clockwise*, from a fixed line which may be either true north, magnetic north or grid north.

1. True north is the geographical north, that is the direction of the north pole. Because the earth is a sphere, true north lines through different places are not parallel. If the degrees of longitude are given on the top and bottom margins these might be used to give true north lines at intervals across the map.

2. Magnetic north is the direction in which an accurate compass points. The difference between true and magnetic north for some point on the map is usually stated in the margin. This value is not exactly the same all across the map but the differences are slight. It

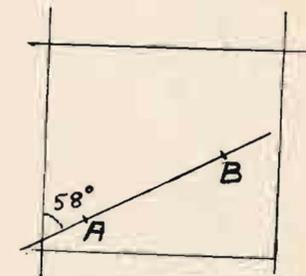


Fig. 3.

*In connection with flying, bearings are always expressed by three digits. 2° or 60° would be stated 002° or 060° .

should also be noted that this difference between magnetic and true north which is called the variation, changes from time to time as the magnetic pole alters its position.

3. Grid north is the direction of lines drawn on gridded maps forming the sides of 1,000 yard squares. The differences between grid north and true and magnetic north are indicated in the margin of the map.

Since there are grid lines everywhere on the map it is usually easier to measure the grid bearings than the others. In finding the grid bearing between points A and B join the two points with a fine pencil line and produce the line to cut a N-S grid line. Measure the angle clockwise from the grid line to the bearing line. As before, if the bearing of B from A is being measured, it is read directly from the protractor. The bearing of A from B is the back bearing of this, i.e. $58^\circ + 180^\circ = 238^\circ$.

6. **Conversion of bearings.** Both magnetic north and grid north may be east or west of true north, and care and practice are necessary in changing one bearing to another.

To convert grid to true or magnetic bearing or for any other conversion a rough sketch of the relative positions of the three norths should be made as in Fig. 4. This sketch will help in changing from one to another and in indicating

whether the correction must be added or subtracted. For example in Figure 4 if the grid bearing of B from A is 58° then the true bearing is 60° and the magnetic bearing is 69° . If the magnetic bearing had been given it would

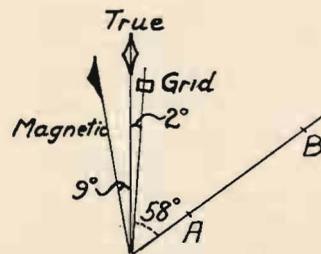


Fig. 4.

have been necessary to subtract 9° and 11° respectively to find the true and grid bearings.

Exercise

- If grid north is 19° E. of true north and the magnetic variation is 11° W.
 - Find the angle between grid and magnetic north.
 - If a grid bearing is 170° what is the true bearing and what is the magnetic bearing?
 - If the compass bearing between two points A and B is 272° what is the grid bearing?

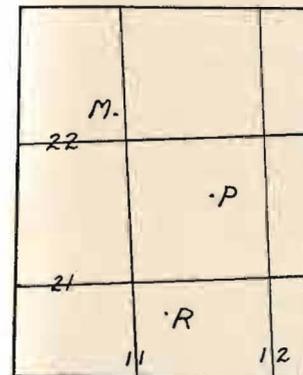


Fig. 5.

2. In Figure 5 the squares are grid lines and the right margin is true north. The magnetic variation for the area is 9° W.

- Find the angle between grid and magnetic north and the angle between grid and true north.
 - Find the grid bearings of R from M, P from M and P from R.
 - Convert these grid bearings to true and compass bearings.
- Select two points on a gridded map. Suppose you have to march by night across country between these points with only a compass to guide you. On what compass bearing would you have to travel? What compass bearing would you use for the return journey?
 - On a gridded map practice finding grid bearings of various landmarks from a fixed point. Convert these bearings to magnetic and true bearings using the information supplied on the map.
 - Use of the compass to find a bearing.** The compass commonly used for this purpose is the army prismatic type but any good compass that has a disc marked with

degrees 0-360 and a mirror or other arrangement for reading the figure on the disc simultaneously with alignment of a distant object, may be used. The compass may be held in the hand or placed on a level support. Sighting through a notch and a vertical hairline, the compass is moved till the object whose bearing is required comes into alignment. The compass card is allowed to come to rest (there is usually an arrangement for damping the swing) and the bearing angle is read through the reflecting prism or mirror.

Exercise

1. Practice taking bearing of distant landmarks. Check the accuracy of these by drawing on the map lines connecting your position with the object and measure the angles with a protractor, working from a magnetic north line.
2. Work out a method of using your compass to plan a cross country march toward a place not directly visible.
3. Work out a method of using your compass to march at night on a given bearing.

8. Setting a map. There are two common ways of setting a map; by compass and by landmarks. A map is set when it is laid out so that the true north direction on the map corresponds to actual true north.

(a) Setting by distant objects. Fasten the map of your locality to a board and place it on a level support (the top of a fence post will serve) at or below eye level. Stick two pins in the map, one at your position and the other at the location of some distant visible object. Turn the map until the pins are in line with the distant object and the map is set.

(b) Setting by compass. Lay out the map as before on a level support and place the compass on the magnetic north line of the map, or a line drawn to represent it

from the data given as to true north and magnetic variation. The map and compass are rotated until the needle coincides with the line.

Exercise

1. When a map has been set in either of these ways, use it to locate the direction across country of places not directly visible from your position. A pin at your location and another at the position of the unseen object, will fix the direction of the object across country.

9. Resection. This is the problem of determining the observer's position on a map from two bearings of distant objects which can be identified on the map. It is useful in the air as well as on the ground. Compass bearings are taken of the landmarks and the bearing lines plotted on the map from these points. The intersection of the bearing lines locates the observer.

Exercise

1. In Figure 5 an observer sees a church tower at M on a grid bearing of 35° and a water tank at P on a grid bearing of 82° . Find the position of the observer.
2. In Figure 5 an observer sees P on a compass bearing 347° and R on a compass bearing 303° . Locate this observer.

10. Map references. For convenience in locating and referring to a point on a map, military maps are marked off in numbered squares or grids. One system commonly used in Canada is called the Modified British Grid. The following points should be noted:—

1. Whether on the one inch per mile or the 1:25,000 maps the squares measure 1,000 yards to a side.
2. The squares are numbered from the lower left corner, towards the east and toward the north.

3. In referring to a square its *easterly* number is given first, then its northerly. The combined number is called a map reference. In the block shown in Figure 6 the

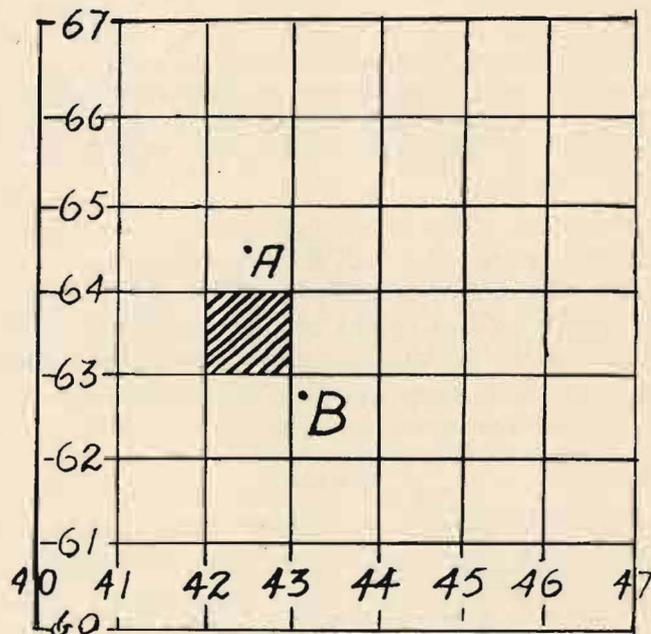


Fig. 6.

lower left square would be referred to as 4060; the shaded square as 4263. Such a map reference locates a point within a 1,000 yard square.

4. For more exact reference the square may be considered as broken up into tenths in each direction. These fractions are included in the reference. For example point A in the center of square 4264 would be referred to as 425,625, point B as 431628. The rule here, as before is that the first *half* of the number refers to direction

east, the second half to direction north. Such a reference locates a point within 100 yards.

5. For convenience in measuring these fractions a device known as a Romer card is useful. The top right hand corner of the card is placed on the point to be found.

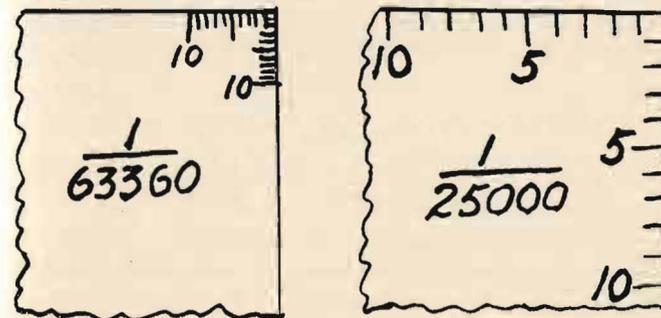


Fig. 7. Romer Cards.

The edges of the card are parallel with the grid, and the numbers on the top and side of the card opposite the grid lines, supply the 3rd and 6th digits of the map reference.

Other systems of coordinates may be met with, but the principles involved can be easily and quickly mastered if the fundamental ideas above are understood. The Air Force and the Navy have their own systems of references.

Exercise

1. Write grid references for a number of squares on your map. (four figures).
2. What is the grid reference for a town, a lake or other considerable area on your map. (four figures).
3. Construct Romer cards for one inch per mile grid and 1:25,000 grid.
4. Find map references for a number of points (bridges, water tanks, road intersections, churches). (six figures).
5. Make up some six figure references and locate them on the map.

11. **Conventional signs.** The one inch per mile maps show in the margin a table of the conventional signs used to represent various features on the map. These are most important since their use enables a great deal of important information to be included in a limited space. Make a careful study of this table and learn the signs because while similar signs are used on all topographical maps, they are not always tabulated for you on every map.

Exercise

1. Locate examples of as many conventional signs as you can find on your map. Check them off on the table.
2. Analyze the detail shown on the map for a certain village. Locate, from the main intersection, the post office, water tank, hotel, railway station, fairgrounds, etc. How many mills, churches, cemeteries? How many blocks of paved streets? How many routes out of the village toward the west?

12. **Altitudes.** There are a number of ways in which altitudes are indicated on military maps. In all cases the figures refer to elevation in feet above mean sea level.

1. *Spot heights.* A dot and a number alongside it (.728) indicates the elevation of a point such as a road intersection.

2. *Bench marks.* A symbol such as (B.M. ↑ 653.2) is often placed near railway bridges or other permanent structures shown on the map. Surveyors use them as starting points for a survey line, and the same symbols are to be found cut into the foundations of the structures referred to. On the map the point of the broad arrow usually points to the location of the mark.

3. *Water levels.* An isolated figure in a water area of

the map gives its elevation (Lake Ontario 245'). Since lake levels are variable this is the mean elevation above sea level. This figure should not be confused with the continuous lines and figures which are depth contours in fathoms.

4. *Contour lines.* These are lines drawn on the map through places having the same elevation. The lines are broken at intervals by a figure showing the elevation represented. The difference in level between adjacent contours is the contour interval or vertical interval, and may be either 20 or 25 feet. Contours for every 100 feet are usually heavier or of a different colour.

5. *Colours.* On aerial navigation maps, altitudes are shown by colours and shades, as well as by contours and spot heights.

13. **Contours.** Suppose that an island was elevated in the ocean by a succession of earthquake shocks; that each

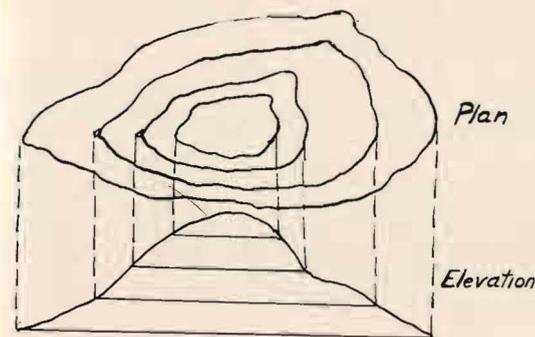


Fig. 8.

shock pushed the whole island up exactly 25 feet; and that there was sufficient time between shocks for the

waves to leave the marks of a shore line. These lines would encircle the island and each would be exactly 25 feet higher than the next. Looked at horizontally from a distance (i.e. in elevation) the lines would appear parallel and equidistant. Looked at from an aeroplane (i.e. in plan) they would appear as concentric rings, and would actually be 25-foot contour lines. In drawing the contours on a map the lines have to be drawn from the results of careful survey. The ability to interpret contours and visualize the country represented is one of the most essential features of map reading.

In studying contours the following characters of slopes should be noted:

Kind of slope	Arrangement of contour lines.
Even	Equidistant.
Gentle	Far apart.
Steep	Close together.
Vertical	Lines coinciding, or shown by hatching.
Concave	Higher contour lines closer together.
Convex	Lower " " "
Stepped	Lines alternately close and distant.
Level areas	Areas without lines or far apart.

It should be noted, however, that an area without contours is not necessarily absolutely flat. There may be ridges, depressions, sand dunes, etc., of less height or depth than the contour interval.

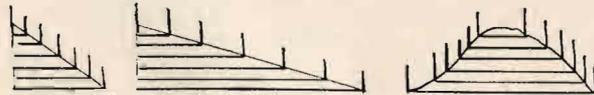


Fig. 9.

Exercise

1. Find on the map examples of as many types of slopes as you can. Where is the steepest slope?
2. Find the most suitable area for a landing field for planes. What is its extent?
3. What is the general direction of slope of the area of your map? Where is the highest point?

14. **Gradients.** The gradient or slope of the ground may be expressed in several ways:—as a ratio, (e.g. a slope of 1 in 50); as a percent (a 5% slope); in degrees; or, for longer slopes, in feet per mile.

Two terms used in this connection need explanation. The Vertical Interval (V.I.) is the difference in height represented by two adjacent contours. The Horizontal Equivalent (H.E.) is the length of the base of the triangle which represents the distance *in plan* or on the map between two contours, not the actual distance on the ground. In considering slopes not steeper than those found in ordinary roads, the difference between the H. E. and the ground measurement can be disregarded.

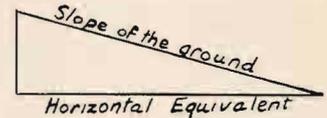


Fig. 10.

To measure a slope where the contour interval is 25 feet, measure with dividers the distance between two contours; find this distance on the line scale in yards; and change the yards to feet. This is the H.E. Suppose it is 600 feet.

The gradient is 25 feet in 600, or 1 in 24.

The gradient is $\frac{25}{600} \times 100\%$ or 4.25%.

The gradient is the angle whose tan is 1/24 or about 3°.

To measure a longer slope of fairly uniform character, greater accuracy can probably be ensured by measuring the full length of the slope, and counting the number of contour intervals. The vertical distance in figure 11 is

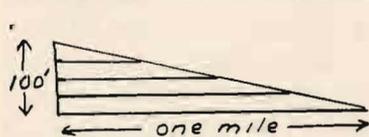


Fig. 11.

$4 \times 25 = 100$ feet. The horizontal distance is one mile or 5,280 feet. The gradient is 100 in 5,280 or 1 in 52.8. (Note that in both figures 10 and 11

the actual angle of slope is not represented since the vertical scale is exaggerated).

The following values are useful in interpreting gradients.

Distance between 25 ft. contours (1 in. per mile).	Approx. Gradient	Significance
1.0 inch	1 in 200	Gentle road gradient
.25 inch	1 in 50	Steep railway gradient
.05 inch	1 in 10	Too steep for bicycle riding
.025 inch	1 in 5	Limit for loaded car, low gear
.01 inch	1 in 2	Hand holds in climbing

Exercise

1. Find the road with the steepest gradient on your map. Determine its gradient. Find the longest stretch of nearly level road.
2. You are to travel along a certain road between two villages. What is the elevation at the start? What elevation at the end? What and where is the greatest elevation reached? Where is the steepest hill? Estimate its gradient. May any portion of the road be considered as nearly level?

3. Select a high point on the map. Draw a circle around it representing a two mile radius. To approach the point from this distance, select the direction in which the gradient would be least. In which direction is it greatest? Plot an indirect route in which the gradient would be most favorable.

15. **Contours and physical features.** As many as possible of the following forms should be identified on the map, and the shape of the contours noted.

(a) Elevations above the surrounding country. Hill, knoll, ridge, plateau, height of land, crest.

(b) Elevations in one direction. Cliff, escarpment or scarp, shoulder or salient or spur.

(c) Depressions due to rivers. Gully, ravine, valley, gorge, river gap, flood plain.

(d) Intervals between elevations. Col or saddle, pass, defile.

16. **Profiles or vertical sections.** A profile is a graphical

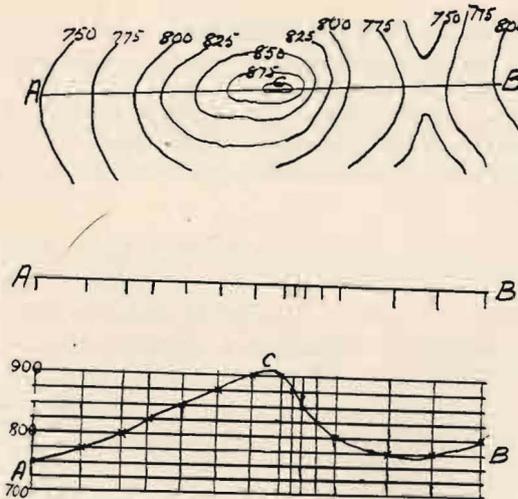


Fig. 12.

representation of the elevations between any two points on a map. It is useful in determining gradients and visibility.

To draw a profile between two points A and B, join the points with a straight pencil line. Lay the edge of a piece of paper along the line and wherever a contour line meets the paper edge, mark the point and the elevation on the paper. On a piece of graph paper arrange a vertical scale (say, one-tenth inch for 25 feet vertical interval) and mark in the required range of elevations. Plot the points on the graph paper using the paper edge to space them horizontally. Note that this profile must not be taken as actually representing a skyline or the shape of the surface, since the vertical scale is exaggerated. If the one inch-one mile map is being used the scales are respectively: vertical one-tenth inch=25 feet; horizontal, one-tenth inch=528 feet.

Exercise

1. Select a line on your map that includes a high elevation and a river valley. Plot a profile for this line.
2. Select four or five miles of straight road and plot a profile using whatever vertical scale you think best.
3. Use the profile to determine the gradient on some stretches of the road.

17. Visibility. From the military point of view it is sometimes very important to be able to determine whether an observer at one point can see another point at some distance. Drawing a profile between the two points is the surest and sometimes the only way of finding out. As far as elevations go, the profile in Figure 12 makes it plain that A is not visible from B, but B is visible from C.

With practice the question of visibility can sometimes

be determined directly from the map, without going to the trouble of drawing a profile. The following favorable and unfavorable factors, among others, must be considered.

1. Are all intervening contours lower than the two points?
2. Are the two points on concave, convex or uniform slopes?
3. Are there ridges, railway embankments, woods or other obstacles which may interfere? Note that woods may be a better screen in summer than in winter.
4. Could the observer's position be improved by moving nearer the edge of a cliff or plateau, or to right or left of his position to avoid obstacles?
5. Is visibility possible at this distance? Would this depend on atmospheric conditions or the position of the sun?
6. What is the nature of the point being observed? Water tanks, church steeples, or other lofty structures are easier to see.
7. What is the background of the object observed? Is it on a skyline or are there contrasting colours?

Exercise

1. Draw several three inch lines on your map and see if you can determine the visibility between the end points, then draw the profiles. Select interesting examples, e.g. across a broad valley or down a curving valley; from an elevated position in several directions; along a road.
2. Select an elevated spot a mile or more distant from a highway. If you were an observer at this point, what portion of the nearest two miles of the road could you keep under observation? Could you select a better position for an observation post for this purpose?

3. If a hostile observer is known to occupy a certain elevated position, C, by what route could you move on a scouting expedition from A to B with the least chance of being seen? By what route could you move from A to C to surprise the observer?
4. Ability to visualize the country represented by a map is one of the main objectives of map reading. It may help if you reverse the process and try to construct a contour map from a photograph or picture or by direct observation of your own locality.
5. The ability to make an accurate sketch of a section of country is also a useful accomplishment. The view from some elevation, with all landmarks and points of interest marked in, and distances roughly indicated should be tried. Later a sketch of what might be seen from a point on a map, using the detail of the map only, will develop the ability to visualize the map correctly.

PART II

AIR NAVIGATION

1. **Air navigation maps.** In a plane flying at 200 m.p.h. an observer using a military map of scale one inch per mile would need a map 16 feet long for one hour's straight flying. The pilot travelling at that speed would make use of only a few outstanding landmarks and much of the data of the military map would be valueless. Air navigation maps then are different in many respects from those used by the army. Some of these differences are worth noting.

(a) *Scale.* Maps of smaller scale (1:500,000) or about 8 miles per inch) are used, specially designed for air navigation. With these, flights of average length require maps of a reasonable size.

(b) *Navigational aids.* Information important in navigation is included such as latitude and longitude, true north and the magnetic variation at intervals across the map, marine and air navigation lights, radio beams with their boundaries and magnetic bearings, dangerous and prohibited areas and all types of landing areas. These involve the use of a number of conventional signs not seen on other maps.

(c) *Detail.* Landmarks which may be useful as additional aids in navigation are also included but not in great detail. Railways are shown in black, power lines in red, main roads in purple, rivers and lakes in blue. Most of these are features which are easily visible from

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considerable distances and are also distinguishable by night.

(d) *Relief*. The nature of the surface of the ground cannot be shown in detail on a small scale map, and under normal circumstances the information is not of special value. Contour lines for a V.I. of 1,000 feet, layer tinting to emphasize the various regions (lighter tints for lower elevations), and spot heights are shown. These provide the information needed to combine with altimeter readings in maintaining suitable elevation and avoiding obstacles, particularly in mountainous regions.

Four mile per inch maps with 200 feet contours and layer tinting are also used but do not show the special navigational aids mentioned above.

Exercise

Study an 8 mile/inch air navigation map and note how the features mentioned above are shown. Study the table of conventional signs and locate as many as possible.

2. **Fixing position on a map.** A pilot flying alone may have to guess his position by recognizing landmarks, but an observer not concerned with actually flying the plane can take compass bearings of distant objects (two or preferably three) as nearly simultaneously as possible. Then by the method described as Resection (Part I, Sec. 9) the position of the plane can be plotted on the map. This is sometimes referred to as a fix.

Exercise

An observer in a plane over Lake Ontario takes bearings of two marine lights, one at the entrance of Port Hope harbor, magnetic bearing 351° , and the other a lighthouse marked Peter Rock, offshore between Port Hope and Cobourg, magnetic bearing 021° . Fix the position of the plane. How far is it from shore? (Mag. Var. 10° W.)

3. **Compass deviation.** Magnetic variation has already been defined as the angle between true north and magnetic north at any point on the earth's surface, the value being stated on the face of the map. Compasses used in planes are subject to the influence of any magnetic bodies in the plane, particularly the engine and other iron or steel objects, and these influences vary with the direction the plane is heading. Compass *deviation* then is the angle between magnetic north and the direction of the compass needle, and is expressed in degrees east or west of magnetic north.

In the case of the navigating compass which is fixed to the instrument panel, a partial correction is made by placing counteracting magnets near the compass. This reduces the deviation but does not wipe it out, nor does it give it a fixed value. A table of deviations for readings from 0 to 360° must be worked out and used in reading this compass. The compass used for taking bearings, not being fixed in the plane cannot be compensated and its deviations are likely to be greater. In every case the deviation of a compass in a particular position must be known and the correction applied before a compass reading becomes a magnetic bearing.

4. **Terms used in dead reckoning navigation.** In sailship days when a vessel might travel for days without a chance to fix its position by sun or stars, the captain estimated his course and progress by dead reckoning. In doing this he had to allow for the course being steered as shown by his compass, the average speed from readings of the log line, the possible effect of any currents shown on his charts and the possibility of sideways drift for which he would use his own judgment based on wind direction and his knowledge of the vessel's char-

acteristics. Hence the name, deduced or dead reckoning.

Air navigation by dead reckoning in its simplest form is concerned with the plane's course, speed and track, and the wind's speed and direction. Two of these require careful distinction to avoid confusion. (a) The plane's *course* is the direction in which its nose is pointed or the direction of its longitudinal axis. In flight this would be maintained by means of the plane's compass. (b) The plane's *track* is the actual path over the ground. Both of these and also the wind direction will be expressed in degrees as a bearing measured clockwise from north and may be true, magnetic or compass bearings. (N.B. A north east wind has a bearing 045° , a west wind a bearing 270° . The bearing is the direction from which the wind blows.)

5. Resultant and component velocities. Suppose that B is directly north of A and a wind from the west is blowing. If a plane starts from A and steers due north (Course 000° True) it will be drifted toward the east by the wind and will arrive at C, after actually travelling along AC. That is, the two forces work simultaneously to produce motion along AC. Then AB represents the *course* and AC the *track*.

Now if the wind velocity was 40 m.p.h. and the plane's air speed 100 m.p.h., the distances AB and BC will be proportional to 100 and 40 (or 5 and 2) respectively and by comparing the length of AC with these we can find the *ground speed* of the plane (the velocity along the track or over the distance AC). Because it represents the combined effect of the other two velocities, this value given by AC is sometimes



Fig. 13.

called the *resultant velocity*. Air speed and wind are called *component velocities* since they combine to cause ground speed. In diagrams the component velocities are marked with single arrows, and the resultant, ground speed, with a double arrow.*

Exercise

1. Measure AC in Fig. 1. Compare with AB which represents 100 m.p.h. and calculate the ground speed.

6. To find track or ground speed. If a triangle is drawn with sides showing the directions of course, track and wind, the lengths of the sides will represent accurately the values of air speed, ground speed and wind velocity. This is called the Triangle of Velocities. In dealing with problems it is sometimes easier to construct a parallelogram instead of a triangle. The directions and proportions are not altered by doing this.

Problem. A plane with air speed 150 m.p.h. steers a course bearing 300° . The wind is 50 m.p.h., from bearing 015° . Find track and ground speed.

Draw AB and AD accurately for direction and with lengths in proportion to 150 and 50, say 3 units and 1 unit. Complete the parallelogram ABCD and join

AC. AC is the track and its length represents the ground speed, in this case 280° and 145 m.p.h. approximately.

*For some purposes it may be found convenient to mark the wind line or vector by *three* arrows.

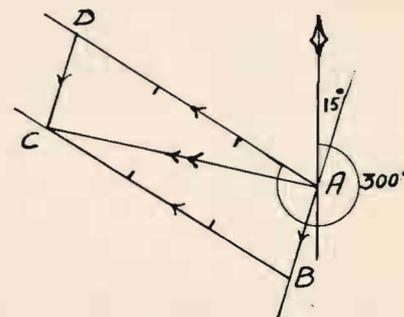


Fig. 14.

Exercise

By accurate construction and measurement of parallelograms find track and ground speeds for the following:

1. Wind 050°, 40 m.p.h. Course 120°, A.S. 180 m.p.h.
2. Wind 180° True. 20 m.p.h. Course 100° Magnetic. A.S. 200 m.p.h. Var. 010°W.

7. **To set a course.** Suppose a plane is to be flown from one place to another, and the wind is known. What course should the pilot steer? This is a fundamental problem of air navigation. Its solution calls for the use of the triangle or parallelogram of velocities. Problem. Destination is on a bearing 75° T. from the starting point and 250 miles distant. Wind 10° T. 40 m.p.h. Air speed 200 m.p.h.

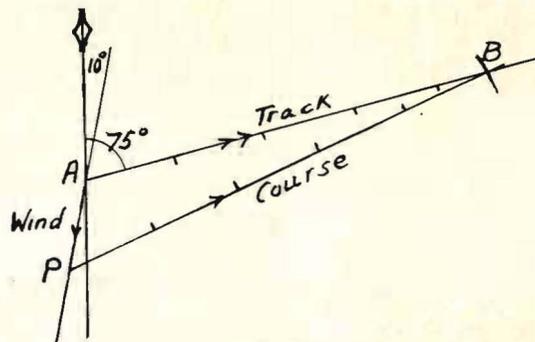


Fig. 15.

Lay off the track on a bearing of 75°. Draw from A the wind direction AP with a scale length chosen to represent 40 m.p.h. (say one unit). From P mark off with compasses or dividers a length to represent airspeed 200 m.p.h. (PB=five units). Then the direction PB is the course to be steered. Its bearing is 67°. Note that the

actual distance does not enter into the calculation here, but that the lengths of the sides of the triangle are proportional to *velocities* only.

Exercise

Find the course to be steered in the following:

1. Track bearing 140° T. Air speed 150 m.p.h. Wind 065° T. 25 m.p.h.
2. Track bearing 270° T. A.S. 200 m.p.h. Wind 240° T. 20 m.p.h.

8. **To calculate E.T.A.** (Estimated Time of Arrival). How long should be required to fly a certain track? In the problem worked out in Figure 15 the distance AB represents the ground speed in the same scale as AP and PB represent the wind velocity and air speed. Its length is approximately $4\frac{1}{2}$ units to represent a ground speed of 180 m.p.h. Since the distance is 250 miles the elapsed time will be $\frac{250}{180}$ hours or one hour 23 minutes.

In calculating E.T.A. allowance is usually made for time taken in rising to and descending from flying height. This will vary with the type of plane, the height, and the wind direction relative to the course, since the direction of take off is likely to be at an angle to the course.

Exercise

In the preceding exercise allow five minutes each for ascent and descent and calculate the E.T.A. adding the following data:

1. Start 0800 hours. Distance 240 miles.
2. Start 1645 hours. Distance 330 miles.

9. **Winds.** In sections 6, 7 and 8 it has been assumed that the wind is constant both as to direction and velocity for the whole trip. Actually this is rarely the case, since winds vary with time, place and altitude. For example a study of a weather map will show that there may be winds of several different speeds and directions along any line

representing a track of a few hundred miles. Our own experience tells us that with the passing of an hour or two there may be considerable change in the force of the wind. This is particularly true following sunrise and sunset, and in coastal or mountainous regions where there are likely to be regular reversals of wind. That winds vary with altitude can be readily seen by watching the movements of high clouds and comparing them with the wind at ground level.

There are so many complicating factors that it is very difficult if not impossible to make an estimate of wind that will enable a course to be set for a whole trip. There are several ways in which a navigator can calculate an allowance for shifting wind. A drift sight is a special instrument to measure the angle of drift and permit a recalculation of course. A fix by bearings of two landmarks or by direct observation will show how far the plane is off its proper track. With this information the navigator can estimate the new wind direction and velocity and lay off a new course. Both of these methods are difficult to carry out in bad weather and poor visibility. This represents the chief difficulty of dead reckoning navigation and the reason why it is supplemented wherever possible by other methods.