AP3456
The Central Flying School (CFS) Manual of Flying

Volume 9 Navigation

CHAPTER 1 - THE EARTH, DISTANCE, AND DIRECTION

THE EARTH

The Form of The Earth

1. For most navigational purposes the Earth is assumed to be a perfect sphere, although in reality it is not. For many centuries man has been concerned about the shape of the Earth; the early Greeks in their speculation and theorizing ranged from the flat disc to the sphere, and even cylindrical and rectangular Earths have been propounded.

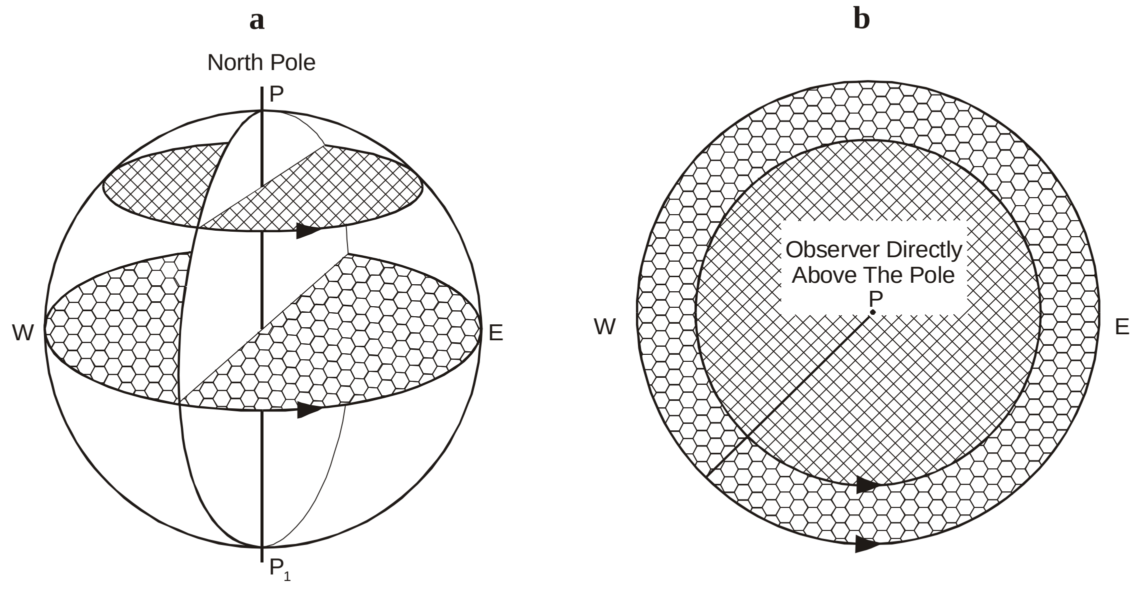
2. The basic shape of the Earth is almost spherical, being slightly flattened at the poles. This shape is more properly termed an oblate spheroid, which is the figure generated by the revolution of an ellipse about its minor axis. Because of this flattening, the Earth's polar diameter is approximately 27 statute miles shorter than its average equatorial diameter.

3. The ratio between this difference and the equatorial diameter is termed the compression of the Earth, and indicates the amount of flattening. This ratio is approximately 1/300 but geodetic information obtained from satellite measurements indicates that the Earth is very slightly 'pear-shaped', the greater mass being in the southern hemisphere.

4. **The Poles.** The extremities of the diameter about which the Earth rotates are called poles. In Fig 1a these are represented by P and P_1.

5. **East and West.** East is defined as the direction in which the Earth is rotating. This direction, anti-clockwise to an observer looking down on the pole P, is shown by the arrows in Figs 1a and b. West is the direction opposite to East.

9-1 Fig 1 Earth References



6. **North and South.** The two poles are distinguished arbitrarily; the North Pole (P in Fig 1a) is said to be the pole which lies to the left of an observer facing East. North is therefore that direction in which

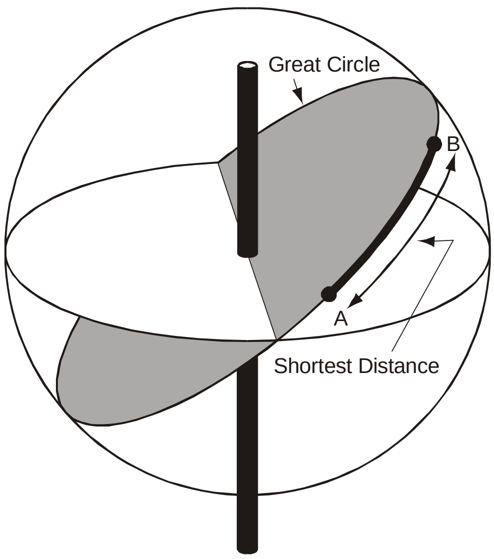
an observer would have to move in order to reach the North Pole; it is at right angles to the East-West direction. The other pole (P_1 in Fig 1a) is known as the South Pole. The directions East, West, North and South are known as the cardinal directions.

Lines Drawn on the Earth

7. The shortest distance between two points is the length of the straight line joining them. It is, however, impossible to draw a straight line on a spherical surface and so all lines drawn on the Earth are curved, some regularly and others irregularly. The regularly curved imaginary lines on the Earth which are of interest to the navigator are described below.

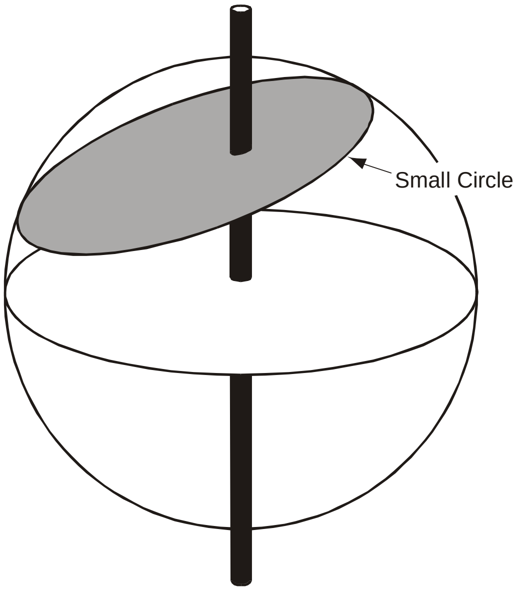
8. **Great Circle**. A great circle is a circle on the surface of a sphere whose centre and radius are those of the sphere itself. Because its plane passes through the centre of the sphere, the resulting section is the largest that can be obtained, hence the name great circle. Only one great circle may be drawn through two places on the surface of a sphere which are not diametrically opposed. The shortest distance between any two points on the surface of a sphere is the smaller arc of the great circle joining them (see Fig 2).

9-1 Fig 2 Great Circle



9. **Small Circle.** A small circle is a circle on the surface of a sphere whose centre and radius are not those of the sphere. All circles other than great circles on the surface of a sphere are small circles (see Fig 3).

9-1 Fig 3 Small Circle

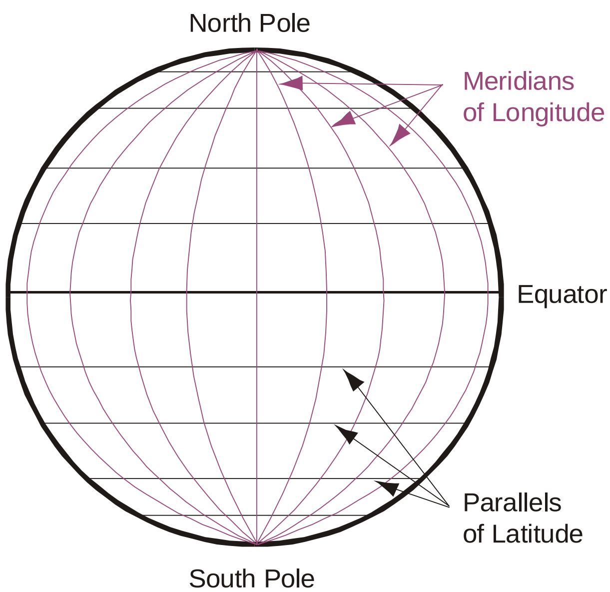


10. **The Equator**. The equator is the great circle whose plane is perpendicular to the axis of rotation of the Earth. Every point on the equator is therefore equidistant from both poles. The equator lies in an East-West direction and divides the Earth into northern and southern hemispheres.

11. **Meridians.** Meridians are semi-great circles joining the poles; every great circle joining the poles forms a meridian and its anti-meridian. All meridians indicate North-South directions.

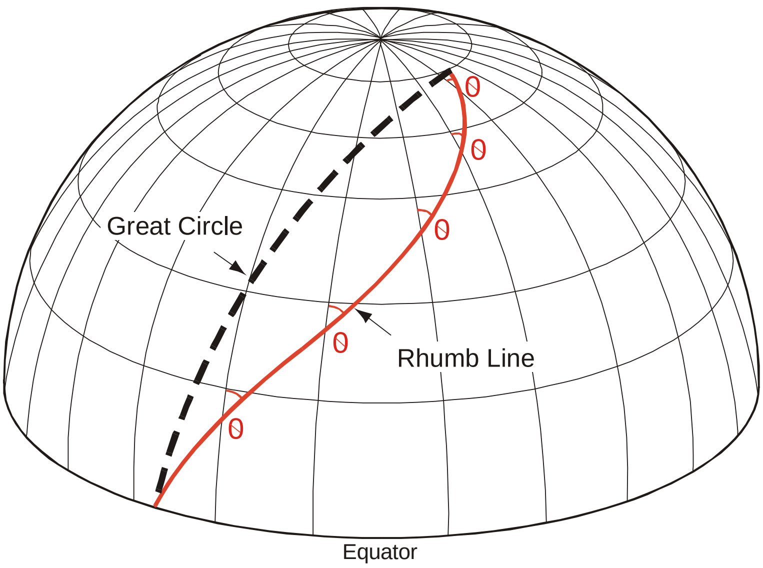
12. **Parallels of Latitude.** Parallels of latitude are small circles on the surface of the Earth whose planes are parallel to the plane of the equator. They therefore lie in an East-West direction (see Fig 4).

9-1 Fig 4 Equator, Meridians and Parallels



13. **Rhumb Line.** A rhumb line is a regularly curved line on the surface of the Earth cutting all meridians at the same angle. Only one such line may be drawn through any two points. Parallels of latitude are rhumb lines as are the meridians and the equator, though the latter two are special cases as they are the only examples of rhumb lines which are also great circles. Thus, when two places are situated elsewhere than on the equator or on the same meridian, the distance measured along the rhumb line joining them is not the shortest distance between them. However, the advantage of the rhumb line is that its direction is constant, therefore the rhumb line between two points may be followed more conveniently than the great circle joining them since the direction of the latter changes continuously with reference to the meridians. The saving in distance effected by flying a great circle rather than a rhumb line increases with latitude but it is appreciable only over great distances, consequently flights of less than 1,000 miles are usually made along the rhumb line. Rhumb lines are convex towards the equator (excepting parallels of latitude, the equator and meridians) and lie nearer the equator than the corresponding great circles (see Fig 5).

9-1 Fig 5 Rhumb Line



Earth Convergence

14. From Fig 5 it can be seen that the meridians are only parallel to one another where they cross the equator, elsewhere the angle of inclination between selected meridians increases towards the poles. This angle of inclination between selected meridians at a particular latitude is known variously as Earth convergence, true convergence, meridian convergence and convergency.

UNITS OF MEASUREMENT

Angular Measurement

15. The sexagesimal system of measuring angles is universally employed in navigation. In this system the angle subtended at the centre of a circle by an arc equal to the 360th part of the circumference is called

a degree; each degree is subdivided into 60 minutes (') and each minute into 60 seconds ("). Thus the size of any angle may be expressed in terms of degrees, minutes and seconds.

16. In spherical calculations it is frequently convenient to express spherical distances (ie great circle distances) in terms of angular measurement rather than in linear units. This is possible because of a simple relationship between the radius, arc, and angle at the centre of a circle. Thus the length of the arc of a great circle on the Earth might be expressed as 10º 38'; this would convey little unless there were some ready means of converting angular units to linear units. This difficulty of converting from angular to linear units has been overcome by the definition of the standard unit of linear measurement on the Earth, the nautical mile.

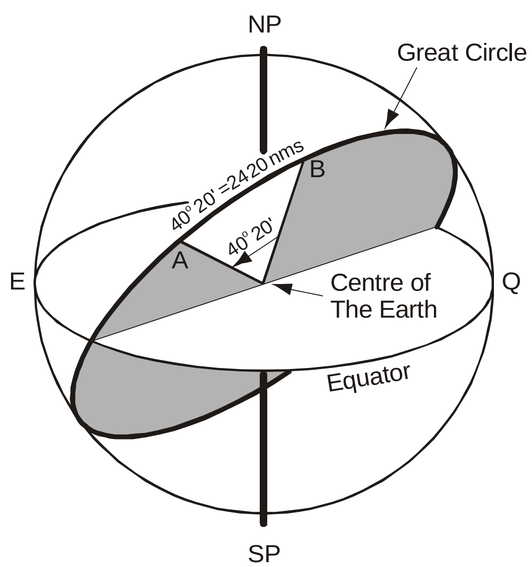
Measurement of Distance

17. Assuming the Earth to be a true sphere, a nautical mile is defined as the length of the arc of a great circle which subtends an angle of one minute at the centre of the Earth. Thus the number of nautical miles in the arc of any great circle equals the number of minutes subtended by that arc at the centre of the Earth. The conversion of an angular measurement of spherical distance to linear units requires only the reduction of the angle to minutes of arc; the number of minutes is equal to the spherical distance in nautical miles.

18. In Fig 6a, if AB*,* the arc of a great circle, subtends an angle at the Earth's centre of 40º 20', AB is said to be 40º 20' in length. Forty degrees 20 minutes is equivalent to 2,420 minutes of arc which is equal to a length of 2,420 nautical miles.

9-1 Fig 6 Angular Distance and the Nautical Mile

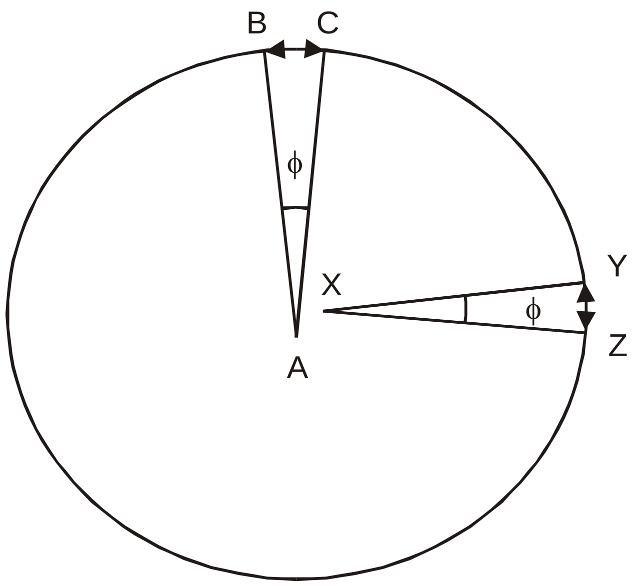
Fig 6a Angular Distance



19. Because of the Earth's uneven shape the actual length of the nautical mile is not constant, but varies with latitude from 6,046 feet at the equator to approximately 6,108 feet at the poles. A more accurate definition of the nautical mile than that given in para 17 is that it is the length of the arc on the

Earth's surface that subtends an angle of one minute at its own centre of curvature. In Fig 6b the arc BC is on a comparatively flat part of the spheroid and the distance to the centre of curvature is relatively long (AB or AC); therefore an angle ϕ is subtended by a comparatively long arc BC. The arc YZ is at a comparatively curved part of the spheroid, the distance to the centre of curvature (XY or XZ) is shorter and the angle ϕ is subtended by a shorter arc length. However, for the purpose of navigation a fixed unit of measurement is helpful. Until 1 March 1971 this was the UK Standard Nautical Mile of 6,080 feet. Since that time the International Nautical Mile of 1,852 metres (6,076.1 feet) has been adopted as the standard unit of distance for air navigation.

Fig 6b Nautical Mile



20. The other mile unit in common use is the statute mile (so called because its length, 5,280 feet, is determined by law). The statute mile evolved from the Roman "milia passuum" (1,000 paces - approximately 4,860 feet). Unlike the nautical mile, the statute mile is not readily converted into angular measurement terms.

21. **Metric Units.** The SI unit of distance is the kilometre. One kilometre is the length of 1/10,000th part of the average distance between the equator and either pole; it is equivalent to 3,280 feet.

Speed

22. Speed is a rate of change of position. It is usually expressed in linear units per hour. As there are three main linear units, there are three expressions of speed:

a. Nautical miles per hour, stated as "knots" (kt).
b. Miles (ie statute miles) per hour (mph).
c. Kilometres per hour (km/hr).

DIRECTION

Direction on the Earth

23. In order to fly in a given direction it is necessary to be able to refer to a datum line or fixed direction whose orientation is known or can be determined. The most convenient datum is the meridian through the current position, since it is the North-South line. By convention, direction is measured clockwise from North to the nearest degree, i.e. from 000º to 360º. It is always expressed as a three-figure group; thus East, which is 90º from North, is written 090º, and West is 270º.

24. **True Direction**. Direction measured with reference to True North, the direction of the North geographic pole, is said to be the True direction. True direction has the following advantages:

a. It is a constant directional reference (ie True direction about a point does not change with time).
b. It is the basis of nearly all maps and charts.
c. It is the direct and continuous output from inertial systems.

However, magnetic direction continues to be used as an aircraft heading reference and as the basic direction reference in non-inertial systems.

25. **Magnetic Direction*.*** The Earth acts as though it is a huge magnet whose field is strong enough to influence the alignment of a freely suspended magnetic needle any where in the world. The poles of this hypothetical magnet are known as the North and South magnetic poles and, like those of any magnet, they can be considered to be connected by lines of magnetic force. Although the magnetic and geographic poles are by no means coincident (the respective North poles are separated by approximately 900 nm), the lines of force throughout the equatorial and temperate regions are roughly parallel to the Earth's meridians. A freely suspended magnetic needle will take up the direction indicated by the Earth's lines of force and thus assume a general North-South direction; the actual direction in which it points, assuming no other influences are acting upon it, is said to be Magnetic North. With such a datum available it is possible to measure magnetic direction. If, at any given point, the angular difference between the directions of Magnetic North and True North is known, then it is possible to convert Magnetic direction to True direction.

Variation

26. The angular difference between the direction of True North and Magnetic North at any given point, and therefore between all True directions and their corresponding Magnetic directions at that point, is called Variation. Variation is measured in degrees and is named East (+) or West (–) according to whether the North-seeking end of a freely-suspended magnetic needle, influenced only by the Earth's field, lies to the East or West of True North at any given point. The algebraic sign given to Variation indicates how it is to be applied to magnetic direction to convert it to True direction. At any point, therefore, the True direction can be determined by measuring Magnetic direction and then applying the local Variation (see Fig 7). A useful mnemonic is:

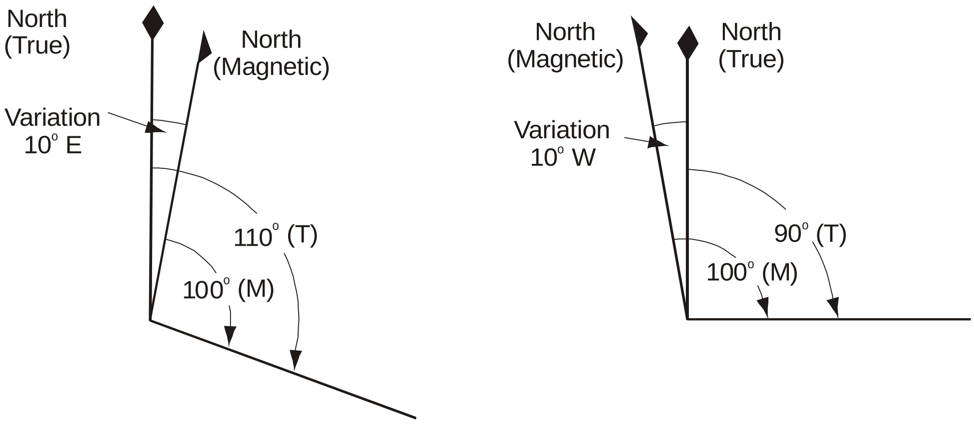
"Variation East, Magnetic least,
Variation West, Magnetic best."

9-1 Fig 7 Variation

In Fig 7a it can be seen that:		
Magnetic direction	=	100º (M)
Variation	=	10º E (+)
∴ True direction	=	110º (T)

In Fig 7b it can be seen that:		
Magnetic direction	=	100º (M)
Variation	=	10º W (–)
∴ True direction	=	090º (T)

a **b**



Isogonals

27. Variation is not constant over the Earth's surface, but varies from place to place. This change is gradual and follows a more or less regular pattern. By means of a magnetic survey, the variation at numerous points is accurately measured and tabulated. From such a survey, it is possible to discover a number of points where variation has the same value. Lines joining these points of equal variation are known as isogonals, and these lines are printed on maps and charts.

28. The variation at any given point is not a fixed quantity, but is subject to gradual change with the passage of time because the magnetic axis of the Earth is constantly changing. This change, which is indicated in the margin of the chart, is not large but, in certain places, may amount to as much as one degree in five years. It is important, therefore, that charts indicate the date to which variation values apply, and also the annual change, so that the isogonal values may be updated.

Deviation

29. When a freely-suspended magnetic needle is influenced only by the Earth's magnetic field, the direction it assumes is known as Magnetic North. If such a needle is placed in an aircraft, it is subject to a number of additional magnetic fields created by various electrical circuits and magnetized pieces of metal within the aircraft; consequently its North-seeking end deviates from the direction of magnetic North and indicates a direction known as compass North.

30. The angular difference between the direction of Magnetic North and that of Compass North, and therefore all Magnetic directions and their corresponding Compass directions, is called Deviation. Deviation is measured in degrees and is named East (+) or West (–) according to whether the North-seeking end of a compass needle, under various disturbing influences, lies to the East or West of Magnetic North. The algebraic sign given to deviation indicates how it is to be applied to compass direction to convert it to Magnetic direction.

31. Deviation is not, as might be imagined, a constant value for a given compass; instead it varies with the heading of the aircraft. Nor is the deviation experienced by two different compasses likely to be the same under identical conditions (see Volume 5, Chapter 15). Thus, in order to convert the directions registered by a particular compass to Magnetic directions, a tabulation of the deviations of that compass, found on various headings, is required. Such a tabulation of the deviation, usually in the form of a card, must be provided and placed near the compass to which it applies. The method by which compass cards are produced (known as 'compass swinging') is covered in detail in Volume 5, Chapter 16.

32. The deviation of a compass will change as its position in the aircraft is changed. Deviation will also change, over a period of time, due to changing magnetic fields within the aircraft. Moreover, as the aircraft flies great distances over the Earth, changes occur in deviation because of the Earth's changing magnetic field. It is not sufficient, therefore, to prepare a deviation card and expect it to last indefinitely, the card must be renewed at frequent intervals in order that it may always record the deviation as accurately as possible. A useful mnemonic for the application of deviation is:

"Deviation East, compass least,
Deviation West, compass best."

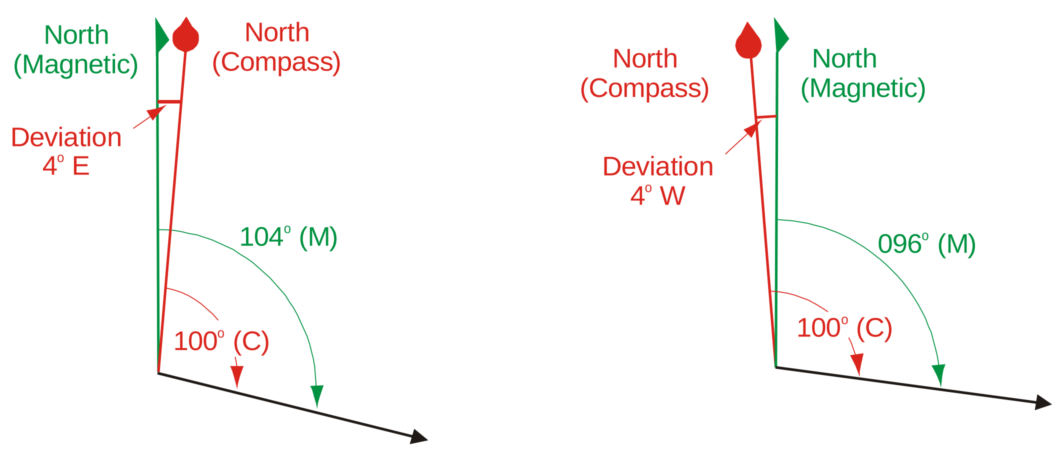
Figure 8 illustrates the two cases, Deviation East and Deviation West, for the following values:

9-1 Fig 8 Deviation

Fig 8a	
Compass direction	100º (C)
Deviation	4º E (+)
Magnetic direction	104º (M)

Fig 8b	
Compass direction	100º (C)
Deviation	4º W (–)
Magnetic direction	096º (M)

a Deviation East **b Deviation West**

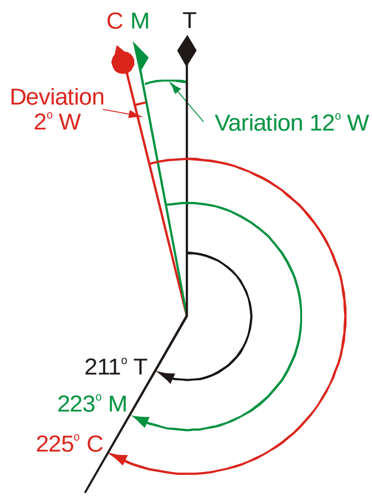


Derivation of True Direction

33. It is possible, therefore, to express a direction given with regard to a particular compass needle as True direction, provided that deviation and variation are known. To avoid the complications arising from the changing values of variation and deviation during flight, plotting is usually carried out using true directions. An example is shown in Fig 9:

9-1 Fig 9 Three Expressions for Direction

Compass direction	225º (C)
Deviation	2º W (–)
Magnetic direction	223º (M)
Variation	12º W (–)
True direction	211º (T)



CHAPTER 2 - POSITION

Introduction

1. Since air navigation is the process of directing an aircraft from one point to another, it is essential to be able to define these points as positions on the Earth's surface.

LATITUDE AND LONGITUDE

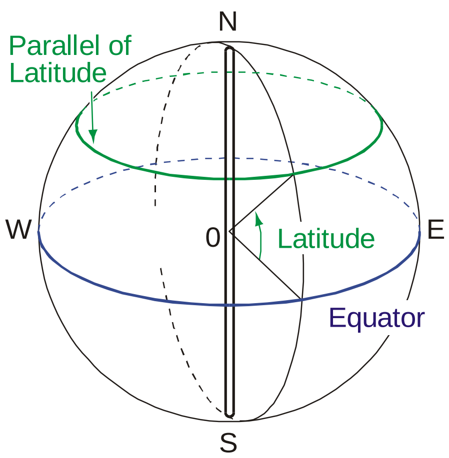
General

2. On the Earth, position is normally defined by a reference system known as latitude and longitude.

Latitude

3. Latitude is defined as the angular distance from the equator to a point, measured northward or southward along the meridian through that point. This quantity is expressed in degrees, minutes and seconds and is annotated N or S according to whether the point lies North or South of the equator (see Fig 1).

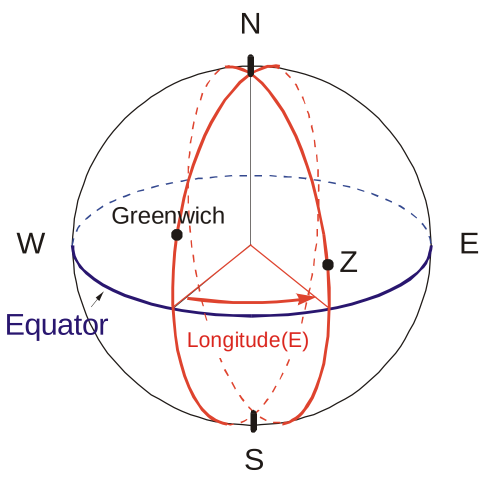
9-2 Fig 1 Latitude



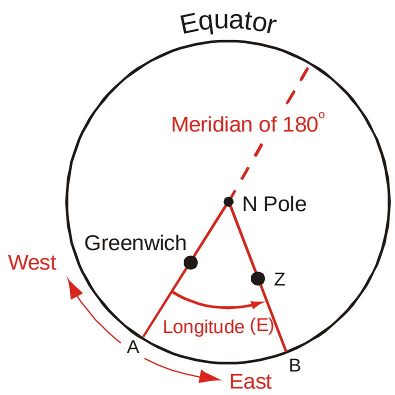
Longitude

4. The longitude of any point is the shorter angular distance along the equator between the meridian running through Greenwich (the Greenwich or Prime Meridian) and the meridian through the point (Fig 2). It is expressed in degrees minutes and seconds, and is annotated E or W according to whether the point lies to the East or West of the Greenwich Meridian. As the plane of the Greenwich Meridian bisects the Earth, longitude cannot be greater than 180º East or West (Fig 3).

9-2 Fig 2 Longitude



9-2 Fig 3 Extremes of Longitude



Recording Position

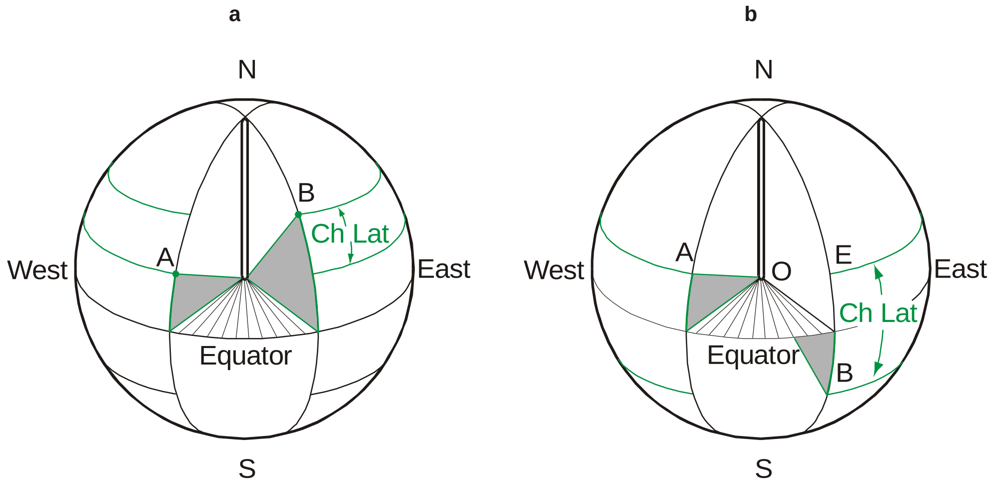
5. In air navigation, it is usually sufficient to express latitude and longitude in degrees and minutes only. By convention, the group of figures representing latitude is always written first and is followed by the figures expressing longitude. To avoid ambiguity, there are always two figures used to denote degrees of latitude, those below ten being preceded by the digit 0. Similarly, three figures are used to denote degrees of longitude, employing leading zeros as necessary. The letters N, S, E, and W are used to indicate the hemisphere. Thus the position of a point situated in latitude 53 degrees 21 minutes North and in longitude zero degrees 5 minutes East, is written: 53 21 N 000 05 E, the spaces being optional.

Change of Latitude

6. The change of latitude (ch lat) between two points is the arc of a meridian intercepted between their parallels of latitude. It is annotated N or S according to the direction of the change from the first point to the second. By convention, northerly latitudes are considered positive, while southerly latitudes are considered negative.

7. If the two points are on the same side of the equator, and thus have the same sign (as in Fig 4a), the ch lat is found by subtracting the lesser latitude, that of A, from the greater, that of B. If A and B are on opposite sides of the equator, and thus have the different signs (as in Fig 4b), the ch lat is equal to the sum of the latitudes of A and B. In Fig 4a the ch lat of point B from an observer at point A is annotated N, in Fig 4b the ch lat of point B from point A is annotated S.

9-2 Fig 4 Change of Latitude

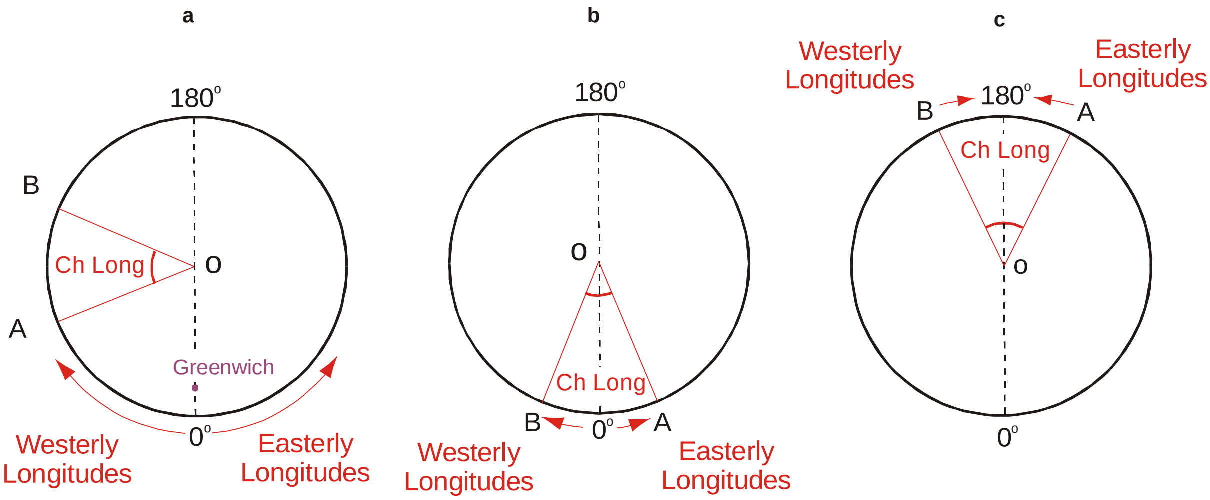


Change of Longitude

8. The change of longitude (ch long) between two points is the smaller arc of a parallel intercepted by the meridians through the two points. It is annotated E or W according to the direction of the change from the first point to the second. By convention, easterly longitudes are considered positive, while westerly longitudes are considered negative.

9. In Fig 5a, the points A and B are in the same hemisphere and so have the same sign. The change in longitude is the difference between them. The ch long from A to B is westerly, while the ch long from B to A is easterly. In Fig 5b, the points A and B are in different hemispheres and so have different signs. The change in longitude is the sum of their longitudes. The ch long from A to B is westerly, while the ch long from B to A is easterly. When considering the example in Fig 5c, it is vital to remember the definition of ch long given in para 8. Points A and B are in different hemispheres and so have different signs. By calculating their sum, the derived ch long would be a measurement of the larger arc of the parallel intercepted by the meridians through the two points. Thus, in this situation, ch long is derived by subtracting the sum of the longitudes of the points from 360º.

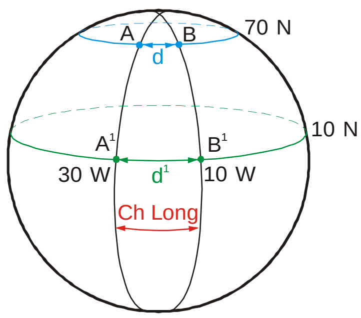
9-2 Fig 5 Change of Longitude



Departure

10. The distance between two given meridians, measured along a stated parallel and expressed in nautical miles, is called departure. In general terms, it is defined as the East-West component of the rhumb line distance between two points. The value of departure between two meridians varies with latitude, decreasing with increasing latitude (Fig 6); the change of longitude between these meridians remains the same, irrespective of the latitude.

9-2 Fig 6 Departure and Change of Longitude



d = 410 nm West (A from B)
d[1] = 1181 nm West (A[1] from B[1])

11. The departure between any two points is a function of their latitudes and the change of longitude. The relationship is given by:

$$\text{Departure (nm)} = \text{ch long (mins)} \times \cos\text{ (mean lat)}$$

$$\text{where mean lat} = \frac{\text{lat A} + \text{lat B}}{2}$$

Disadvantages of the Latitude and Longitude Reference System

12. The latitude and longitude method of reporting position suffers from certain disadvantages:

a. The possibility of confusion in areas close to the equator and the prime meridian.

b. The necessity of giving an 11 character group to obtain positional accuracy of 1 min e.g. 5136 N 00125 W.

c. One minute of latitude and one minute of longitude represent different distances on the earth, except at the equator, and the distance represented by one minute of longitude decreases with increasing latitude.

13. To overcome these disadvantages, military forces use reporting systems based on networks of lines (grids) which are a fixed distance apart and cut each other at right angles. Examples of these systems discussed in this chapter are:

a. The British National Grid System (covering Great Britain and the Isle of Man).

b. The Irish Grid (covering Northern Ireland and the Republic of Ireland).

c. The Universal Transverse Mercator Grid (UTM) (covering the latitudes between 80º S and 84º N).

d. The Universal Polar Stereographic Grid (covering the north and south polar regions).

e. The Geographic Reference System (GEOREF). Note that this system is based on graticule lines (latitude and longitude), and is not a true grid system.

THE BRITISH NATIONAL GRID SYSTEM

Description of the Grid

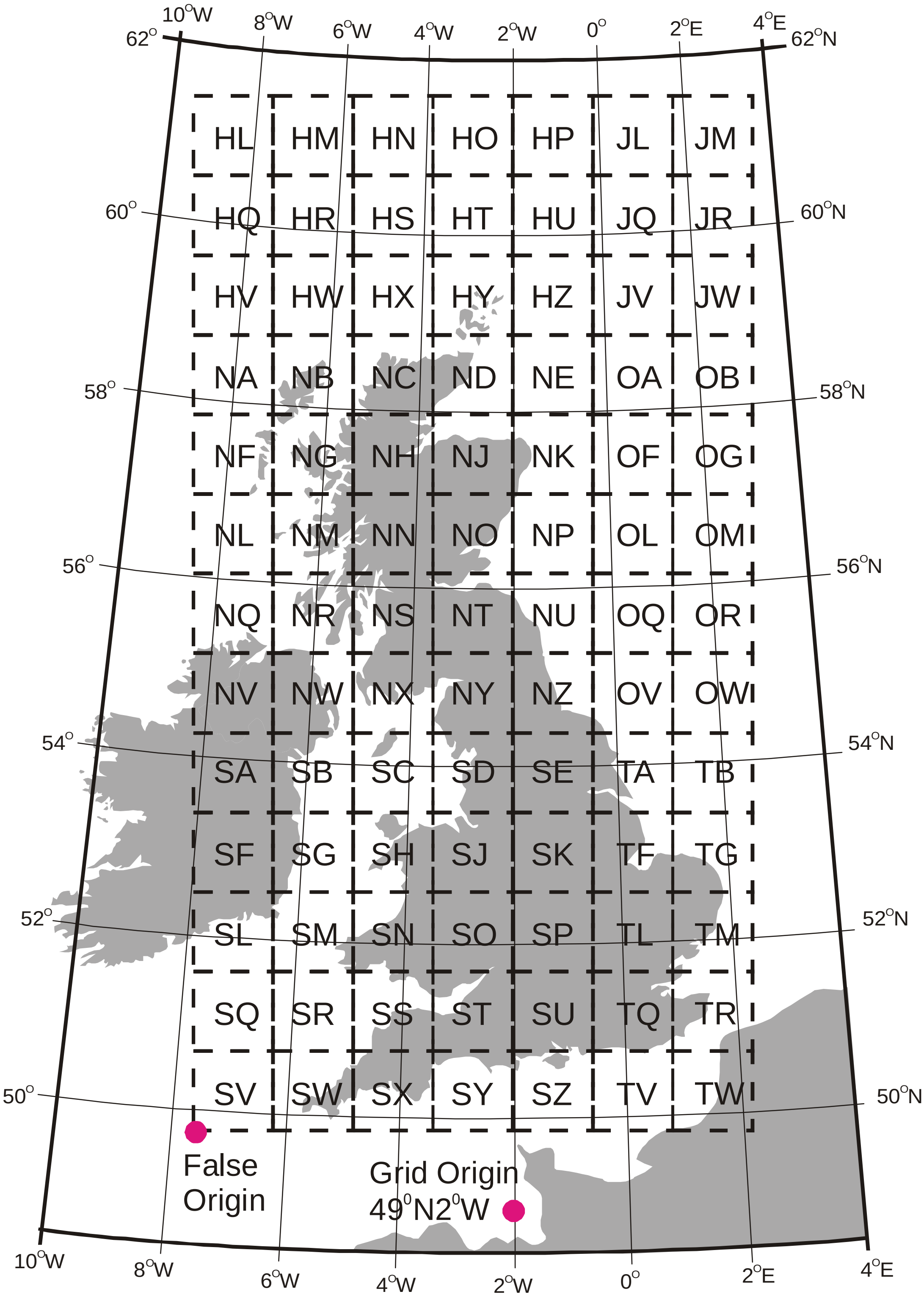
14. The British National Grid is the national grid for Great Britain and is a unique system for use by both civilian and military authorities. It is based on the Transverse Mercator projection with a central meridian at 2º W, to which all grid lines are parallel or perpendicular. The origin of the grid is at 49º N 2º W, with a false origin located 100 km north and 400 km west of the grid origin to ensure that all coordinates on the grid are positive (see Fig 7). British National Grid coordinates are given in terms of metres east and metres north of the false origin. Depending on the scale of the chart, the distance between grid lines shown on the chart is 10,000 metres, 1,000 metres or 100 metres. The distance between grid lines shown on the chart is termed the 'grid interval'.

The British National Grid Reference System

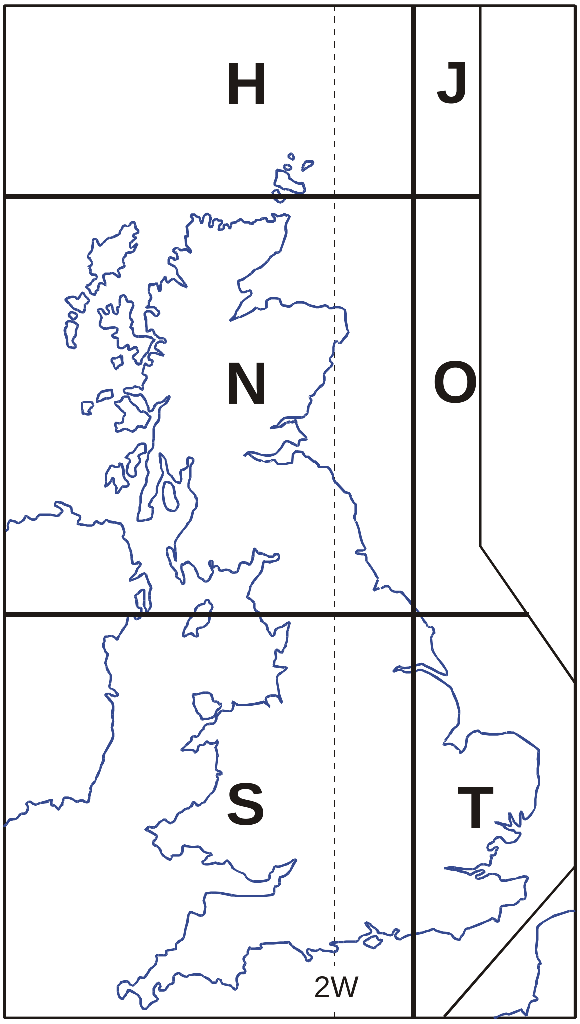
15. The British National Grid Reference System is the means by which national grid references are given using the British National Grid. The British National Grid is first divided into 500 km grid squares. Each 500 km square is assigned a letter, referred to as the 500 km 'square identification', as shown in Fig 8. Each 500 km square is subdivided into 100 km squares, each of which is assigned a 'square identification' letter. The 100 km squares are lettered A to Z (omitting I), starting in the top left of the whole 500 km grid square, as shown in Fig 7. It can be seen from Fig 7, that by combining the square identification letters, each 100 km square has a unique identifier. The 100 km squares can be further sub-sub-divided into 10 km, 1 km, and 100 metre squares, depending on the scale of the chart in use (see para 14). Each grid square within the 100 km square is designated by the respective metric distances of its South-West corner

from the West and South margins of the 100 km square. The user can extract these distances from the figures printed in the margins of the maps against the grid lines.

9-2 Fig 7 The National Grid showing the Grid Origin and False Origin



9-2 Fig 8 The 500 km Grid Squares of the British National Grid



16. A full grid reference consists of the two letters representing the square identifications, followed by a numerical element to identify a position within the square. The numerical part of a grid reference consists of an even number of digits in two equal groups. The first group represents the eastings and the second group the northings. Each group is made up as follows:

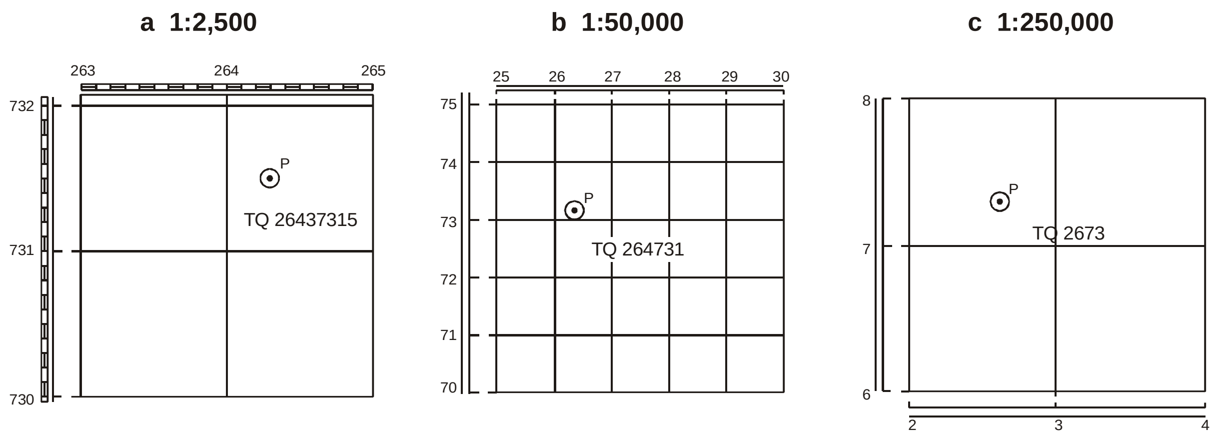
a. **Principal Digits**. Principal digits label the grid lines and are shown on the chart. For a chart with a 100 metre grid, each grid line has three principal digits (Fig 9a). For a 1,000 metre grid, each grid line has two principal digits (Fig 9b). For a 10,000 metre grid, each grid line has one principal digit (Fig 9c).

b. **Estimated Tenths**. A 'standard reference' obtained from a chart is a grid reference to a precision of one tenth of the grid interval of the chart. The grid square is divided into tenths, either by measurement or estimation, in an easterly and northerly direction and counted respectively from the left and south grid lines.

An eight figure reference identifies a point to a precision of 10 metres. A six figure reference identifies a point to a precision of 100 metres. A four figure reference identifies a point to a precision of 1,000 metres. This can be seen in Fig 9. In Fig 9a, the grid interval is 100 metres and so the estimated tenths gives a precision of 10 metres. Grid references always read right (eastings) first and then up (northings). A grid reference is written without any spaces.

17. Examples of standard grid references, appropriate to various scales, are illustrated in Fig 9.

9-2 Fig 9 Grid References on Various Scale Charts



THE IRISH GRID

Description of the Grid

18. The Irish Grid is shown on military maps and charts that cover Northern Ireland and the Republic of Ireland. It is based on the Transverse Mercator projection with a central meridian at 8º W to which all grid lines are parallel or perpendicular. The origin of the grid is 53º 30' N and 8º W, with a false origin 250 km south and 200 km west of the grid origin. Irish grid coordinates are given in terms of metres east and metres north of the false origin. Depending on the scale of the chart, the distance between grid lines shown is 10,000 metres, 1,000 metres or 100 metres. The distance between grid lines shown on the chart is termed the 'grid interval'.

The Irish Grid Reference System

19. The system for reporting grid references on the Irish Grid is almost identical to the British National Grid Reference System (para 16). The difference is that the whole of the island of Ireland falls within a single 500 km square which is designated by the letter 'I'. This letter is not used anywhere else, either in the reference system used with the Irish Grid, or in the British National Grid Reference System. As with the British National Grid Reference System, a full grid reference consists of two letters, the first identifying the 500 km square in which the point lies, and the second identifying the 100 km square in which the point lies. Grid letters are followed by the numerical part of the grid reference that identifies a position within a grid square.

THE UNIVERSAL TRANSVERSE MERCATOR GRID

Introduction

20. Any rectangular grid system must be based on a flat projection of the Earth's surface. However, because the Earth's surface is curved, any flat projection will become increasingly distorted as the area of projection is extended. Therefore, the area covered by one particular grid must not be extended beyond the limits at which its distortion becomes excessive.

Description of the Grid

21. The Universal Transverse Mercator (UTM) Grid is a world-wide grid extending from 80º S to 84º N. It is based on sixty separate grid zones, each one covering six degrees of longitude and each with its own projection. The UTM Grid is based on the Transverse Mercator Projection with each grid zone having a central meridian, central to that zone, to which all grid lines are parallel or perpendicular. The origin of each of the grid zones is the intersection of its central meridian with the equator. Each grid origin is assigned false coordinates which are 500,000 metres east and 0 metres north for the northern hemisphere, and 500,000 metres east and 10,000,000 metres north for the southern hemisphere. This effectively creates false origins 500 km west of the true origins on the equator, for the northern hemisphere, and 500 km west and 10,000 km south of the true origins for the southern hemisphere. UTM Grid coordinates are given in terms of metres east and metres north of the false origin in the hemisphere of the UTM grid zone in which the point falls. Some UTM grid zones are extended at the expense of others. These are shown in Table 1. Depending on the scale of the chart, the distance between the grid lines shown is 10,000, 1,000 or 100 metres. The distance between the grid lines shown is termed the 'grid interval'.

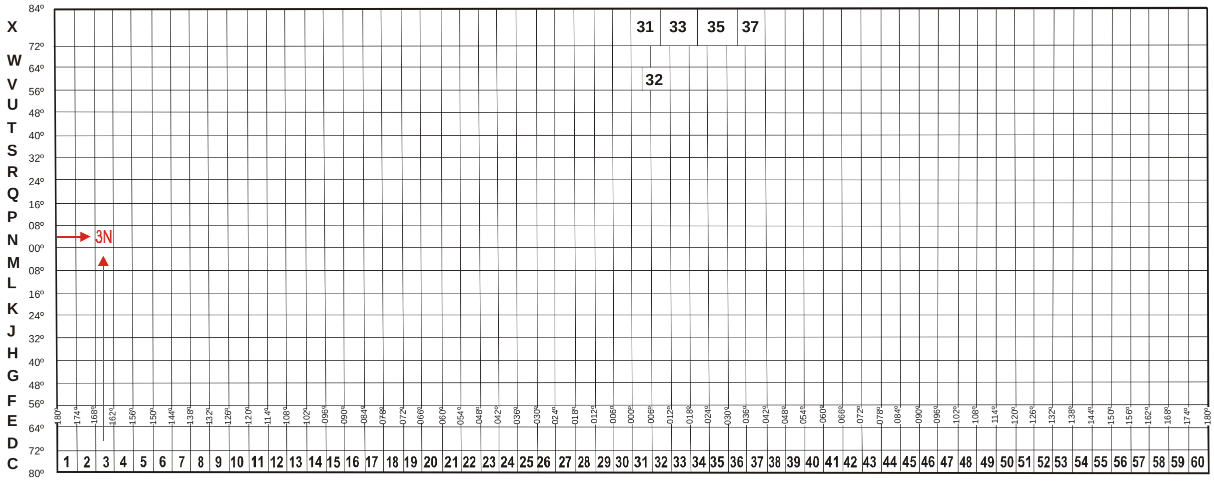
9-2 Table 1 Extended UTM Grid Zones

Latitude Band	Zone	Width
55º N to 64º N	31	3º (0º to 3º E)
	32	9º (3º E to 12º E)
72º N to 84º N	31	9º (0º to 9º E)
	32	Eliminated
	33	12º (9º E to 21º E)
	34	Eliminated
	35	12º (21º E to 33º E)
	36	Eliminated
	37	9º (33º E to 42º E)

22. The UTM grid is further divided into twenty bands of latitude. Each band covers eight degrees of latitude, (except for the most northerly band which covers the twelve degrees between 72º N and 84º N). Each band of latitude is given a designation letter from C to X (omitting letters I and O) starting at 80º S and continuing to 84º N.

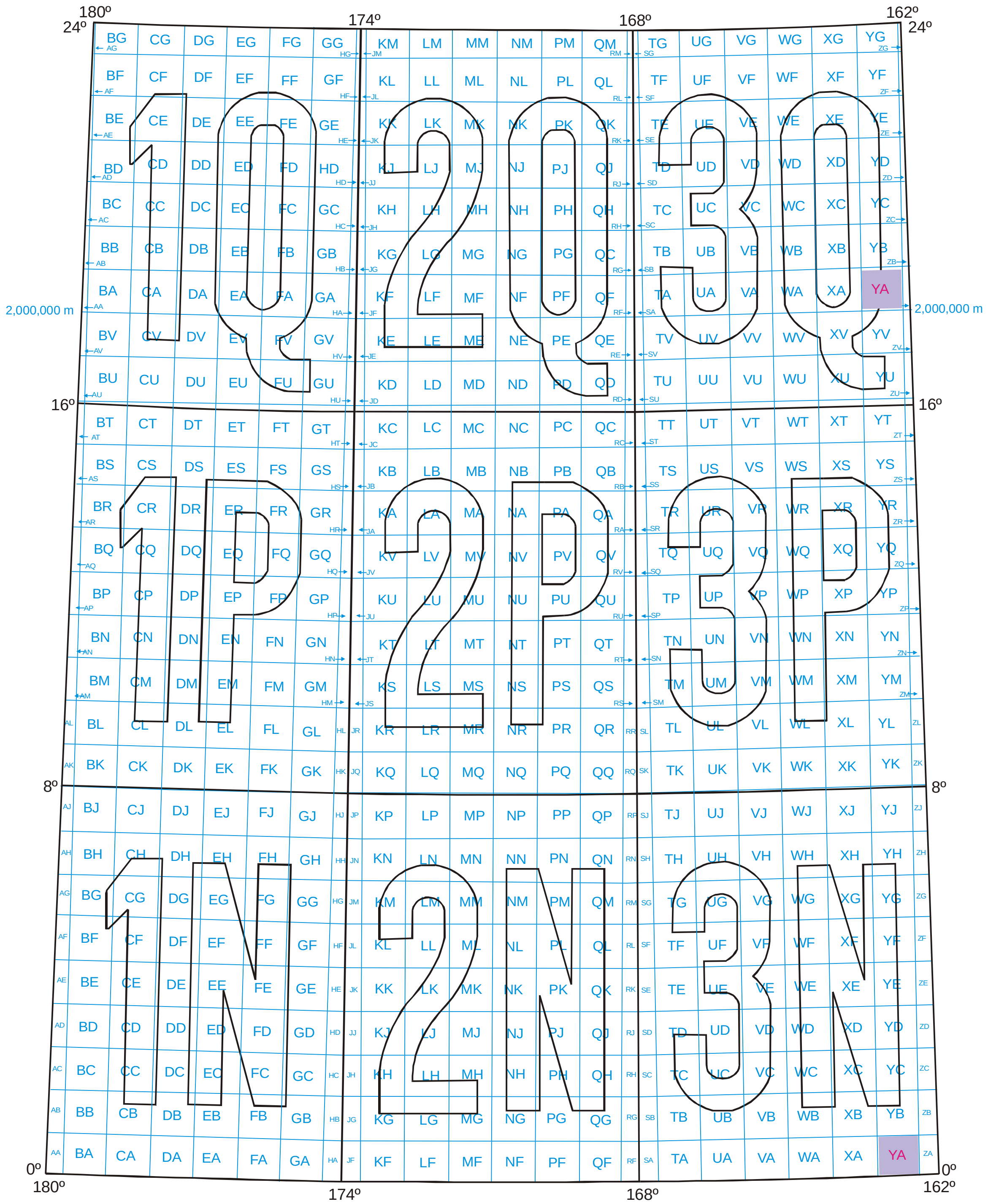
23. Grid Zone Designation Areas are formed by the intersection of the UTM Grid Zones and the latitude bands. Each Grid Zone Designation Area is identified by a unique Grid Zone Designation (GZD). The GZD consists of the number of the UTM grid zone followed by the designation letter of the latitude band. Grid Zone Designation Areas are illustrated in Fig. 10.

9-2 Fig 10 The UTM Grid



24. Each Grid Zone is sub-divided into columns and rows to form 100,000 metre (100 km) squares (Fig 11). Each column and row is given an identifying letter. Thus, each 100,000 metre square is identified by two letters corresponding to its column and row respectively. This pair of letters is termed the 100,000 metre square identification. Because the UTM Grid covers much of the Earth's surface, 100,000 metre square identifications will be repeated. To identify individual 100,000 metre squares, the square identification is preceded by the grid zone designation. In Fig 11, it can be seen that there are two 100,000 metre squares designated YA but they are differentiated by the prefix of their UTM Grid Zone Designation Area, (in this case 3Q and 3N). The 100,000 metre squares are fitted into each 6º zone so that they are uniformly spaced about the central meridian of the zone and along the equator. As a result, the 'grid squares' along the borders of the 6º zones do not form squares.

9-2 Fig 11 Identification of 100 km Squares on the UTM Grid



25. Starting at the 180º meridian and moving eastwards for 18º along the equator, the 100,000 metre columns (including those along 6º zone borders) are lettered alphabetically from A to Z (with I and O omitted). This is repeated at 18º intervals.

26. In odd numbered UTM Grid Zones, the rows of 100,000 metre squares are lettered northwards alphabetically from A to V (with I and O omitted), the partial alphabet being repeated every 20 rows. In even numbered UTM Grid Zones, starting at the equator, the rows are lettered F to V (omitting I and O) followed by A to V (omitting I and O). This is done to increase the distance between 100,000 metre squares with

the same square identification. Below the equator, the 100,000 metre rows are lettered northwards in such a way that they fit into the sequence of letters above in the same zone.

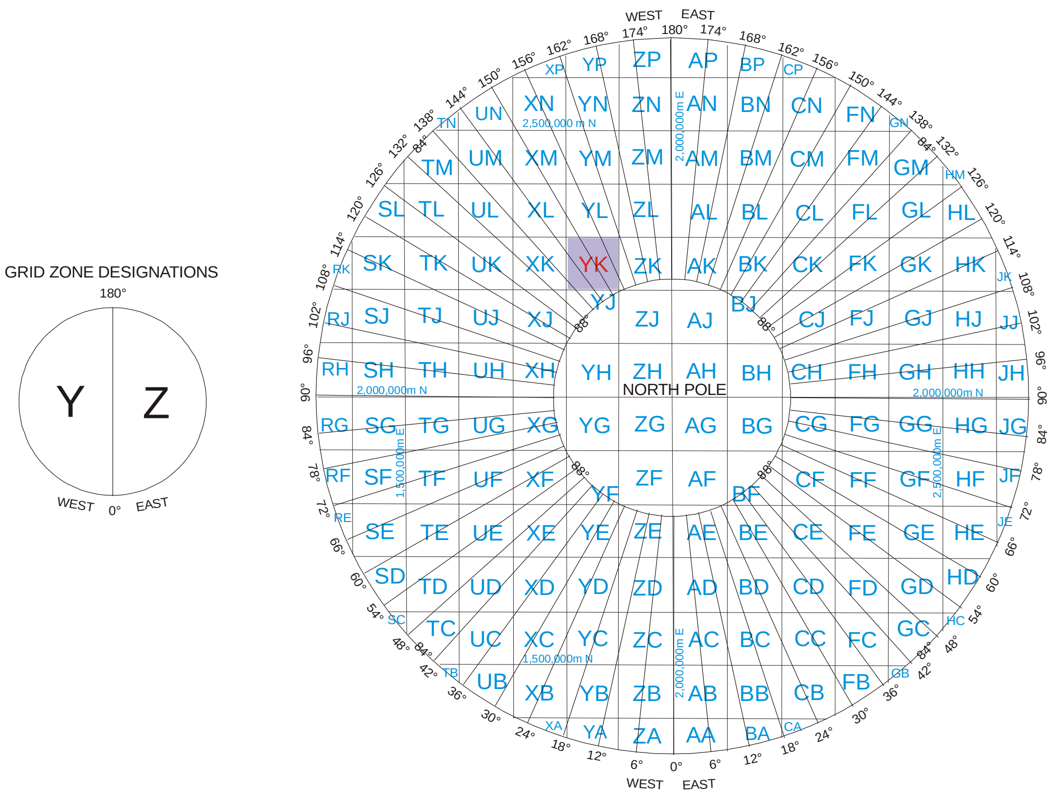
THE UNIVERSAL POLAR STEREOGRAPHIC GRID

Description of the Grid

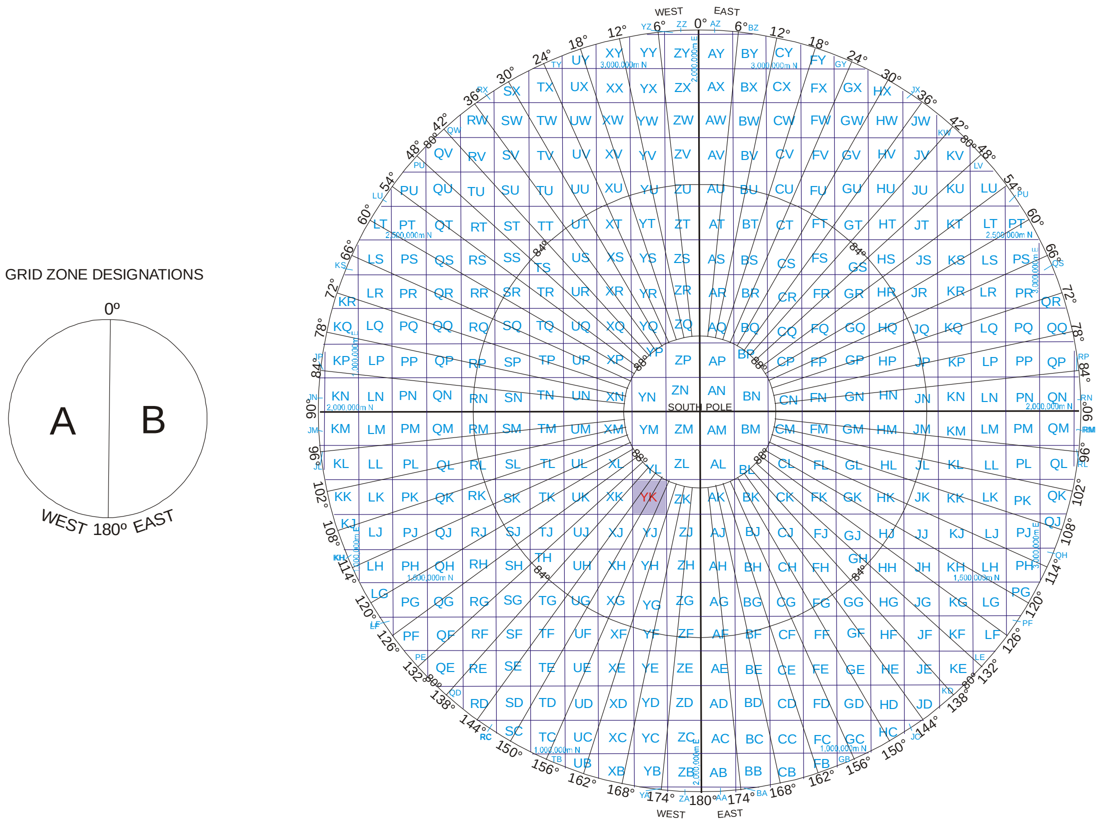
27. The Universal Polar Stereographic Grid consists of two grids - one covering the North Polar area, (north of 84º N), and the other, the South Polar area (south of 80º S). These grids are based on a polar stereographic projection with the origin of each at the respective pole. The Northern and Southern UPS grids extend to 83º 30' N and 79º 30' S respectively to provide a 30' overlap with the UTM grid. Easting grid lines are parallel to the Greenwich Meridian (0º) and the 180º meridian. Northing grid lines are parallel to the 90º W and 90º E meridians. The grid origins are assigned false coordinates of 2,000,000 metres east and 2,000,000 metres north. When used in conjunction with the UTM grid the UPS Grids provide world-wide coverage.

28. The North polar area is divided into two parts by the Greenwich and 180º meridians (Fig 12). The half containing the West longitudes is given the grid zone designation Y whilst that containing the East longitude is given the grid designation Z. Similarly, the South polar area (Fig 13) is divided into two halves. The half containing the West longitudes is lettered A, whilst the other half, containing the East longitudes, is lettered B. No numbers are used in conjunction with these letters.

9-2 Fig 12 The UPS Grid - North Polar Area



9-2 Fig 13 The UPS Grid - South Polar Area



29. Both polar regions are divided into 100,000 metre squares in a similar manner to the UTM system. Columns are defined to be parallel to the 180º /0º meridian and rows parallel to the 90º W/90º E meridian. In the eastern hemisphere, columns are lettered consecutively eastwards, starting at the 180º/0º meridian with A and omitting the letters D, E, I, M, N and O. In the western hemisphere, the columns start at the 180º/0º meridian with Z and the lettering proceeds backwards through the alphabet omitting W, V, O, N and M. The omission of the letters shown ensures that there is no duplication with UTM references within 18º in any direction. In the North polar region, rows start with A at 84º N 0º E, the letters increasing northwards to the Pole, then southwards finishing with P at 84º N 180º E and omitting I and O. In the South polar region, rows start with A at 80º S 180º E, the letters increasing southwards to the Pole, then northwards finishing with Z at 80º S 0º E and omitting I and O.

THE MILITARY GRID REFERENCE SYSTEM

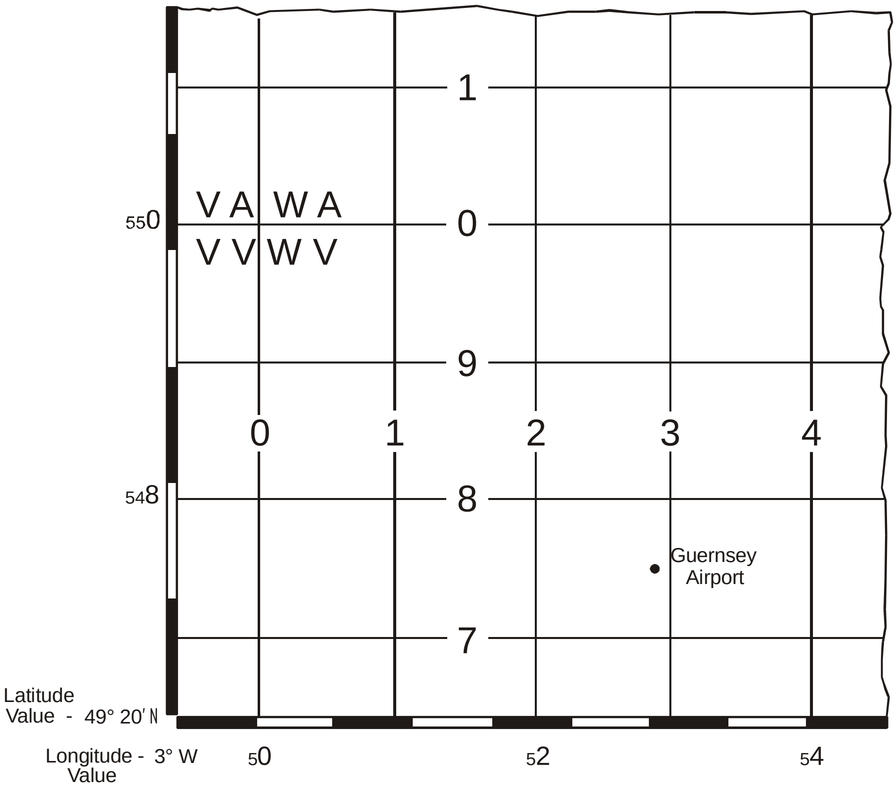
Description of the System

30. The Military Grid Reference System (MGRS) is a grid reference system designed to be used with the UTM and UPS grids. It is a method of defining any point by means of a Grid Reference. A full grid reference is reported in the same way as that for the British National Grid (see para 16), and consists of the Grid Zone Designation (see para 23 for the UTM Grid and para 28 for the UPS Grid), followed by two letters representing the square identifications, followed by an even number of digits that identify a position within the grid square.

31. Most military maps and charts that carry the UTM Grid have a grid reference box in the margin that explains how to report a grid reference. The grid reference box will indicate the Grid Zone Designation(s) applicable to the map or chart. On larger scale products, the grid reference box will also show the grid square identifications that fall on the map or chart.

32. The MGRS Grid reference of the point marked Guernsey Airport in Fig 14 is obtained in the following manner:

9-2 Fig 14 Example Grid Reference



Grid Zone Designation 30U*

*(This can be found from the grid reference box on the chart, ONC E1 in this example)

100 km square identifier WV
Easting 2 followed by 9 (estimated tenths)
Northing 7 followed by 5 (estimated tenths)

Full grid reference
Guernsey Airport 30UWV2975

This four figure reference defines the point to a precision of 1,000 metres.

WORLD GEOGRAPHIC REFERENCE SYSTEM (GEOREF)

Introduction

33. The use of latitude and longitude as a method for reporting position suffers from the disadvantages stated in para 12. These disadvantages can be overcome by the use of a reporting system based on a lettered rectangular grid. However, rectangular grids which ignore the curvature of the earth, while satisfactory over a limited area, become excessively distorted with any great extension of the area of use. To avoid this distortion, any reference system which is to have universal coverage, must be based on the graticule of meridians and parallels.

34. The World Geographic Reference System (GEOREF) was introduced with the object of providing a simple, speedy, unambiguous method of defining position which is capable of universal application. It incorporates the best of both systems by utilizing the orthodox graticule of meridians and parallels and by expressing the position of any point, in relation to it, by a system of alphanumeric references. In this way, the disadvantages of latitude and longitude (stated in para 12 sub-paras a and b) are overcome.

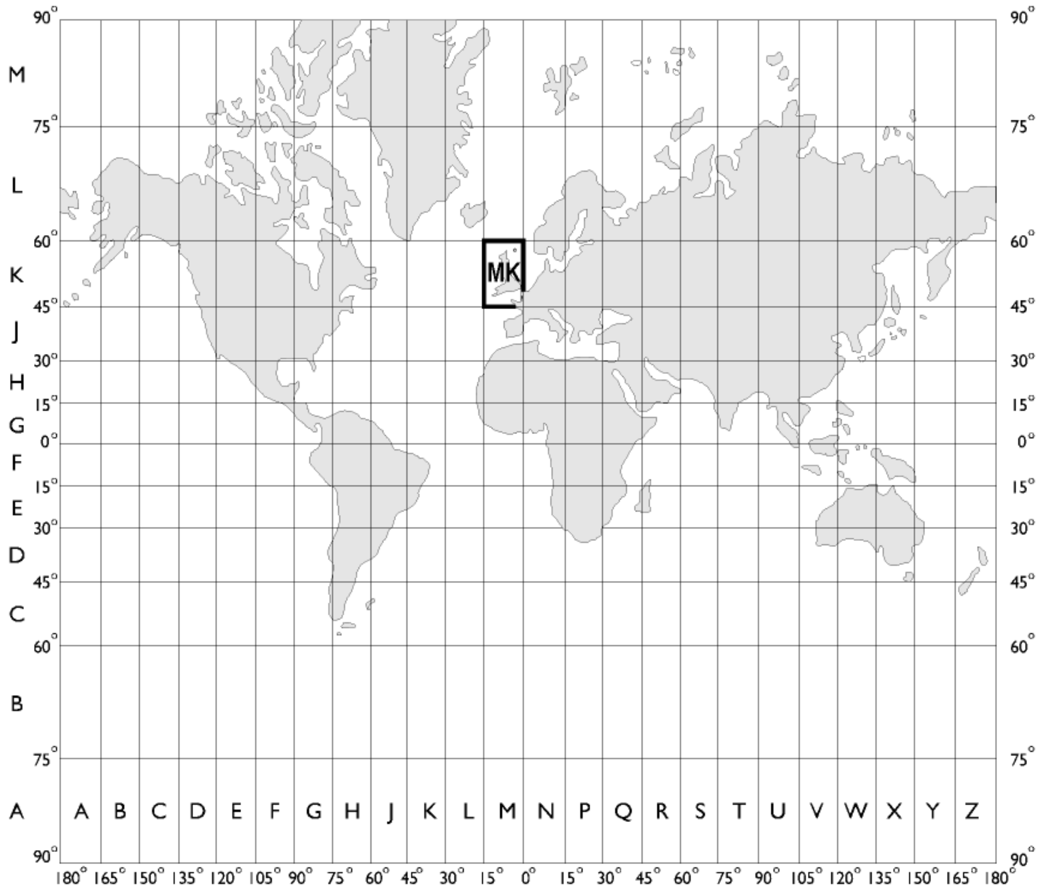
35. It is emphasized that the GEOREF system replaces neither the latitude and longitude nor the rectangular grid methods of reporting positions. However, it provides a convenient means of reporting position within the framework of the latitude and longitude system.

Description of the System

36. The GEOREF system divides the surface of the Earth into quadrangles, the sides of which are specific arc lengths of longitude and latitude. Each quadrangle is then identified by a simple, systematic, lettered code.

37. The first division of the Earth's surface is into 24 longitudinal zones, each 15º wide, which are lettered A to Z inclusive (omitting I and O), commencing eastwards from the 180º meridian. A corresponding division is made of the Earth's surface into 12 latitudinal bands, each 15º wide, which are lettered A to M inclusive (omitting I), commencing northwards from the South Pole. The Earth is therefore divided into 288 quadrangles, of 15º sides, each of which is identified by a unique combination of two letters. The first letter is always that of the longitude zone or easting, and the second that of the latitude band or northing. In this respect, the system differs from that of latitude and longitude in which the latitude is always given first. For example, in Fig 15, it can be seen that the majority of the UK is in the 15º quadrangle MK.

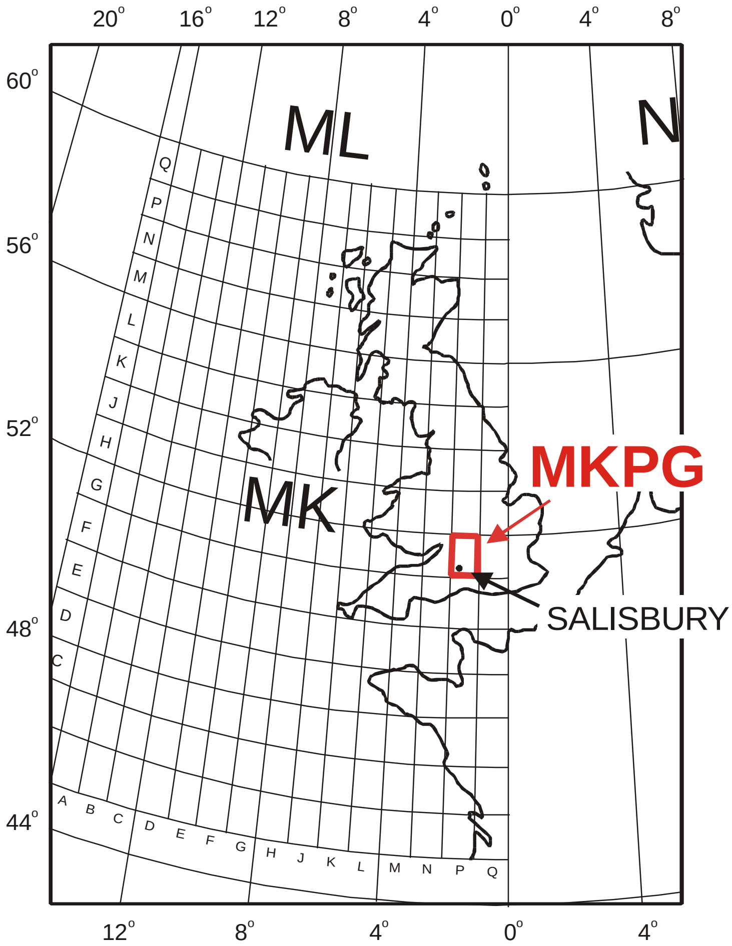
9-2 Fig 15 GEOREF System of 15º Identification Letters



38. Each 15º quadrangle is now sub-divided into 15 one-degree longitudinal zones and latitudinal bands, lettered A to Q inclusive (omitting I and O), commencing eastwards and northwards respectively from the South-West corner of the 15º quadrangle. Thus, the 15º quadrangles are sub-divided into 225 one-degree quadrangles, each being identified by means of four letters. The first two letters identify the 15º quadrangle, the third letter the one-degree zone of longitude, and the fourth letter the one-degree band of latitude.

39. Salisbury, in the County of Wiltshire, therefore lies in the one-degree quadrangle MK PG (see Fig 16).

9-2 Fig 16 One-degree Quadrangles



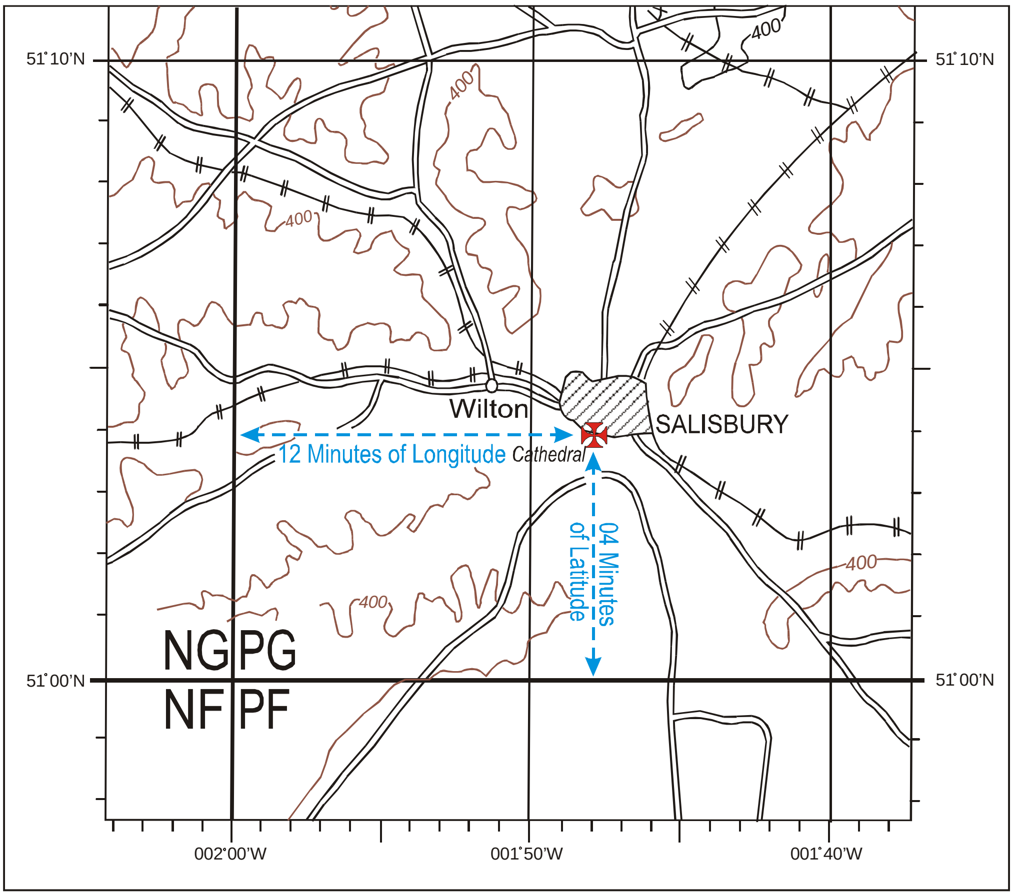
40. Each one degree quadrangle is divided into sixty minutes of longitude, numbered eastwards from its western meridian, and sixty minutes of latitude, numbered northwards from its southern parallel. This method of numbering is used no matter where the one degree quadrangle is located, and does not vary even though the location may be west of the Prime Meridian or south of the equator.

41. A unique reference defining the position of a point to a precision of one minute in latitude and longitude (a precision of 2 km or less) can now be given by quoting four letters and four numerals. The four letters identify the one degree quadrangle. The first two numerals are the number of minutes of longitude by which the point lies eastward of the western meridian of the one degree quadrangle. The second two numerals are the number of minutes of latitude by which the point lies northward of the southern parallel of the one degree quadrangle. If the number of minutes for either of the longitude or latitude values is less than ten, the first numeral of the pair will be zero and must be written. Thus the reference of Salisbury Cathedral (51° 04' N 001° 48' W) is MKPG 1204 (see Fig 17).

42. Occasions may arise (very infrequently) when it is necessary to define a position to an accuracy greater than one minute. The GEOREF system can be expanded to allow for this. A reference to one tenth of a minute of longitude and latitude is obtained by a further sub-division of the one-minute

quadrangle into tenths of a minute of longitude eastwards and into tenths of a minute of latitude northwards from the bottom left-hand corner of the minute quadrangle. The accuracy is now approximately 608 ft, and the reference is given by quoting six numerals instead of four. A further refinement to an accuracy of approximately 61 ft is obtained when the eastings and northings are given additional figures. In this case, the first four numerals represent the eastings in minutes and hundredths of a minute of longitude and the remaining four numerals represent the northings to a similar accuracy. Thus the GEOREF of Salisbury Cathedral, to an accuracy of one-tenth of a minute, is MKPG 122039 and to a hundredth of a minute, MKPG 12250386 (see Fig 17).

9-2 Fig 17 Part of the One-degree Quadrangle containing Salisbury Cathedral in detail



43. On local operations, where the risk of ambiguity with a neighbouring 15º quadrangle is unlikely, the first two letters of the reference may be dropped. The reference given in para 41 would then become PG 1204.

44. When a position lies on a dividing meridian of two longitudinal zones, or a dividing parallel of two bands of latitude, the reference letters quoted are for the most easterly zone or the most northerly band; e.g. the GEOREF of 50º N 00º W is NKAF 0000 (see Fig 16).

Use of GEOREF

45. The GEOREF system is used specifically in:

a. The control and direction of forces engaged in the air defence of the United Kingdom and the countries of the North Atlantic Treaty Organization.

b. The coastal defence of the United Kingdom.

46. Although the system has a restricted use, it is available for universal application should the occasion arise. Whenever security demands, it is a simple operation to change the code letters periodically.

Conversion of Latitude and Longitude to GEOREF Co-ordinates

47. Using the description of the GEOREF system (para 36) and Fig 15, a method of deriving a GEOREF coordinate from a latitude and longitude position can be determined. It must be remembered, when following the example below, that in the latitude and longitude system, latitude is always written before longitude, but, in the GEOREF system, the longitude value is written before the latitude value.

Example: To convert 55º 05' N 010º 29' W to GEOREF

a. Apply the conventional signs for N(+), S(–), E(+) and W(–) to the latitude and longitude position. Thus, 55º 05' N 010º 29' W becomes +55º 05' –10º 29' (The preceding zero can dropped from the longitude degree value).

b. Add 90º to the latitude and 180º to the longitude.

90º 00'	180º 00'
+55º 05'	–10º 29'
145º 05'	169º 31'

c. Divide both of the whole degree portions (145 and 169) by 15:

$$145 \div 15 = 9 \quad (135) \quad \text{remainder } 10 \qquad 169 \div 15 = 11 \quad (165) \quad \text{remainder } 4$$

9	11	(This gives respective quotients of 9 and 11)
15)145	15)169	
135	165	
10	4	(This gives respective remainders of 10 and 4)

d. Add 1 to the quotients: 9 + 1 = 10 and 11 + 1 = 12.

e. Write down the letters corresponding to these numbers, omitting I and O in the count.

A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S	T	U	V	W	X	Y	Z
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

The longitude value (12) gives M and the latitude value (10) gives K.

f. Combine the letters to give MK; this is the 15º quadrangle identifier.

g. Add 1 to each remainder: 10 + 1 = 11 and 4 + 1 = 5.

h. Write down the letters corresponding to these numbers, omitting I and O in the count. The longitude value (5) gives E and the latitude value (11) gives L.

i. Combine the letters to give EL; this is the 1º quadrangle identifier.

j. The numerical portion of the GEOREF is taken from the minutes part of the latitude and longitude values **after** the sum in sub-para b. The longitude minutes are 31 and the latitude minutes are 05.

k. Thus 55º 05' N 010º 29' W corresponds to MKEL 3105 in GEOREF.

Advantages and Disadvantages of the GEOREF System

48. **Advantages.**

a. GEOREF provides an easy and quick method of position reference.

b. There is no risk of ambiguity.

c. It is eminently suitable for use over R/T or telephone.

d. It is capable of universal application.

e. For purposes of security, it is comparatively simple to change the code letters periodically.

f. To provide a reference to a precision of l minute, the group is smaller than the corresponding reference by latitude and longitude.

49. **Disadvantages**.

a. Like the latitude and longitude system, it compares unfavourably with a rectangular grid, since a different scale has to be used for the measurement of the number of minutes of longitude and latitude.

b. The system can be confusing because, contrary to latitude and longitude procedures, the minutes of longitude are given before the minutes of latitude. Similarly, the method of reporting a GEOREF in the southern and western hemispheres is the same as for the northern and eastern hemispheres.

LOCAL DATUMS

Introduction

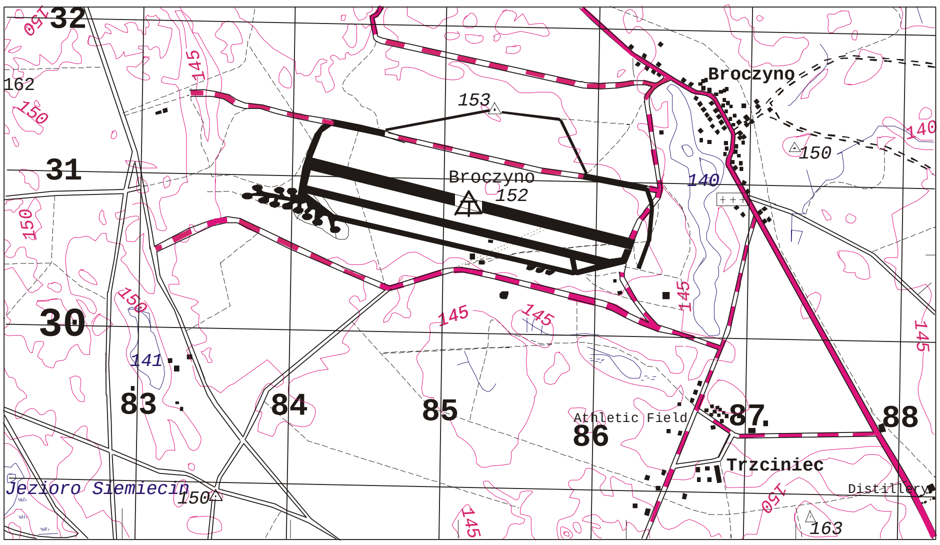
50. A datum can be considered as a set of mathematical constants that define the size and shape of the ellipsoid and how that ellipsoid is fixed to the geoid. It is used in conjunction with the production of a particular map. Despite the introduction of world-wide standards such as WGS 84, many nations still produce maps and charts using local datum references. Provided that all references to position are based upon the same datum, little confusion will ensue. However, co-ordinates for a point on the Earth's surface using one datum will, in most cases, not match the co-ordinates for the same point using another datum.

Error Potential

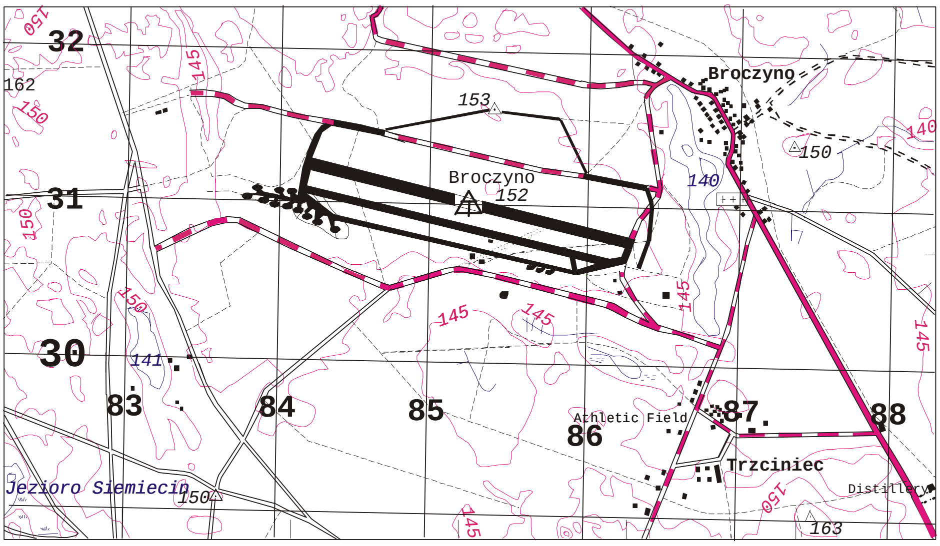
51. Fig 18 shows two maps of the same area but bearing differing grid overlays. Fig 18a is based upon WGS 84 and Fig 18b on the European Datum (ED) 50. The position of the centre of the runway at BROCZYNO can be identified by the co-ordinates 851308 under WGS 84 and as 852310 under ED 50. If this airfield were to be a target, provided that both the target planner and the tasked aircrew were using maps with the same datum, there would be no problem. If not, the position tasked would not be the position attacked.

9-2 Fig 18 Grid Position Comparison

a WGS 84 Grid - Target Position 851308



b ED 50 Grid - Target Position 852310



OTHER METHODS OF EXPRESSING POSITION

Introduction

52. The methods so far discussed have defined position relative to a pair of reference lines. However, there are occasions when simpler methods will suffice.

Pin-points

53. The simplest method of reporting an aircraft's position is to name the point directly beneath the aircraft at that time. This is known as a 'pin-point', and may be a town, airfield, radio beacon etc. However this may be an imprecise method because:

a. Easily recognized features are rarely small.

b. It is difficult for the pilot to determine, and view, the position vertically beneath the aircraft.

c. It relies on the receiving agency's knowledge of the area, and is therefore open to some confusion.

Range and Bearing

54. An alternative method is to express the aircraft's position as a range (distance in nautical miles) and bearing (angular relationship) from an easily identified datum or feature. This method is sometimes referred to as a rho-theta (ρ, θ) system.

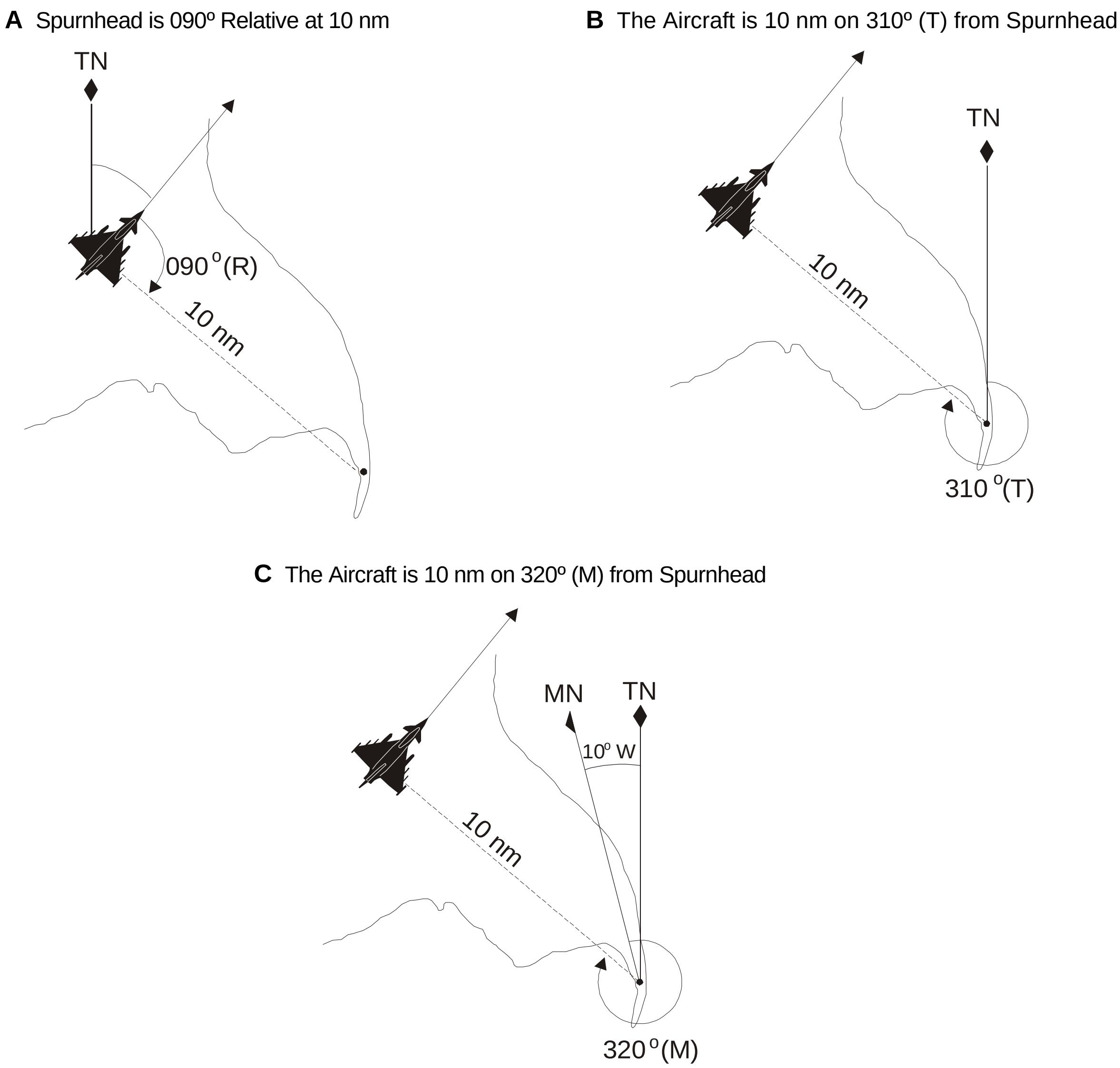
55. Fig 19 illustrates three expressions of bearing for the same aircraft position:

a. Fig 19a shows the relative bearing (measured from the fore-and-aft axis of the aircraft) of the feature from the aircraft. The receiving agency must know the aircraft's heading to interpret this message.

b. Fig 19b shows the true direction of the line joining the feature and the aircraft, measured at the feature. This is known as a 'true' bearing.

c. Fig 19c shows the magnetic direction of the line joining the feature and the aircraft, measured at the feature (known as a 'magnetic' bearing). This method is often used in conjunction with TACAN and VOR/DME beacons, which provide this information directly. When obtained from beacons, magnetic bearings are normally referred to as 'radials', e.g. "I am on the 180 radial from Wallasey VOR", indicates that the aircraft is on a line drawn at 180º (M) from Wallasey VOR.

9-2 Fig 19 Range and Bearing



CHAPTER 3 - MAP PROJECTIONS

Introduction

1. The Earth is an irregularly shaped solid figure whose surface is largely water, out of which the various land masses rise. A map or chart is a representation of this surface at some convenient size on a flat sheet. The term 'map' is generally taken to be a representation of land areas while 'chart' is traditionally reserved for sea area representation. The aviator is not always concerned with this distinction and the air chart covers both. Other terms used are 'plan', to describe a bird's-eye view of a small area, and 'graphic', to describe maps which vividly portray topography.

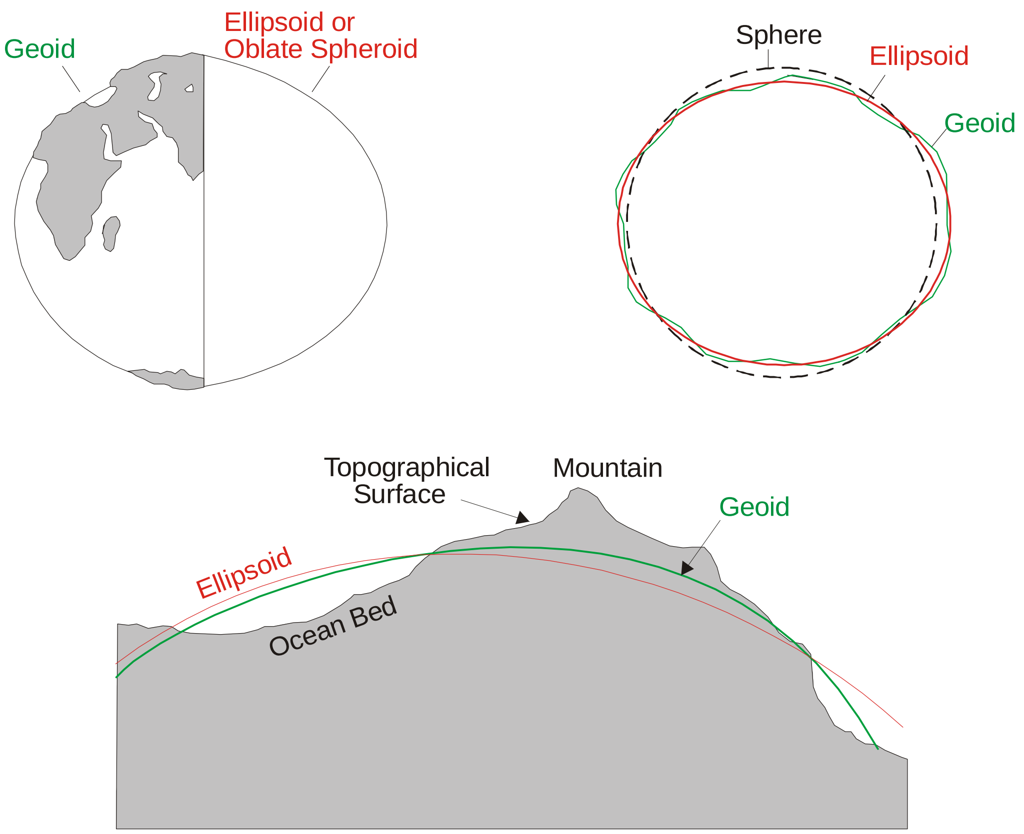
2. A map projection is a systematic laying down of the meridians and parallels on to a flat sheet in such a way that the result displays certain features of the actual surface. There are many ways in which this can be done and clearly a way must be chosen which generates a useful product. However, just as it is meaningless to try to represent a circle by a square, so it is not feasible to represent the Earth's three-dimensional shape on a flat plane in a wholly accurate manner.

3. It would, however, be possible to construct a square which had some features in common with a circle, e.g. the same area, the same perimeter, or the diagonal equal to the diameter. In order to represent all of the circle's features, many different squares would be necessary. Similarly, not all of the Earth's features can be represented accurately on a single map projection. The user must therefore select the correct projection to meet a specific use.

4. For navigation purposes it is important that bearings and distances are correctly represented and easily measured; for convenience the path which is flown should be shown as a straight line and the plotting of radio and other bearings should be straightforward. In order to achieve these characteristics, other properties must be sacrificed; areas may be out of proportion and it may be necessary to restrict the area of coverage of any single map.

5. Before looking at projections and properties closely, the shape of the Earth deserves some more attention. The true topographic surface, with mountains, valleys and oceans, is too irregular for any simple treatment, and it is easier to deal with if approximated by less complicated shapes. There are various possibilities. The water surface (the mean sea surface together with the outline which would be traced if frictionless canals were let into the land masses) is known as the 'geoid'. The geoid is also an irregular surface, but it can be well represented by the smooth surface of an oblate spheroid (or ellipsoid), which is a regular mathematical figure. For many charting purposes, a further simplification can be made by replacing the oblate spheroid by a sphere of the same general size. These are all shown in Fig 1.

9-3 Fig 1 Shape of the Earth



The Vertical Datum

6. The zero surface to which elevations or heights are referred is called the Vertical Datum. Because it is available worldwide, traditionally, surveyors and mapmakers have taken sea level as the definition of zero elevation. The Mean Sea Level (MSL) is determined by continuously measuring the rise and fall of the oceans at 'tide gauge' stations on sea coasts. This averages out the highs and lows of the tides caused by the changing effects of the gravitational forces from the sun and moon, which produce the tides. It is evident, however, that there can be a considerable variation in the average of the local sea level for a particular ocean and that of another. MSL, therefore, becomes more properly defined as the zero elevation for a local or regional area. The heights of mountains or structures on locally produced maps of the area are determined by using the local MSL as the datum. With the advent of satellite navigational systems, which compute heights against a worldwide standard datum, some variation may be observed between heights depicted on the map and those calculated by the instrumentation. If such instrumentation (e.g. Global Positioning System) is being used to provide height information for an instrument approach, it is of paramount importance that the height being presented to the pilot is based upon the same datum as the radar picture being monitored by the approach controller.

Zero Surfaces of Height Systems

7. The differences encountered in height measurements and their representation on maps or equipment displays can be attributed to the differences between the topographic surface of the Earth, the associated flattened spheroid (ellipsoid) and the geoid as described in para 5 and illustrated in Fig 1.

8. **Topographic Surface**. The topographic surface is the actual surface of the Earth tracing the ocean floors to the tops of mountains.

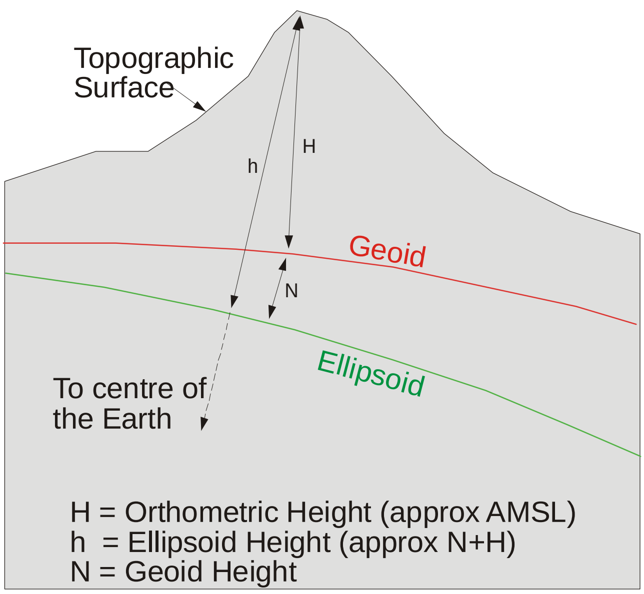
9. **Geoid**. The geoid is the physical model of the Earth and approximates MSL. It is the zero surface as defined by the Earth's gravity. The direction of gravity is perpendicular to the geoid at every point. Variations in the topography and the different densities within the Earth's crust produce slight variations in the gravity field, described by the dips and peaks of the geoid. Since the sea surface conforms to this gravity field, sea level also contains slight hills and valleys similar to, but much smoother than, the topographical surface. At any one point on the ocean, therefore, the sea level may be closer to, or farther from, the centre of the Earth than another such point and this variation may be as much as 5 metres.

10. **Spheroid or Ellipsoid**. The ellipsoid is a smooth representation of the oblate spheroidal shape of the Earth and is used as its geometric model. An ellipsoid is generated by the revolution of an ellipse about one of its principal axes. The ellipsoid which approximates the geoid is an ellipse rotated about its minor axis. In some texts describing the Earth, the term oblate spheroid is abbreviated to spheroid and is synonymous with ellipsoid. The term ellipsoid will be used in this chapter hereafter.

Height Calculation

11. Any zero surface can be used as a datum to express height, even the centre of the Earth. Fig 2 is an enlargement of detail from Fig 1 and shows how each datum discussed may be used to express height.

9-3 Fig 2 Detail from Fig 1 - Representation of Height



12. **Orthometric Height**. Height above MSL is approximately the same as orthometric height (H), the technical name for height above the geoid. There are a few points on land which fall below the geoid, and in such cases, H can be negative.

13. **Geoid Height**. Geoid height (N) is the separation between the geoid and the ellipsoid. It can be plus or minus depending upon whether the geoid is further from, or closer to, the centre of the Earth than the ellipsoid. N is positive where the geoid is further from the centre of the Earth than the ellipsoid, zero when they are coincident and negative when the geoid is closer to the Earth's centre.

14. **Ellipsoid Height**. Ellipsoid height (h) is a measure of distance above or below the ellipsoid (plus or minus). h is also called geodetic height. h is approximately equal to N + H.

Height Interpretation by Global Positioning System (GPS)

15. GPS receivers normally output elevations based upon the ellipsoid. However, the system has the capability to output height, on demand, converted to MSL and most modern receivers are able to access that option. GPS MSL height is based on the best geoid information available for the area in question and this is being continually improved with technological advances in geodesy and instrumentation.

Map Projections

16. Many maps are drawn on projections of the ellipsoid. As stated in para 10, the ellipsoid is the solid figure generated by rotating an ellipse about its minor axis, Fig 3, and lends itself to a tolerably simple mathematical treatment. The minor axis PP′ is the polar axis and the major axis EE′ is the equatorial axis; an ellipsoid can be defined by stating one radius and the ratio $\frac{a-b}{a}$, known as the flattening (f). A single mean ellipsoid can be used to represent the whole Earth, but because the geoid is irregular an ellipsoid can be found which represents one part of the world with fair precision and yet is unsuitable in another part. Some of the ellipsoids in use are listed in Table 1 below.

9-3 Fig 3 The Ellipsoid

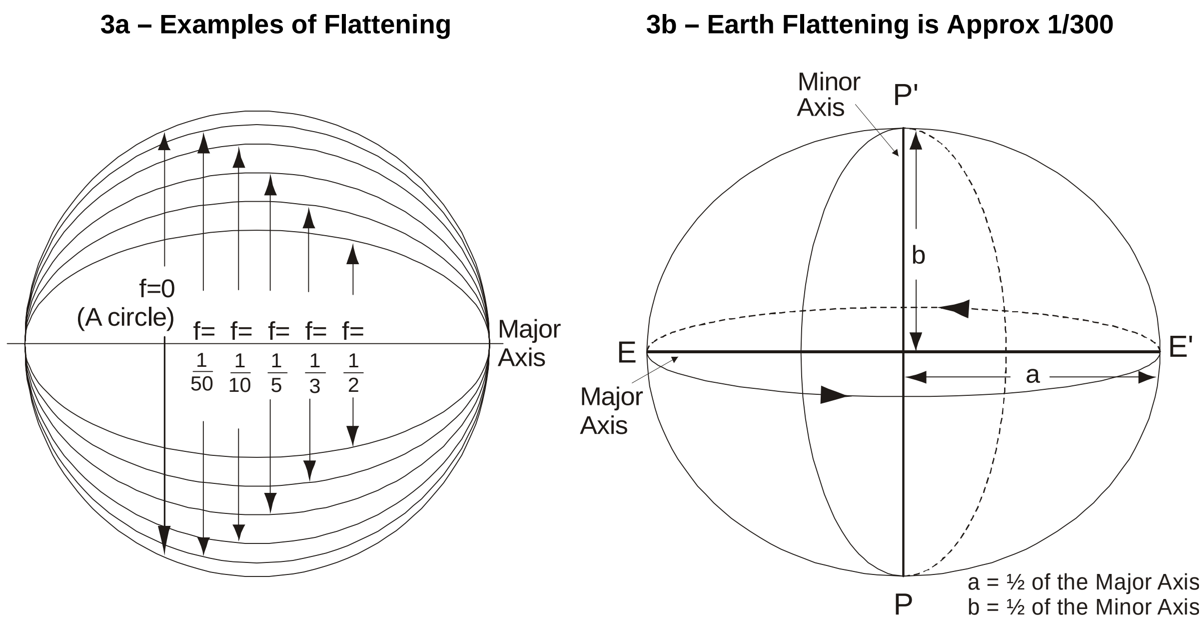


Table 1 Examples of Ellipsoids in Use

Area	Ellipsoid Name	Radius km	Radius nm	Flattening
Russia	Krassovsky	6378.250	3443.98	1/298.3
N America	Clarke 1866	6378.206	3443.96	1/295.0
Europe	International 1909	6378.388	3444.05	1/297.0
Japan	Bessel 1841	6377.397	3443.52	1/299.2
Africa	Clarke 1880	6378.249	3443.98	1/293.5
India	Everest	6377.276	3443.46	1/300.8
World Geodetic System 1972 (WGS72)		6378.135	3443.55	1/298.3
World Geodetic System 1984 (WGS84)		6378.137	3443.56	1/298.3

17. Because of the difference between the ellipsoids, the position discrepancies between maps based on neighbouring ellipsoids can give errors as great as 1500 m. However, it is possible to select the correct datum in advanced navigation systems to alleviate this.

18. The ultimate simplification of the figure of the Earth is the sphere. The geometry is easy, and projections can be reduced very often to ruler and compass constructions. In the chapters which follow, projections of the sphere, which are often used in practice, are described; projections of the ellipsoids follow similar patterns but are very much more complicated. From a practical point of view no projection allows precise measurement of bearing and distance, and there is little advantage to be gained from complexity. When great precision is required the quantities are best calculated, rather than measured, from the appropriate ellipsoid.

19. **Summary**. The points which this introduction has attempted to make are as follows:

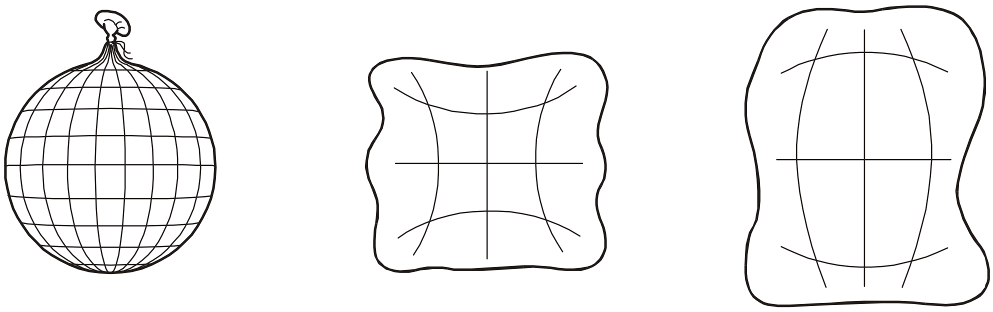
a. The Earth's figure can be described in order of reducing precision as the geoid, an ellipsoid (sometimes called a spheroid) or a sphere. Map projections are drawn using a sphere or an ellipsoid as the figure of the Earth.

b. A map projection is not in general a picture of the Earth. It is a plane drawing on which certain distances, areas, directions, or other features on the Earth required for navigation purposes are reproduced.

Classification of Map Projections

20. A simple insight into the problems of representing the Earth on a flat surface can be gained by imagining a balloon blown up to some manageable size to make a model of the Earth. Having drawn all the shapes and lines on the balloon, it could be deflated, and the piece required cut out and stretched to make it flat. Of course, it could be stretched more in one direction than another and a great variety of shapes obtained. Each time the flat elastic plane was altered, another map projection would result. Fig 4 illustrates some of the many possibilities.

9-3 Fig 4 Elastic Projections

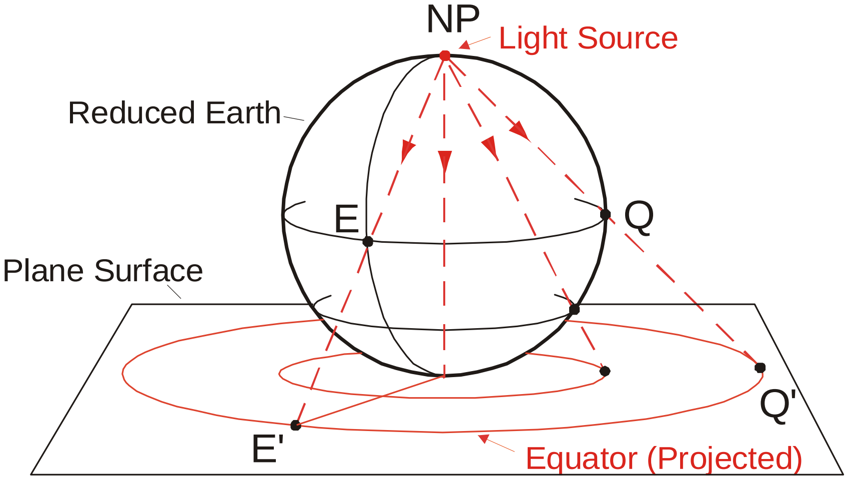


21. Most of the projections obtained in this way would not be very useful. It would be more convenient if the meridians were straight lines for example, and this could be obtained by suitably manoeuvring the material; also, by sticking down parts of the rubber the amount of stretch in a given direction could be varied along that direction. But it would be difficult to control the rubber to give any predetermined projection and this model is not used in practice.

22. In actual map projections a relationship between points on the surface of the Earth and the corresponding point on the plane is formulated mathematically. For each of the odd-looking diagrams in Fig 3 some such point-to-point relationship exists. The relationship may be a complicated formula involving many variables, or it may be extremely simple.

23. **Perspective Projections**. The simplest relationships are those which can be reproduced by simple geometric construction. They are called perspective projections since they are nothing more than drawings of the shadows which would be cast by the meridians and parallels on a transparent model Earth on to a plane surface, or on to a surface which can be made plane. One example of this is given in Fig 5 where a point source of light at the North Pole of the model Earth (usually called the reduced Earth) projects the meridians and parallels on to a plane tangential at the South Pole. Variety is obtained by moving the light and the plane.

9-3 Fig 5 A Perspective Projection

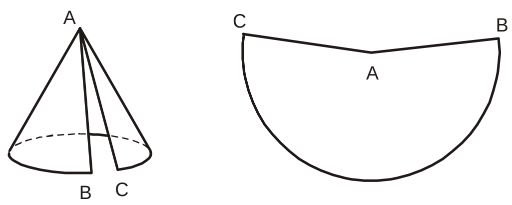


24. **Non-perspective Projections**. When the relationship is such that simple geometric construction is impossible the projection is designated non-perspective. The majority of map projections are non-perspective, but every non-perspective projection can be thought of as perspective projection which has been adjusted in some way. Hence a study of the simple projections leads without too much difficulty to the more complicated ones. In this section each of the non-perspective projections, which comprise nearly all the most useful ones, will be dealt with under a generic title which really describes its perspective primitive.

Types of Perspective Projections

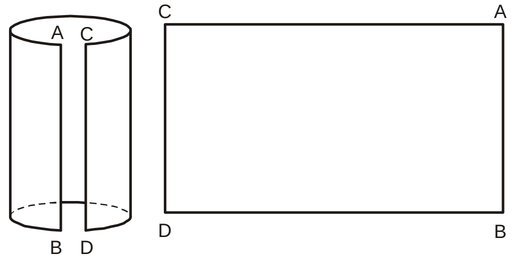
25. The surface on to which the shadows described in para 23 are cast need not be a simple flat surface, and any surface which can be subsequently opened out and laid flat will do. For example a cone (Fig 6) can be placed over the reduced Earth, the projections carried out, and then the cone can be cut and opened (the technical expression is 'developed') to lie flat.

9-3 Fig 6 Development of a Cone



26. A cylinder can also be wrapped around the reduced Earth and developed after projection as shown in Fig 7.

9-3 Fig 7 Development of a Cylinder



27. These three projection surfaces provide the generic titles as follows:

a. Azimuthal projections are perspective projections on to a plane surface, together with certain associated non-perspective projections.

b. Cylindrical projections are perspective projections on to a cylinder, together with the associated non-perspective projections.

c. Conical projections are perspective projections on to a cone, together with the associated non-perspective projections.

28. Variety in each group is obtained by varying the light source position. In fact the classification is somewhat artificial since a cylinder is a cone whose apex angle is 0º, and a plane is a cone whose apex angle is 180º. The cylinder and the plane are therefore limiting cases of the cone.

Representation of Scale

29. The balloon model of the Earth in para 20 was impractical because it would be difficult to control the stretching of the rubber to obtain a particular projection. However, one point was quite clear - stretching was required to lay it absolutely flat. This point is vital. It is not possible to project a sphere on to a plane without at least some elongation taking place.

30. Scale is defined as the ratio of chart length to Earth length; because of the distortion which takes place it is impossible for this ratio to be constant all over any projection and small lengths only can be considered. The rubber can be stretched to make the scale constant along one line for example, or it can expand in all directions from a point; it cannot be arranged to have the same value everywhere.

31. On a great many charts scale changes by different amounts in different directions from a point. It is usual therefore when stating scale to quote where it exists.

32. **Methods of Expressing Scale**. Three methods of expressing scale are in general use:

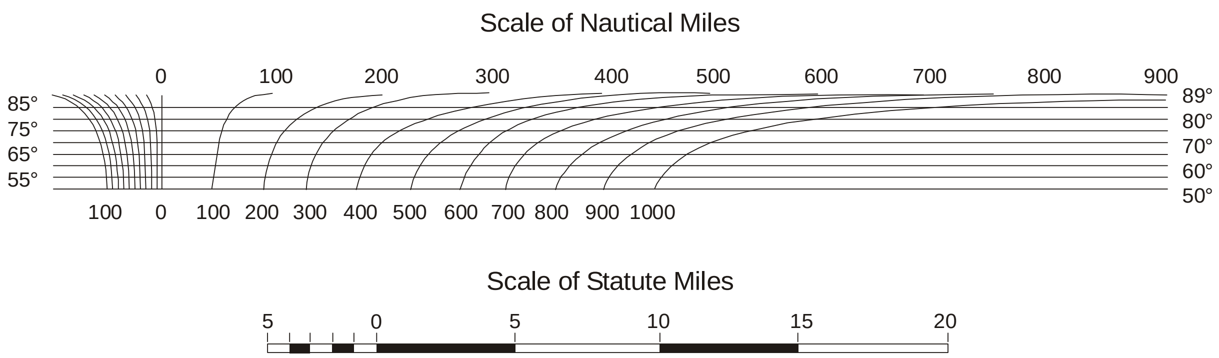
a. The representative fraction, e.g. $\frac{1}{500{,}000}$ or 1 in 500,000, or 1: 500,000.

b. The plain statement, e.g. "2 cm to 1 km".

c. The graduated scale, as shown in Fig 8.

In most calculations it is convenient to use the representative fraction; note that 1:500,000 is referred to as a larger scale than 1: 1,000,000.

9-3 Fig 8 The Graduated Scale



33. **Scale Factor**. Mention has been made already of the reduced Earth. Since this is a model of the Earth its scale can be expressed as a ratio of Reduced Earth length to Actual Earth length and will be constant. In map projections a reduced Earth of given scale is used as the basis of a given projection;

somewhere on each projection a point or line (or lines) will exist with the same scale as the reduced Earth. This is the scale usually printed on maps and charts and scale at other points is determined with the aid of a ratio known as scale factor.

Scale factor is defined as:

$$\text{Scale Factor} = \frac{\text{Chart Scale}}{\text{Reduced Earth Scale}}$$

or

$$\text{Scale Factor} = \frac{\text{Chart Length}}{\text{Reduced Earth Length}}$$

the length being those of a given distance element on Earth.

34. **Scale Deviation**. The stated scale of a chart is usually the reduced Earth scale, hence at a point where stated scale is correct (ie where Chart scale equals Reduced Earth scale), Scale Factor = 1. At other places the scale factor will be other than unity, it may be more if the scale has expanded, or less if there has been compression. The difference between scale factor and unity describes the scale deviation and is expressed as a percentage change, i.e.,

$$\text{Scale Deviation \%} = (\text{Scale Factor} - 1) \times 100.$$

As an example, suppose it is necessary to find the scale and scale deviation at a point, B, where the scale factor is 1.01, and where the stated scale of the map is 1: 1,000,000.

$$\text{Scale at B} = \text{Scale factor at B} \times \text{Reduced Earth Scale}$$

$$= 1.01 \times \frac{1}{1{,}000{,}000}$$

$$= \frac{1}{990{,}099}$$

or 1 in 990,099

$$\text{Scale Deviation at B} = (1.01 - 1) \times 100 = 1\%$$

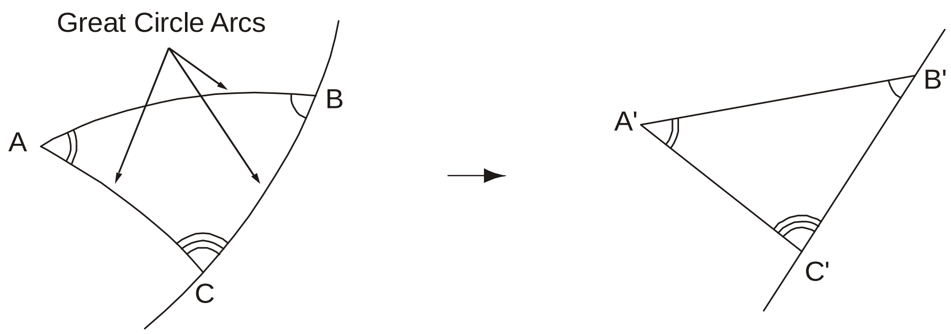
35. **Measurement of Distance**. One of the prime requirements of a map projection is that distance measurement should be simple and accurate. Since a constant scale is impossible throughout any projection the demand is realized by using charts on which the pattern of scale expansion is well defined in any direction from a point, or by using only those small sections of a given projection over which scale expansion is so small that the chart can be regarded as having a constant scale (for practical purposes a limit of ± 1% scale deviation is accepted).

Conformal Projections

36. For navigation purposes it is important that a chart should give an accurate representation of bearings; the bearing of one point from another on the Earth's surface should be represented by the same angle on the chart. This requires that at a given point on the chart the scale expansion is the same in all directions. A projection which has this property is called conformal or orthomorphic. Some of the features of conformal projections are discussed below.

37. **Representation of Great Circles**. The sum of the angles of a plane triangle is 180°, but the sum of the angles of a spherical triangle, whose sides are great circles, is always in excess of 180°; the triangle contained by two meridians and an arc of the equator has two right angles. Hence it is not possible to project all great circles as straight lines on a conformal projection (Fig 9). As with scale, however, it is often possible to use a restricted section of a projection in which all great circles are approximately straight lines.

9-3 Fig 9 Great Circle as Straight Lines

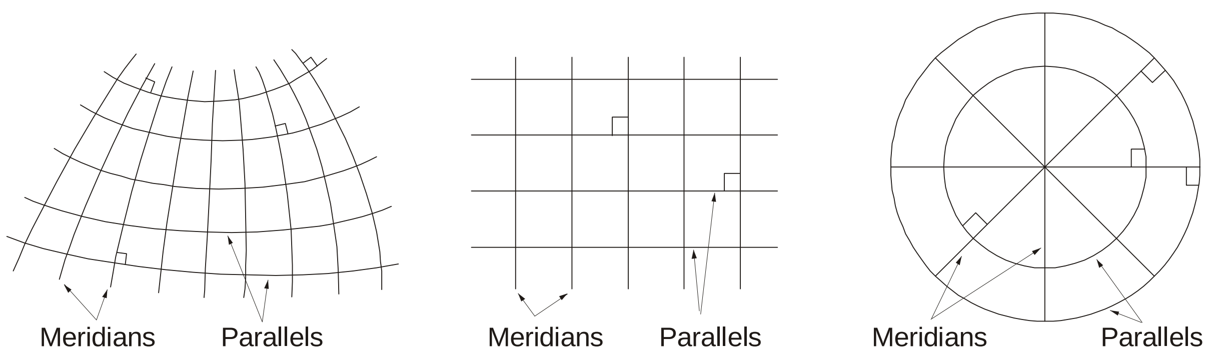


If $\hat{A} + \hat{B} + \hat{C} > 180°$, then A' B' C' is impossible

38. **Representation of Rhumb Lines**. Since rhumb lines cut successive meridians at the same angle they can be represented by straight lines. Of course, this does not mean that they are straight lines on all charts; indeed, as a general rule they are not.

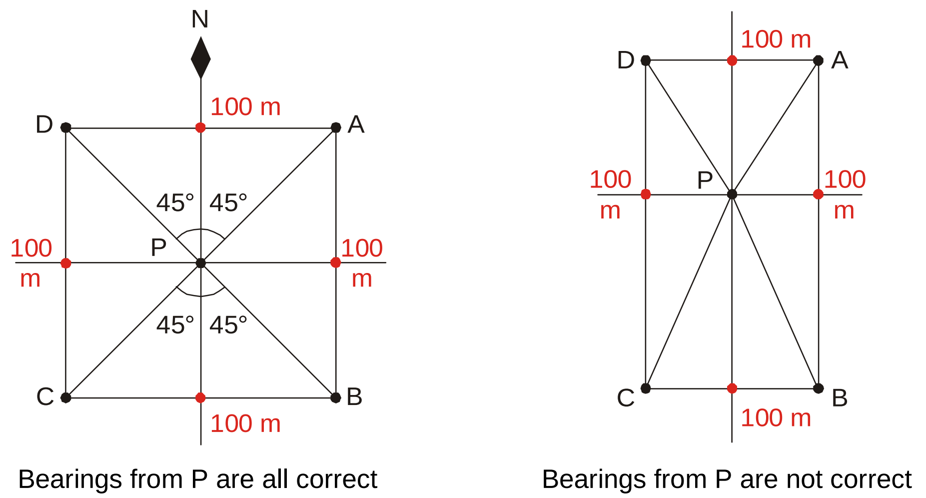
39. **Meridians and Parallels**. Since the meridians and parallels intersect at right angles on the Earth, they must intersect at right angles on a conformal projection. They need not be straight lines and Fig 10 illustrates some of the possibilities.

9-3 Fig 10 Meridians and Parallels



40. **Scale at a Point**. By definition scale at a point must be the same in all directions. If a point, P, and a small area around it is considered, (so small that the Earth is sensibly flat) then if 100 m to the North of P is represented by 1 mm so also must 100 m in any direction be represented by 1 mm if the compass rose at P is not to be distorted. The result of different scales in various directions is illustrated in Fig 11. It is not always possible to check scale in all directions, but if the meridians and parallels are orthogonal and scale is the same along both at a point then the chart is conformal.

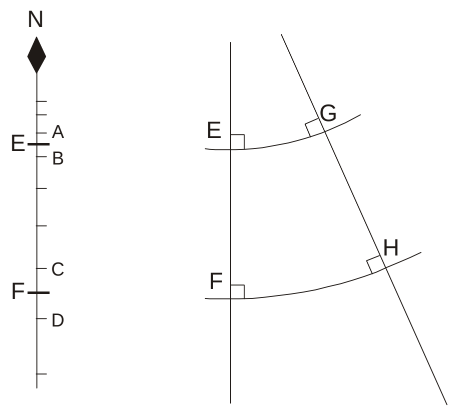
9-3 Fig 11 Scale of a Point



41. **A Meaning for 'Same Scale'**. Since there has to be a scale expansion it is a useful starting point to define what it will be in one direction and then to see what must happen in other directions if the chart is to be conformal. Suppose that scale along a meridian on a given projection follows the pattern shown in Fig 12, let the mean scale over CD be 1:500, and the mean scale over AB be 1:1000. Since these values apply exactly only at points somewhere in CD and AB, suppose they apply at E and F (not necessarily the mid-points). If the chart is conformal the scales in any direction at the points E and F must be 1:1000 and 1:500, and in particular these scales apply in the directions East and West. Applying this pattern to a larger area of the chart, if on this conformal projection the parallels are concentric then the meridians must be radii of those circles. In other words the scale expansion along GH must be the same as that along EF. The scale at G must equal the scale at E, and that at H equal that at F, and so for all points on the parallels EG and FH. There can only be one conclusion, the scale

must be constant along each parallel and have the value given by the expanding meridian scale at its latitude. Thus, the apparent paradox that while scale expansion differs about a point, nevertheless the scale about the point is the same, is seen to be meaningful. Parallels and meridians have been considered here for simplicity. In some projections it is convenient to define different co-ordinate systems, but the same rules will apply.

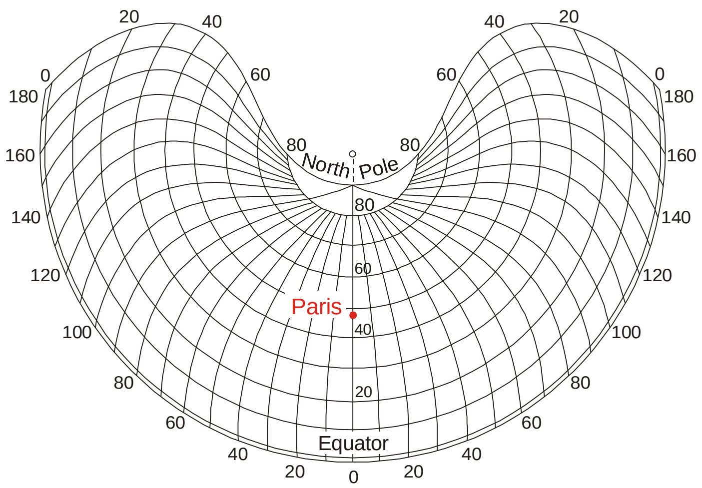
9-3 Fig 12 Same Scale in all Directions



Non-conformal Projections

42. For many purposes, outside navigation, charts having properties other than orthomorphism are required. In atlases it is often useful to have a map on which areas are shown in their correct proportion. This property is obtained by elongation, or shearing, so that scale is not the same in all directions at a point, but the product of the scales in two perpendicular directions is the same everywhere. A typical equal area, or equivalent, projection is shown in Fig 13.

9-3 Fig 13 Bonnes Equal Area Projection



43. Very few non-conformal projections are useful for navigation, but it is clearly useful to have charts on which all great circles are straight lines, or on which distances from a specified place (and no other)

can be precisely measured using a constant scale. These properties can be obtained on non-conformal projections known as the gnomonic and azimuthal equidistant projections respectively.

Earth Convergency

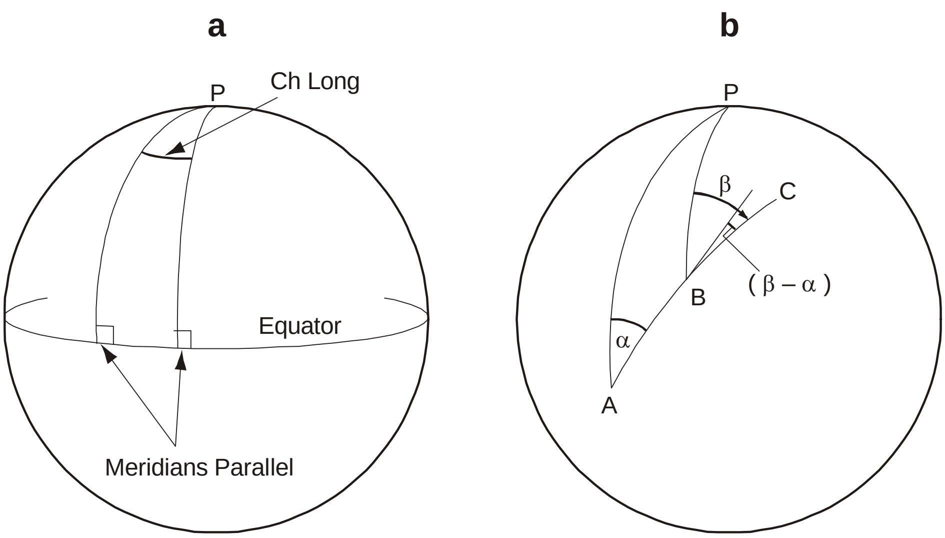
44. The angle which one meridian on the Earth makes with another is known as Earth convergency. At the poles its value is ch long (Fig 14a), but it reduces away from the pole until, at the equator where the meridians are parallel to one another, its value is 0º. If the Earth is considered as a sphere its value is given by:

Earth convergency = ch long sin lat

45. More generally this term applies to the difference in great circle bearing over two meridians. The angle ($\beta - \alpha$) in Fig 14b is Earth convergency given approximately by:

Earth convergency = ch long sin mean lat.

9-3 Fig 14 Earth Convergency



46. Convergency, as defined in para 45, is one feature which can never be faithfully projected, for, like scale, it is a property inherent in the sphere. It describes the shape of the Earth's surface, and any map on which it is correctly shown must itself be a spherical surface.

Chart Convergence

47. The angle which one meridian makes with another on a projection is known as chart convergence. If the meridians are represented by straight lines, then chart convergence will be a constant; if the meridians are curved, it will differ from one point to another.

Definitions and Dimensions

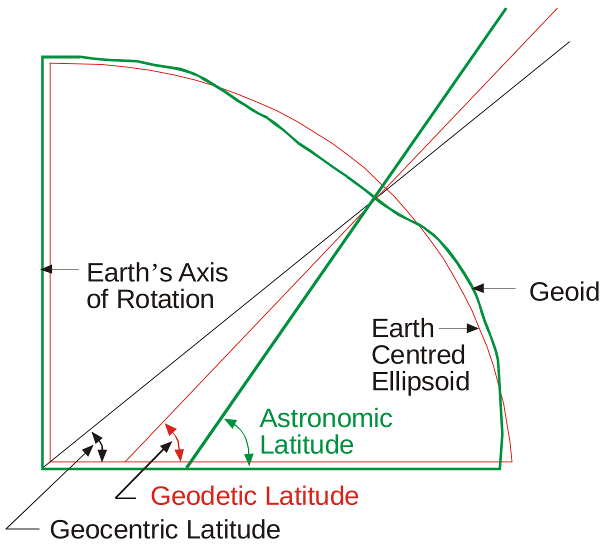
48. Depending on the degree of simplification which is applied to the shape of the Earth, so different definitions of latitude arise. These are illustrated in Fig 15 as follows:

a. **Astronomical Latitude**. On the geoid, the astronomic latitude is the angle between the vertical (the direction of gravity) at a place and the plane of the equator. It is therefore indicated by the normal to the geoid at the place.

b. **Geodetic (or Geographic) Latitude**. On an ellipsoid, the geodetic latitude is the angle between the normal to the ellipsoid meridian at a place and the plane of the ellipsoidal equator. This is the latitude plotted on navigation charts.

c. **Geocentric Latitude**. The geocentric latitude at a point is the angle made with the Earth's equatorial plane by the radius from the Earth's mass geocentre through that point.

9-3 Fig 15 Definitions of Latitude



49. In practice, when using astro, the astronomic latitude is determined (for example when a Polaris sight is taken), but the difference between this and geodetic latitude is so small that a correction is not usually applied. Geocentric latitude is useful in certain problems. If the Earth is considered as a sphere, then geodetic and geocentric latitude coincide.

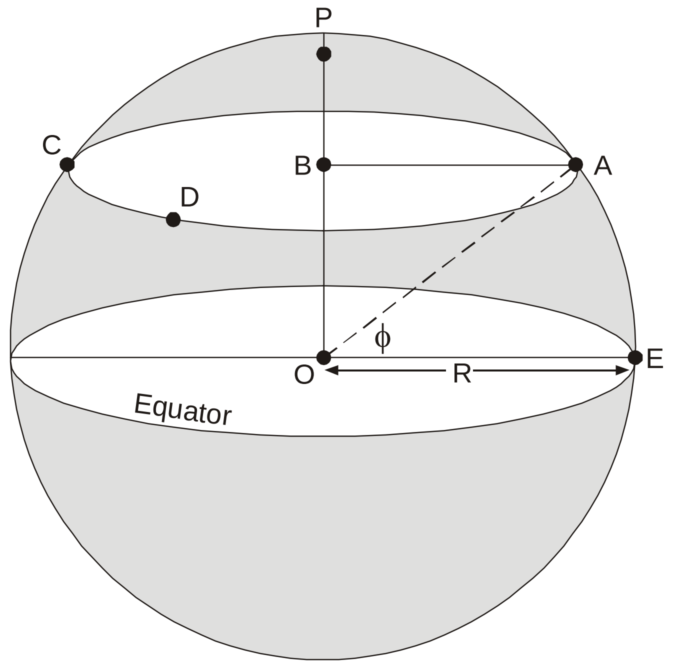
50. **Reduced Earth**. The first stage in map projection is the making of a reduced Earth to the scale required. This model can be ellipsoidal or spherical. If it is spherical then, in effect, the projected latitudes which result are corrected by the difference between the geodetic and geocentric latitudes. This difference is known as reduction of latitude; it is a quantity which also occurs when certain navigation tables based on the sphere are used. Reduction is maximum at latitude 45º when its value is about 11.6 minutes.

51. **Length of a Parallel of Latitude**. By considering the Earth as a sphere, a simple expression for the length of a parallel of latitude can be found. In Fig 16, the length of the parallel of latitude is the circumference of the circle, centre B, radius BA swept through ADC. Since:

$$\begin{aligned} \text{Circumference} &= 2\pi r \\ \therefore \text{ length of parallel} &= 2\pi BA \\ &= 2\pi OA \cos \phi \\ &= 2\pi R \cos \phi \\ &= 2\pi R \sin (90 - \phi) \\ &= 2\pi R \sin \kappa \end{aligned}$$

where R is the radius of the sphere, ϕ is the latitude and κ the co-latitude. By substituting R = reduced Earth's radius, the length on the model Earth can be found.

9-3 Fig 16 Length of Parallel of Latitude



52. **Arc of a Meridian - The Nautical Mile**. The nautical mile, at a given place on the Earth's surface, is the length of an arc of the meridian subtended by an angle of 1' at the centre of curvature at that place. If the Earth were a sphere, this distance would be constant, but because of the ellipticity it must clearly vary with latitude, being shorter at the equator than at the poles. An expression for the nautical mile is:

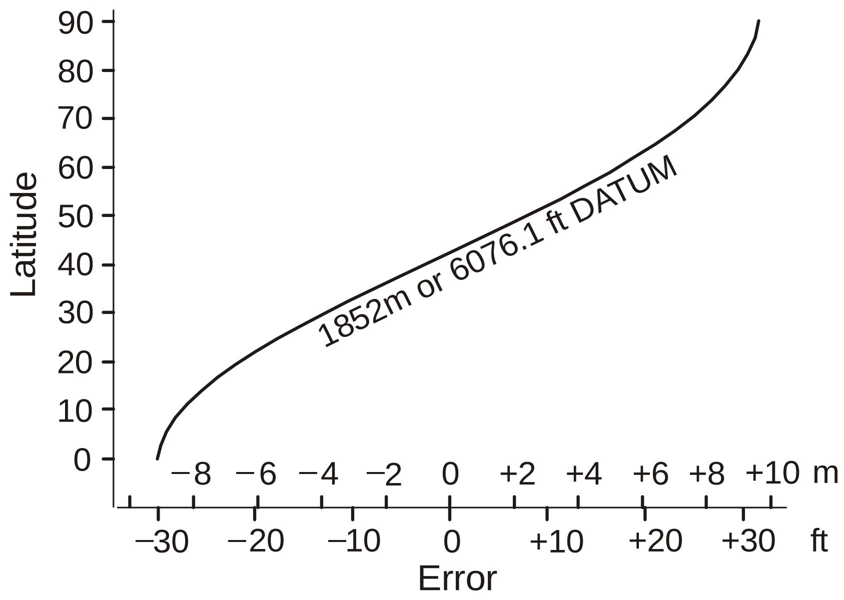
Length of nautical mile = 1852.9 m (9.3 cos 2ϕ metres)

or 6079.2 ft (30.6 cos 2ϕ feet)

In practice, a mean figure is convenient, and the standard adopted since 1 Mar 1971 is the International Nautical Mile = 1,852 m (6,076.1 ft) - (prior to that date the UK Standard Nautical Mile was taken to equal 6,080 ft). The 1,852 m standard is correct at about 42º 08' on the International Ellipsoid, on which the true nautical mile varies from 1,843.6 m (6,048.5 ft) at the equator to 1,862.3 m (6,109.8 ft) at the poles. When a standard unit is adopted for use within automatic instruments, some errors will accrue, as discussed below.

53. **Latitude Error**. For most practical purposes, an aircraft which flies one nautical mile is assumed to have changed its position by the length of an arc which subtends an angle at the centre of the Earth of one minute. This is not strictly accurate as the relationship between a standard nautical mile and the angle subtended at the Earth's centre varies with latitude. A graph of the difference between the International Nautical Mile and the true nautical mile is at Fig 17.

9-3 Fig 17 Errors in the Length of a Nautical Mile



54. **Height Error**. Since an aircraft will fly at a height above the surface of the earth, instruments will, in general, indicate too great a distance flown between two points as measured on the map. The discrepancy will increase with increasing height. From Fig 18 it will be seen that an arc S (representing the ground distance to be flown) subtended by an angle θ radians at the centre of the Earth of radius R is equal to R θ. For an aircraft flying at a height (h), there is a small increase in arc flown equal to δ S such that:

$$S + \delta S = (R + h)\,\theta$$

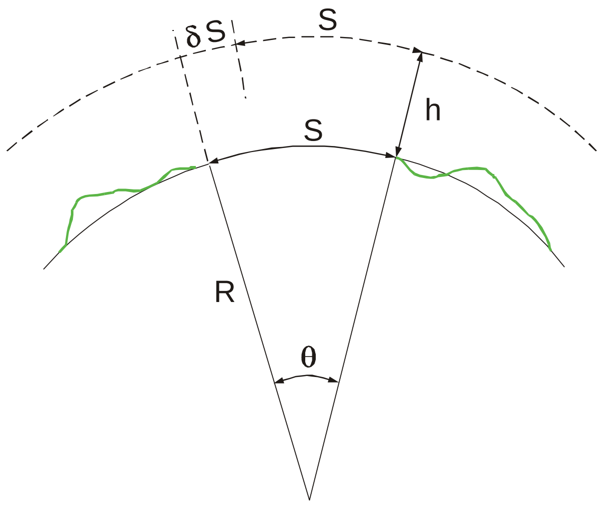
$$= R\,\theta + h\,\theta$$

$$\therefore \delta S = h\,\theta$$

$$\text{as } \theta = S / R$$

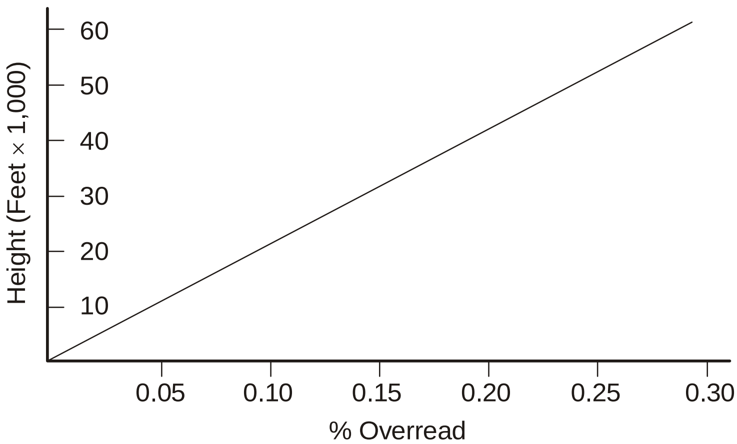
$$\delta S = \frac{hS}{R}$$

9-3 Fig 18 Height Error



A graph of the height error values for heights between 0 ft and 60,000 ft is given in Fig 19.

9-3 Fig 19 Height Error Values



Some Map Projections Compared

55. In Fig 20, a sphere has been projected by various devices. On the sphere, a man's face is outlined, and his appearance is seen to alter from one projection to the next.

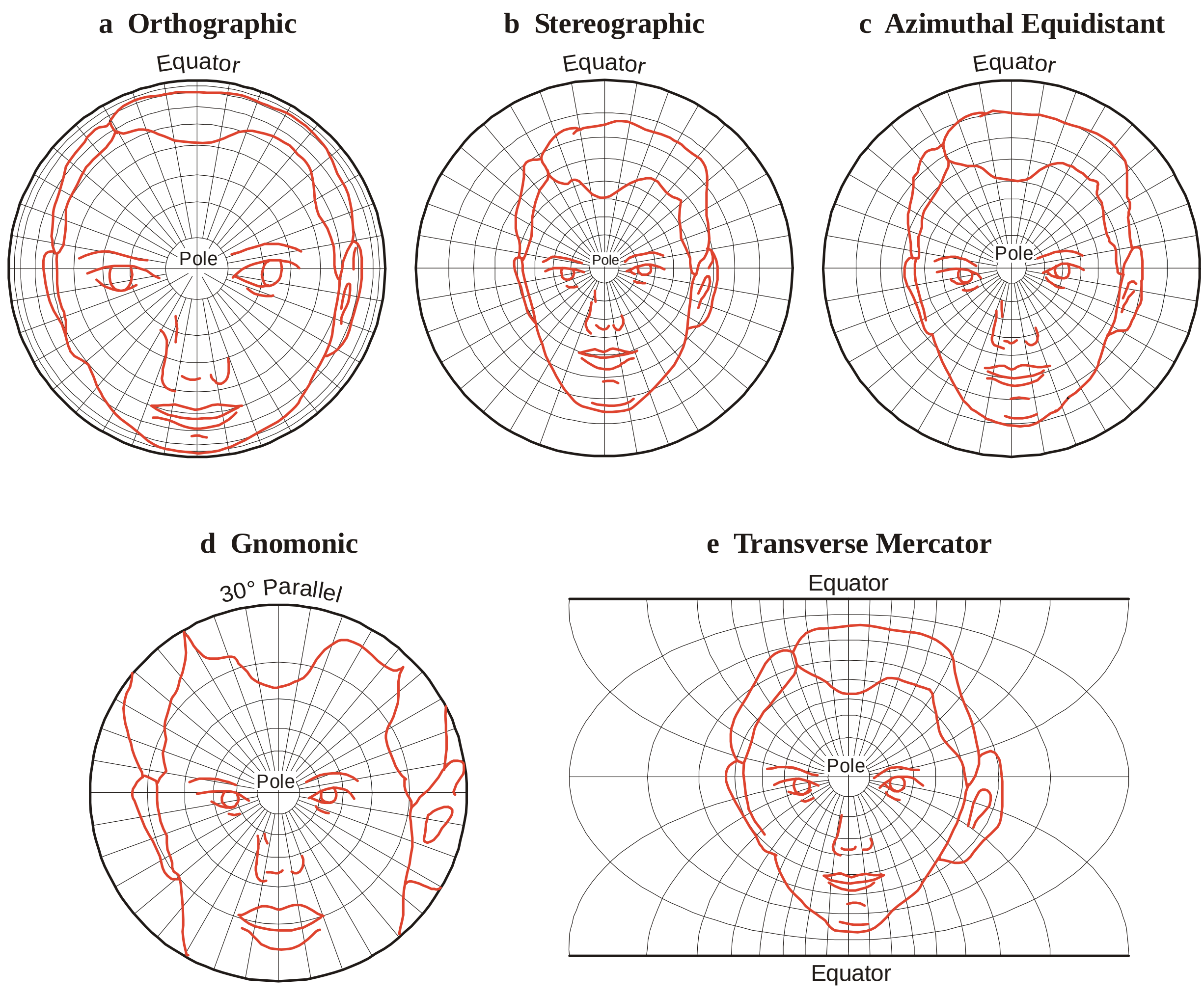
56. If the sphere is seen from an infinite distance (i.e. it is projected by parallel rays on to a flat surface) the face has the podgy look of Fig 20a. This particular projection is known as orthographic, it is neither conformal, nor equal area, nor has it any other particularly useful property, but it can be regarded as a starting point since it is how the face would appear if viewed through a telescope from a great distance.

57. Figs 20b and e are conformal projections. The bearing of one place from another (measured from the local meridian) is the same on each projection and is the same as that obtained on the surface of the sphere. It should be noted that the meridians are curved in e and straight in b, and that the face is quite different in each; Fig 20b is a polar stereographic projection, and e is a transverse Mercator projection.

58. Figs 20c and 20d, (the azimuthal equidistant and gnomonic respectively), are non-conformal projections. In c the scale is constant along all meridians, in d it expands very rapidly along the meridians, so much so that the equator cannot be shown - it is at an infinite distance from the pole. Once again, the face changes.

59. These drawings illustrate the important point that none of the projections reflects what the face is really like. Each face is different, yet the similarities are sufficient to show that the same face is portrayed on each. In the same way a map projection will illustrate all the topographical features of the Earth's surface - and yet it cannot show what the surface really looks like.

9-3 Fig 20 Projections of a Sphere



AZIMUTHAL PROJECTIONS

Introduction

60. This chapter deals with one of the limiting cases of the conic projections; the azimuthal (or zenithal) projection. Unless otherwise specified, the Earth is treated as a sphere for simplicity.

61. In this case the apex angle of the cone is 180°, i.e. the projection is on to a plane tangential at a point to the reduced Earth. All projections of this type have the property that bearings from the point of tangency are correctly represented. Three types of azimuthal projection are discussed:

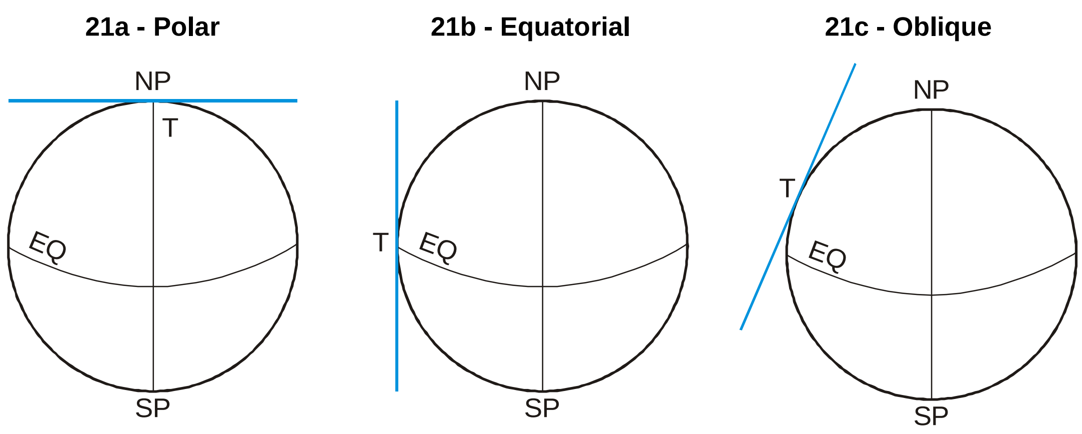
a. **The Gnomonic Projection**. The gnomonic projection is a perspective, non-conformal projection, on which great circles are straight lines.

b. **The Stereographic Projection**. The stereographic projection is conformal and perspective.

c. **The Azimuthal Equidistant**. The azimuthal equidistant projection is a non-conformal, non-perspective projection on which distances from the point of tangency are represented at a constant scale.

The plane can, in each type, be orientated to be tangential at a pole, or at the equator, or more generally in an oblique attitude as shown in Fig 21.

9-3 Fig 21 Azimuthal Projections



THE GNOMONIC PROJECTION

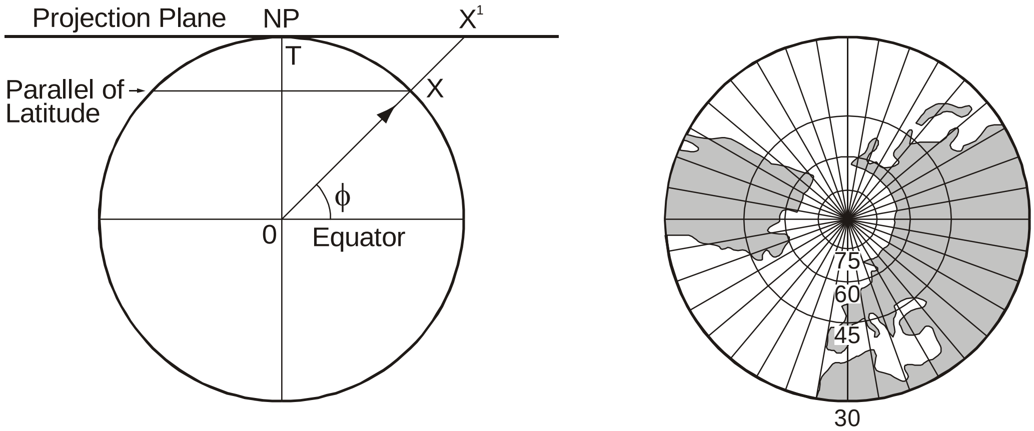
General

62. The gnomonic projection is perspective; the meridians and parallels being projected on to the plane surface from the centre of the sphere. It has the unique property of representing all great circles as straight lines. Scale increases away from the point of tangency, but as the scale is not the same along the meridians and the parallel at any point (except the point of tangency) the projection is not conformal.

The Polar Gnomonic

63. The point of tangency in this case is at one of the poles. The graticule is projected from the centre of the Earth (Fig 22); the parallels appear on the projection as concentric circles about the pole and the meridians are radials from the same point.

9-3 Fig 22 Polar Gnomonic



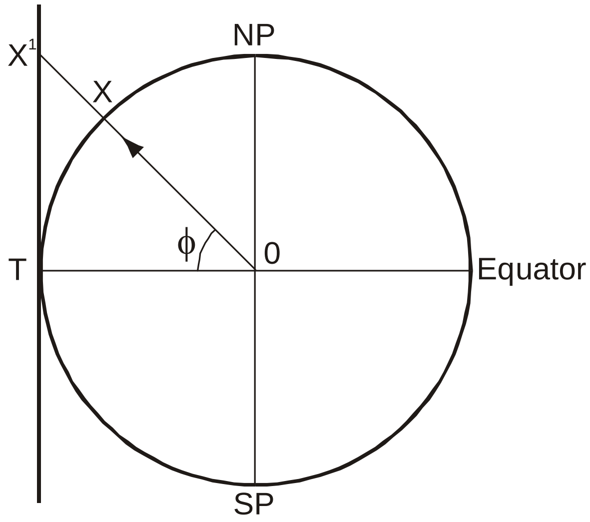
64. **Scale**. Scale increases away from the pole of tangency, but the rate of change along the meridians differs from that along the parallels. At a latitude ϕ, the scale factor along the parallel is given by sec (90° – ϕ) and the scale factor along the meridian by $\sec^2$ (90° – ϕ).

65. **Coverage**. This projection is limited in extent to less than 90° from the point of tangency; the equator cannot be shown since it would project as a plane parallel to the tangent plane.

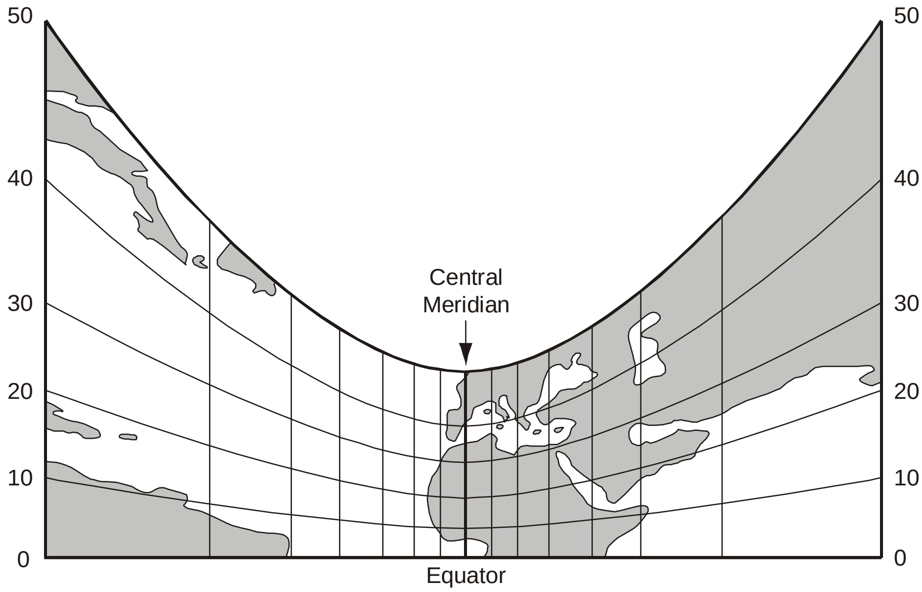
The Equatorial Gnomonic

66. The principle of projection is the same as for the polar gnomonic but in this case the point of tangency is on the equator (Fig 23). The meridians appear on the projection as parallel straight lines perpendicular to the equator, and the parallels as curves concave to the nearer pole, as shown in Fig 24.

9-3 Fig 23 Equatorial Gnomonic Projection



9-3 Fig 24 Equatorial Gnomonic Graticule

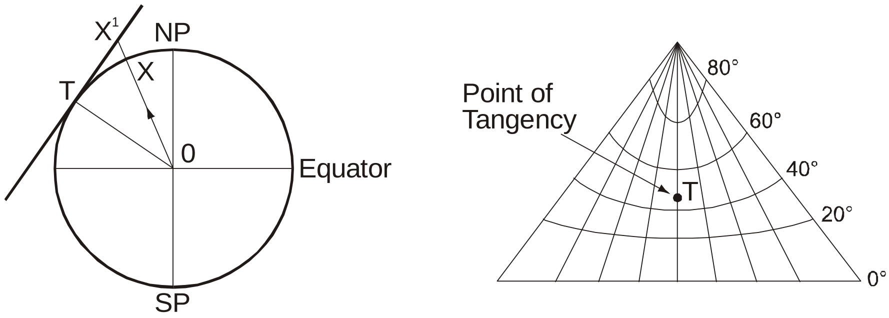


67. **Scale**. Scale increases away from the point of tangency with the same pattern as the polar case.

The Oblique Gnomonic

68. The oblique gnomonic projection uses a point of tangency at any point on the Earth other than a pole or on the equator (Fig 25). The graticule appears on the projection with the meridians as radial straight lines from the nearer pole and the parallels as curves concave to the same pole.

9-3 Fig 25 Oblique Gnomonic Projection



69. Scale, as before, expands away from the point of tangency.

Properties of Gnomonics

70. The properties of all gnomonic charts are as follows:

a. Any straight line on the projection exactly represents a great circle.

b. Bearings are correctly represented from the point of tangency, but not otherwise. The projection is not conformal.

c. Rhumb lines are curves concave to the nearer pole.

d. Coverage is limited to less than 90° from the point of tangency.

e. Scale increases away from the point of tangency.

Uses of Gnomonics

71. **Great Circle**. Great circle tracks can be found on the gnomonic chart and transferred to the plotting chart. A chart designed with this purpose in view is the Meade's Great Circle Diagram (Admiralty Chart 5029) discussed in para 75.

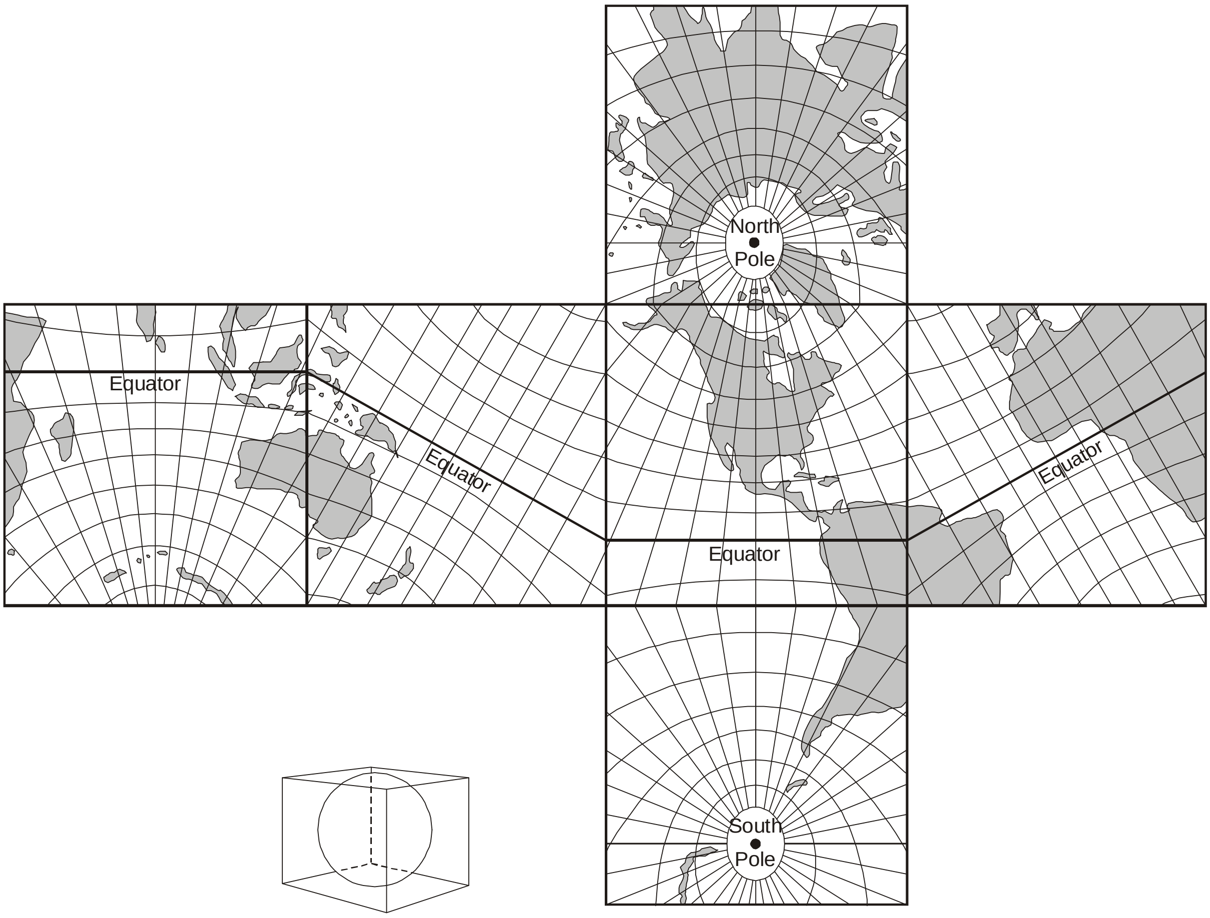
72. **Radio Bearings**. Gnomonic charts are sometimes used for D/F triangulation. The bearings (which are great circles) are passed to the master station where they are plotted on a gnomonic chart. An oblique gnomonic is used, the point of tangency being the position of the master station. The slave stations are plotted in their correct positions on the chart and offset compass roses are drawn about them to allow for distortion.

World Projection on to a Cube

73. Gnomonic projections can be used to obtain complete coverage of the world by arranging orthogonal planes around the sphere. The cube formed can be orientated to produce two polar and four equatorial projections, or six oblique projections.

74. The oblique case is illustrated in Fig 26. Care is required in using such a chart since a straight-line joining positions in adjacent projection squares represents two great circle arcs which intersect on the boundary, and not the great circle joining the places.

9-3 Fig 26 Projection of the World on a Cube



Meade's Great Circle Diagram (Admiralty Chart 5029)

75. Meade's Great Circle Diagram, (Admiralty Chart 5029), is a chart on which the blank graticules of polar and equatorial gnomonic projections are shown. The polar gnomonic extends from lat 60° N or S to 83° N or S, and the equatorial gnomonic from the equator to 65° N or S. Both graticules cover 150° ch long and are graduated in degrees. The meridians on both graticules can be renumbered to any required longitude.

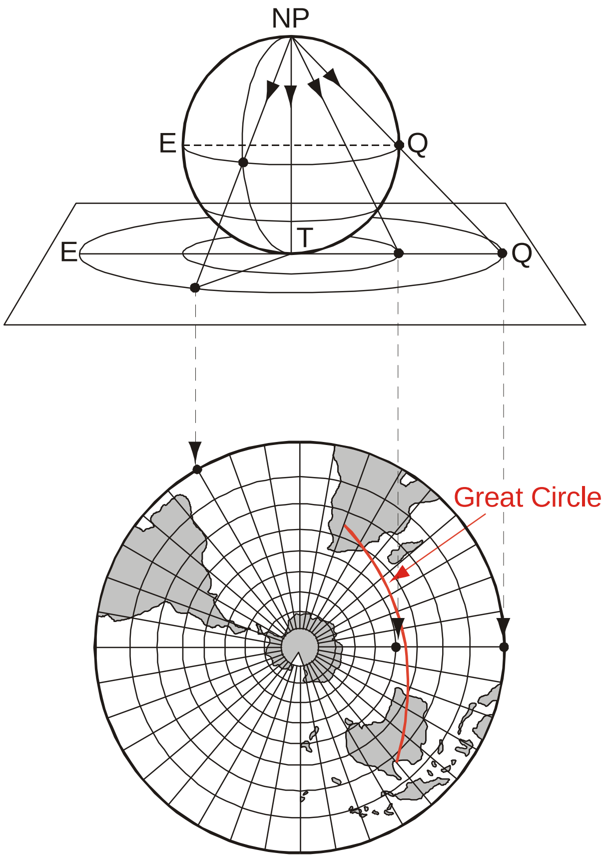
76. Since a straight line on either graticule represents a great circle, positions may be plotted on this chart and the great circle track between them transferred to the plotting chart. Full directions for use are provided on the actual diagram.

THE STEREOGRAPHIC PROJECTION

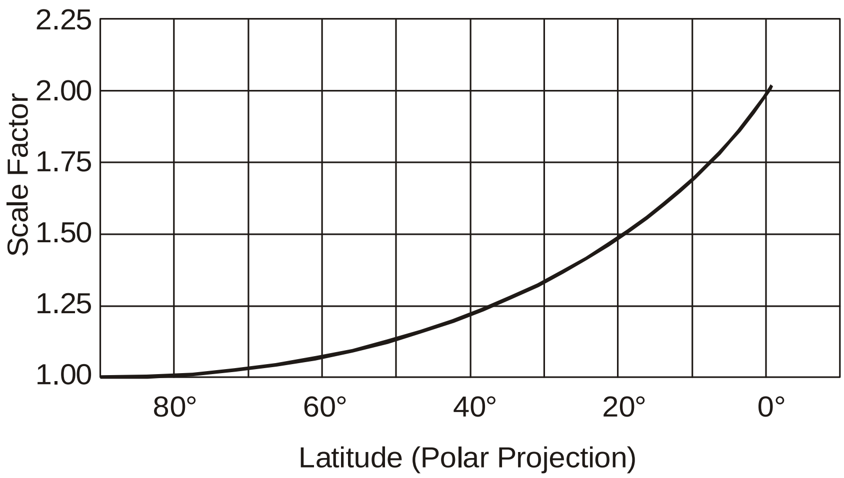
General

77. The stereographic projection is also perspective but differs from the gnomonic by having the point of projection diametrically opposite the point of tangency instead of at the centre of the sphere (Fig 27). As with all other azimuthal projections there are three cases but only the polar case is extensively used in navigation. In the final presentation of the polar graticule, the meridians are represented by radial straight lines from the point of tangency (the pole) and the parallels of latitude by concentric circles about it. The polar stereographic projection can be extended to cover points more than 90° from the point of tangency and the equator can be shown. Scale expands away from the point of tangency along the meridians, and scale along a parallel is equal to the meridian scale at that latitude; scale is therefore the same in all directions at a point and the projection is conformal. A graph of polar stereographic scale factor is shown in Fig 28.

9-3 Fig 27 South Polar Stereographic Projection



9-3 Fig 28 Stereographic Projection Scale Factor



Properties

78. The properties of the polar stereographic are as follows:

a. Scale expands along the meridians with distance from the point of tangency.

b. The scale at any point is the same along its meridian and parallel; the projection is therefore conformal.

c. All meridians are projected as straight lines; all other great circles are represented by arcs of circles, but because of the large radii they are not usually easy to plot. Near the pole the great circle and the straight line are almost coincident.

d. A rhumb line is a curve concave to the pole of tangency.

e. Scale may be taken to be constant near the pole of tangency (scale deviation is less than 1% above latitude 78.5°).

f. It can be extended to cover a whole hemisphere or more.

g. The constant of the cone (n) = 1.

Plotting of Radio Bearings

79. The plotting of radio bearings on a polar stereographic is simple near the pole since the divergence of the straight line from the great circle is very small. This divergence, Δ, is given by:

$$\Delta = \tfrac{1}{2}\text{ ch long (sin mean lat} - n)$$

Typical values of Δ are:

ch long	mean lat	Δ
10º	75º	0.17º
20º	75º	0.34º
35º	85º	0.066º

These divergences are too small to be of any significance using ordinary plotting instruments, and, providing the chart is not used below, say, 75° no correction need be applied.

Uses

80. The common uses of the polar stereographic are:

a. Polar plotting charts.

b. Topographical maps of polar regions.

THE AZIMUTHAL EQUIDISTANT PROJECTION

General

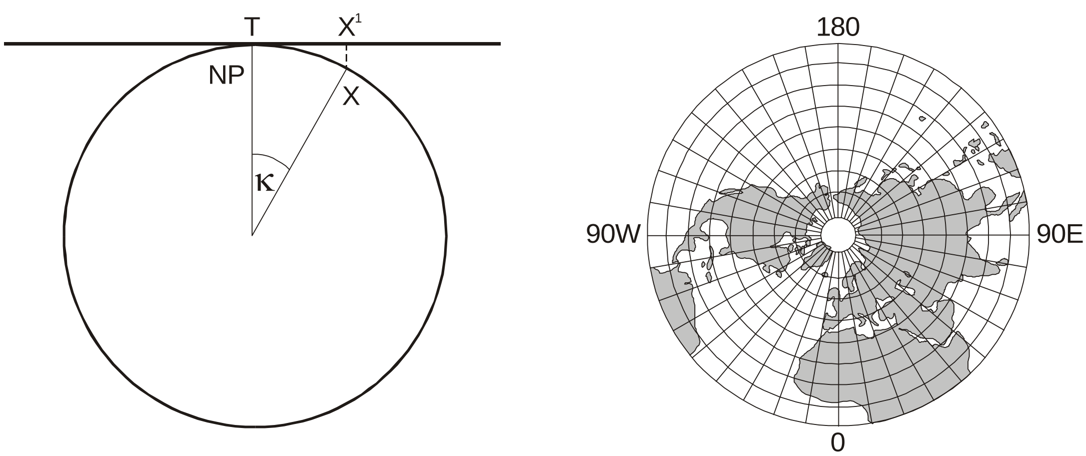
81. This is not a perspective projection; it is drawn so that all distances from the point of tangency are correct to scale. On this type of projection, the bearing and distance of any point may be measured correctly from the point of tangency. Only the polar and oblique projections of this type are discussed; remarks made on the oblique case apply equally to the equatorial case.

The Polar Equidistant

82. The point of tangency is the pole and the graticule presents the meridians as radial straight lines from the point of tangency and the parallels as equally spaced concentric circles about that point (Fig 29). The scale along the meridians is constant but along the parallels is given by:

$$\frac{K \text{ radians}}{\sin K} \qquad \text{Where } K = \text{co - lat}$$

9-3 Fig 29 Polar Equidistant Projection



83. **Properties**.

a. The scale along the parallels increases with distance from the pole. Scale along the meridians is correct. Scale errors are small provided the projection does not extend far from the pole (1% scale deviation at about 84°).

b. It is not conformal.

c. Except for meridians, a straight line does not represent a great circle.

d. The whole world can be represented on a single projection.

84. **Uses**.

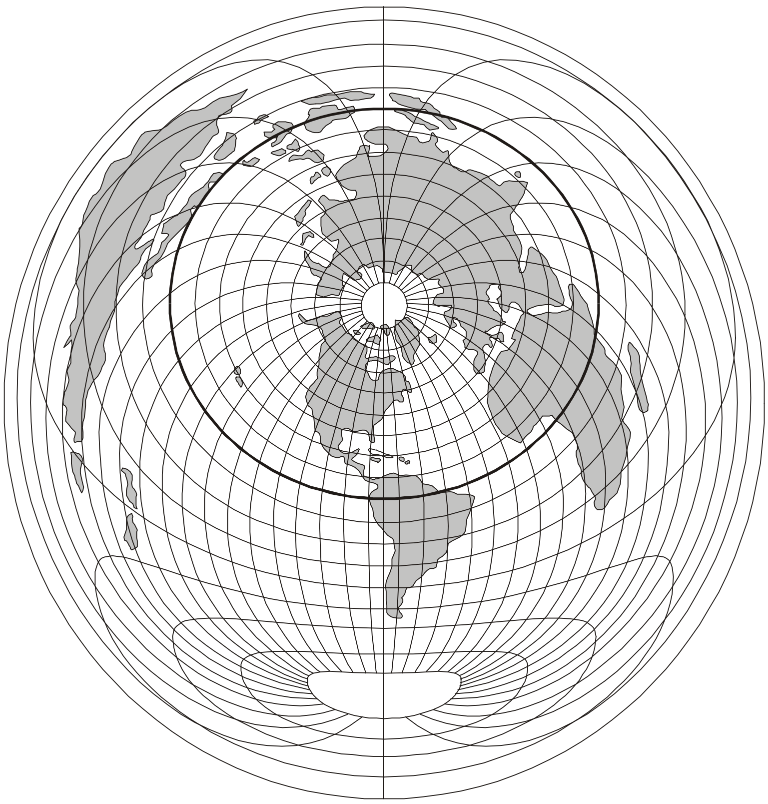
a. Admiralty maps of polar regions.

b. Star maps, including Sky diagrams of Air Almanacs.

Oblique Azimuthal Equidistant

85. The graticule for the oblique azimuthal equidistant projection is difficult to construct and complicated in appearance (Fig 30). The chart is constructed using the bearings and distances of required points from the point of tangency.

9-3 Fig 30 Oblique Azimuthal Equidistant Projection



86. **Properties**.

a. Scale along radials from the point of tangency is constant. In other directions, scale variation is complicated and measurement very difficult.

b. Straight lines passing through the point of tangency are great circles. A straight line elsewhere does not represent a great circle.

c. It is not conformal.

d. The whole world can be shown on the projection.

87. **Uses**.

a. **Maps for Strategic Planning**. The projection is based on a point of importance. Concentric circles from this point show correct ranges which could represent, for example, radii of action.

b. **Civil Uses**. For example, a projection based on the position of a radio transmitter will show the great circle distance and bearing of any receiver in the world.

CYLINDRICAL PROJECTIONS

Introduction

88. The cylindrical projections are those in which the apex angle of the cone is zero; the cone becomes a cylinder tangential to the reduced Earth along a great circle and the meridians and parallels are projected onto it. When developed the great circle of tangency is shown as a straight line as are all great circles orthogonal to it. The poles of the projection, those points removed 90° from the great circle of tangency, cannot be shown on most projections of this type.

89. When the great circle of tangency is the equator the projection is known as a normal cylindrical; when it is other than the equator it is a skew cylindrical.

SIMPLE NORMAL CYLINDRICALS

General

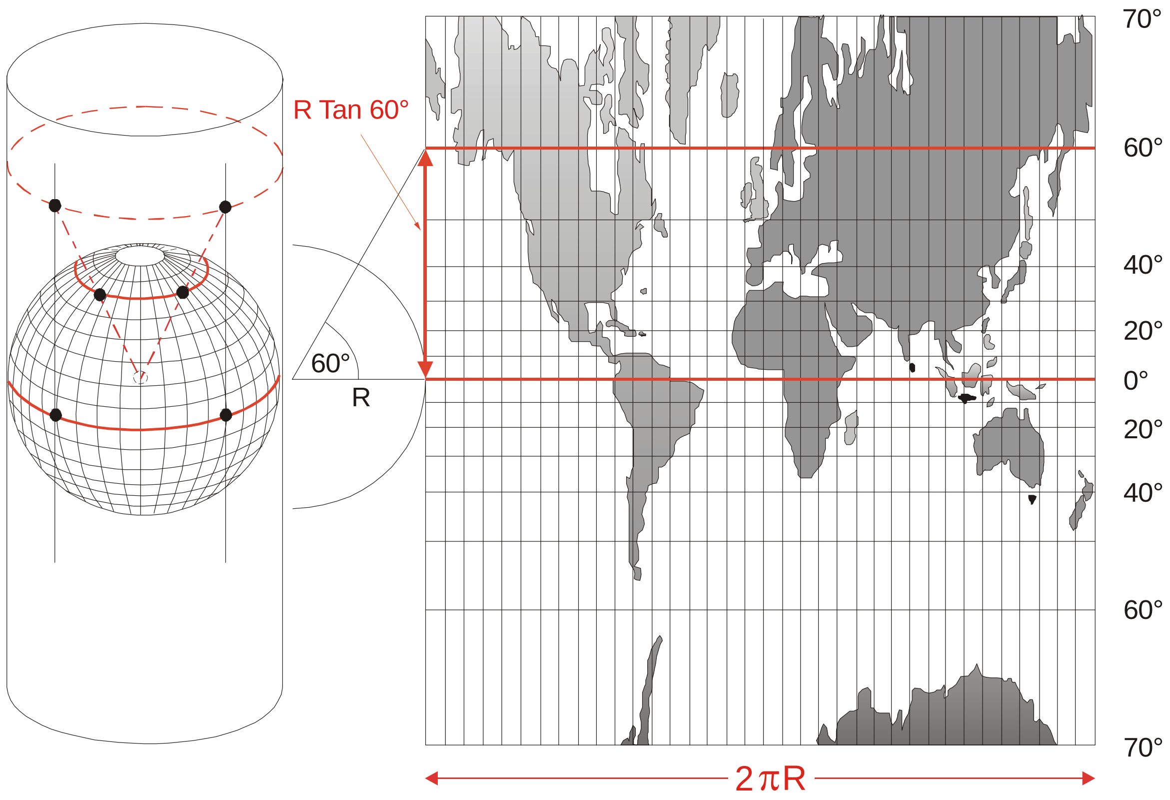
90. Two simple normal cylindrical projections are discussed; the first is perspective, the second non-perspective.

Geometric Cylindrical Projection

91. The geometric cylindrical projection is provided by a light source at the centre of the reduced Earth which projects the parallels and meridians on to a cylinder wrapped around the reduced Earth and tangential at the equator. The developed projection shows the equator as a straight line of length equal

to the equatorial circumference of the reduced Earth. The meridians are parallel straight lines at right angles to the equator while the parallels of latitude are straight lines parallel to the equator and of length equal to it. The general appearance is shown in Fig 31, where it can be seen that the meridian spacing at the equator is the actual reduced Earth spacing.

9-3 Fig 31 Geometrical Cylindrical Projection



92. Since the equator of the reduced Earth has length 2πR, so the equator and all parallels are of length 2πR on the chart. The parallels are drawn (Fig 1) at heights above or below the equator given by R tan ϕ, and it is clear from this, and from Fig 30, that latitudes 90° N and 90° S cannot be shown.

93. **Scale**. Scale factor along the parallels is equal to the secant of the latitude. Along the meridians scale factor can be shown to equal the square of the secant of the latitude.

94. **Properties**. Since scale increases at one rate along the meridians and at another along the parallels the projection is not conformal. Further, the difference in scale expansion means that it is very difficult to measure intercardinal directions. The chart is not equal area, nor indeed has it any useful property beyond its simplicity.

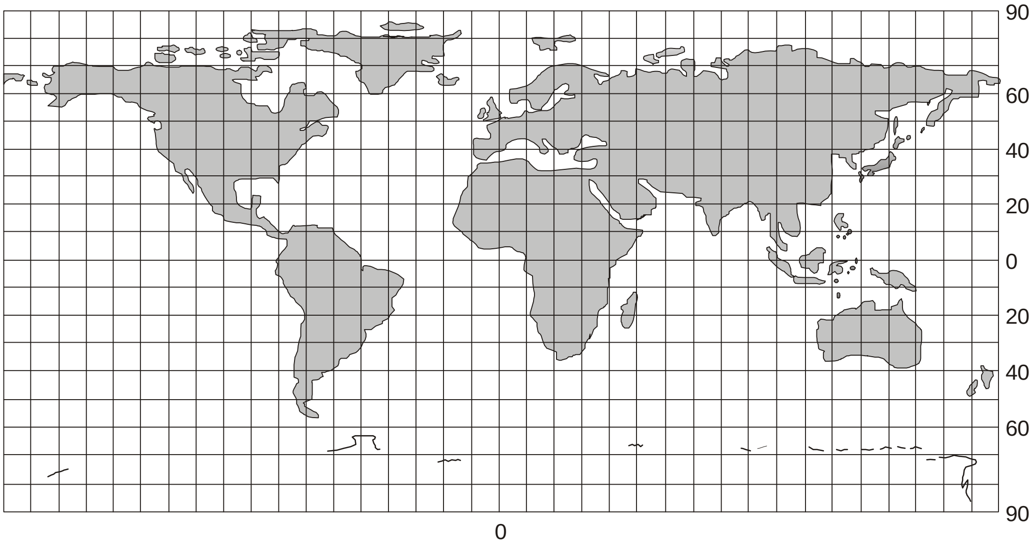
Equidistant Cylindrical Projection

95. The equidistant cylindrical projection, also called the Plate Carree, is non-perspective, but is like the geometric cylindrical in some ways. The equator is represented by a straight line of length 2πR. The meridians are shown as parallel straight lines at right angles to the equator, at intervals on it equal

to the reduced Earth interval. The parallels of latitude are straight lines parallel to the equator and of length $2\pi R$.

96. The difference between the two charts lies in the heights above or below the equator at which the parallels of latitude are drawn. In the equidistant cylindrical, they are erected at their actual reduced Earth distance from it; thus 40° N is drawn at a scale distance of 2,400 nm from the equator. The complete sphere can be projected, the poles being represented by straight lines at a scale distance of 5,400 nm from the equator. The graticule appearance is shown in Fig 32.

9-3 Fig 32 Equidistant Cylindrical



97. **Scale**. Scale factor along the meridians is clearly 1, since the parallels are laid down at correct distances from the equator. Along the parallels scale factor is the same as that on the geometric cylindrical, sec ϕ.

98. **Properties**. This chart was much used by navigators prior to the sixteenth century. Scale is correct and constant along the equator and meridians and is reasonably constant between 8° N and 8° S; beyond this the expansion along the parallels exceeds 1%, and the measurement of distance is difficult. The chart is neither conformal nor equal area, but it has the advantage of projecting the complete sphere.

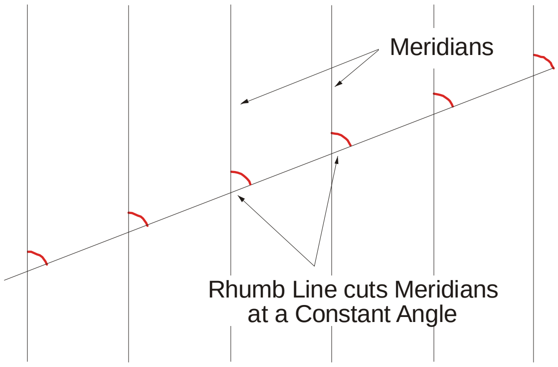
MERCATOR'S PROJECTION

Orthomorphic Cylindrical Projection

99. An orthomorphic, or conformal, projection is one on which angles, and therefore the shapes of elementary areas, are correct. Such a projection will result if the meridians and parallels are drawn at right angles and if the scale along the meridians is made to be the same as that along the parallels.

100. On the geometric cylindrical and on the equidistant cylindrical, the meridians and parallels are at right angles and the scale factor along the parallels in each case is sec ϕ. If the scale factor can be made to equal sec ϕ along the meridians, the new projection will be conformal. This is precisely the method adopted in Mercator's projection which, because it provides straight rhumb line tracks, remains one of the most important projections for navigation charts (see Fig 33).

9-3 Fig 33 Rhumb Line

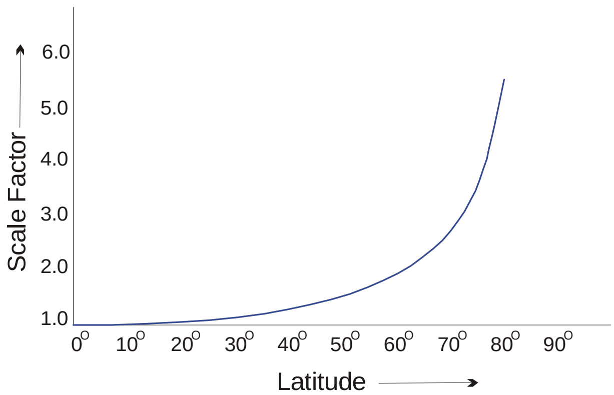


101. **Appearance of Graticule**. The final projection is very like the geometric cylindrical projection. T e equator is a straight line equal in length to the reduced Earth equator; the meridians are straight lines mounted on the equator at right angles to it and spaced upon it at reduced Earth spacing; the parallels of latitude are straight lines parallel to the equator and of length equal to it. The parallels are drawn in at heights above and below the equator which are a little less than on the geometric projection, but the poles remain at infinity and cannot appear on the projection.

Scale

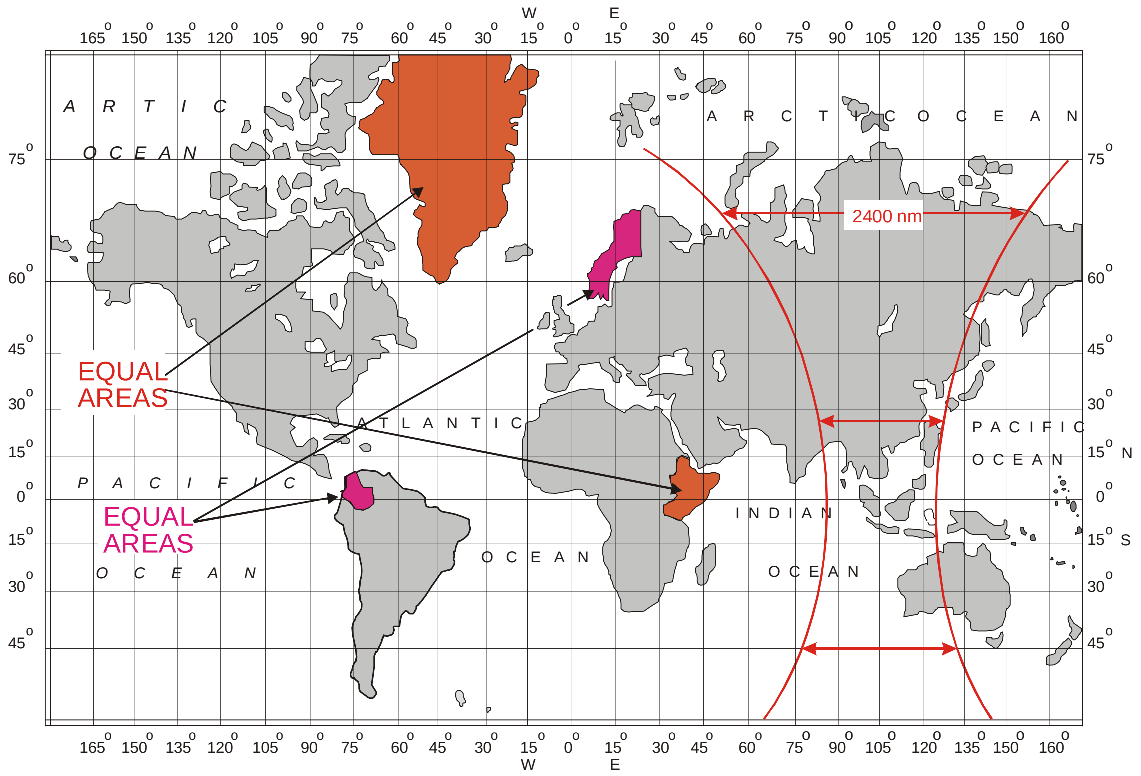
102. Scale factor along the parallels of latitude can be derived as sec ϕ. A graph of Mercator scale factor is shown in Fig 34.

9-3 Fig 34 Scale Factor



103. The distortion of areas and the excessive scale expansion away from the equator, characteristic of the Mercator projection, are illustrated in Fig 35.

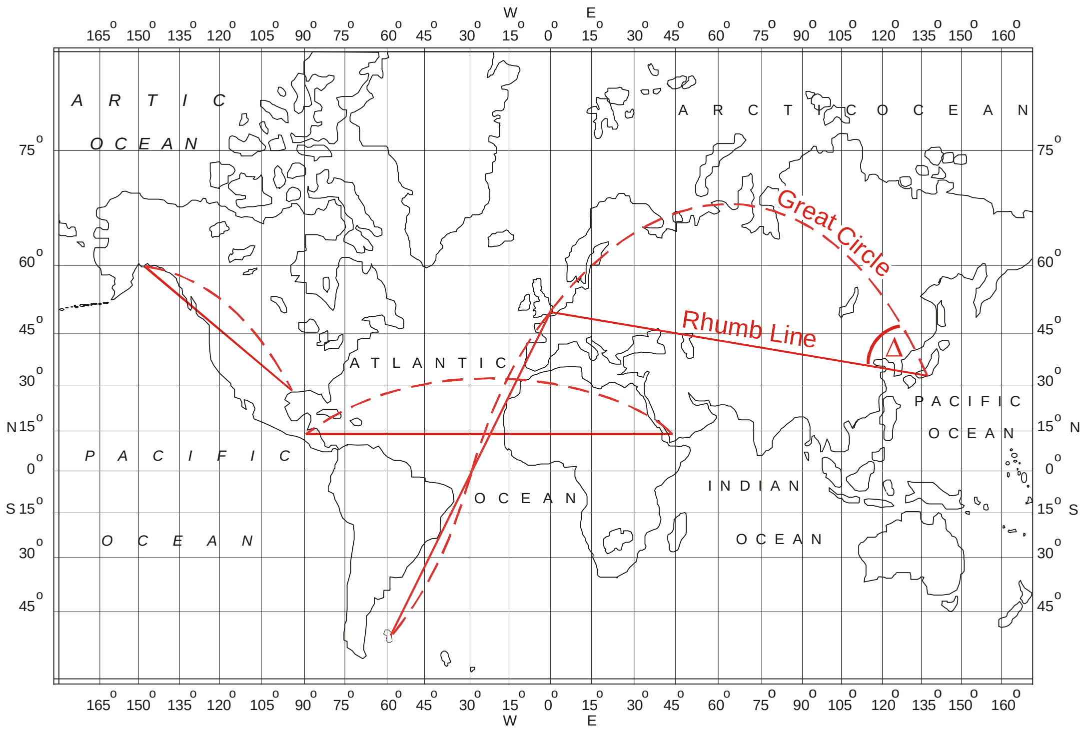
9-3 Fig 35 Distortion of Mercator Projection



Great Circles

104. Only the equator and the meridians are projected as straight lines; all other great circles appear as curves concave to the equator. Some examples are shown in Fig 36.

9-3 Fig 36 Great Circle and Rhumb Lines



105. **Conversion Angle**. In Fig 36, the angle (Δ) between the straight line and the great circle is known as conversion angle. The projected great circle is not an arc of a circle, and strictly speaking, the angle Δ is not the same at each end, unless the end points are at the same latitude. Nevertheless, if the change of latitude is small, they can be assumed to be equal and can be given the value
½ ch long × sin mean lat

106. **Great Circle Tracks**. The great circle route is, of course, a shorter distance than the straight rhumb line route, but the difference is small enough to be ignored in equatorial regions (12° N to 12° S). In other latitudes, when the distance exceeds about 1,000 nm it is best to examine the great circle by transferring points from a gnomonic projection or by calculation, to discover if a significant economy can be made.

Measuring Distances

107. Distances must be measured using the scale at the given point, since scale expands with latitude. Acceptable results are obtained by splitting the line to be measured into 100 to 200 nm sections and using the latitude scale at the midpoint of each section for its measurement.

Uses

108. The main feature of the Mercator is that straight lines are rhumb lines. For this reason, the Mercator will probably remain one of the most popular plotting and topographical charts in equatorial regions.

109. Near the equator the Mercator chart is the optimum projection. Scale may be considered constant within 8° of the equator, and a straight line in any direction, although still a rhumb line, is almost a great circle.

110. In middle and high latitudes, the Mercator projection is not the best available, because of the difficulty of precise distance measurement, the extravagance of rhumb line flight paths, and the problem of determining great circles. It is impossible to use the Mercator projection for polar flights.

Summary of Properties

111. The properties of the Mercator may be summarized as follows:

a. Scale is correct only along the equator; elsewhere it increases as the secant of the latitude.

b. Because the secant of 90° is infinity, the poles cannot be shown.

c. A straight line represents a rhumb line.

d. A great circle (apart from the equator and the meridians) is represented by a curved line convex to the nearer pole. Great circles near the equator are satisfactorily represented by straight lines.

e. The projection is conformal. It is not equal area and areas are greatly exaggerated in high latitudes.

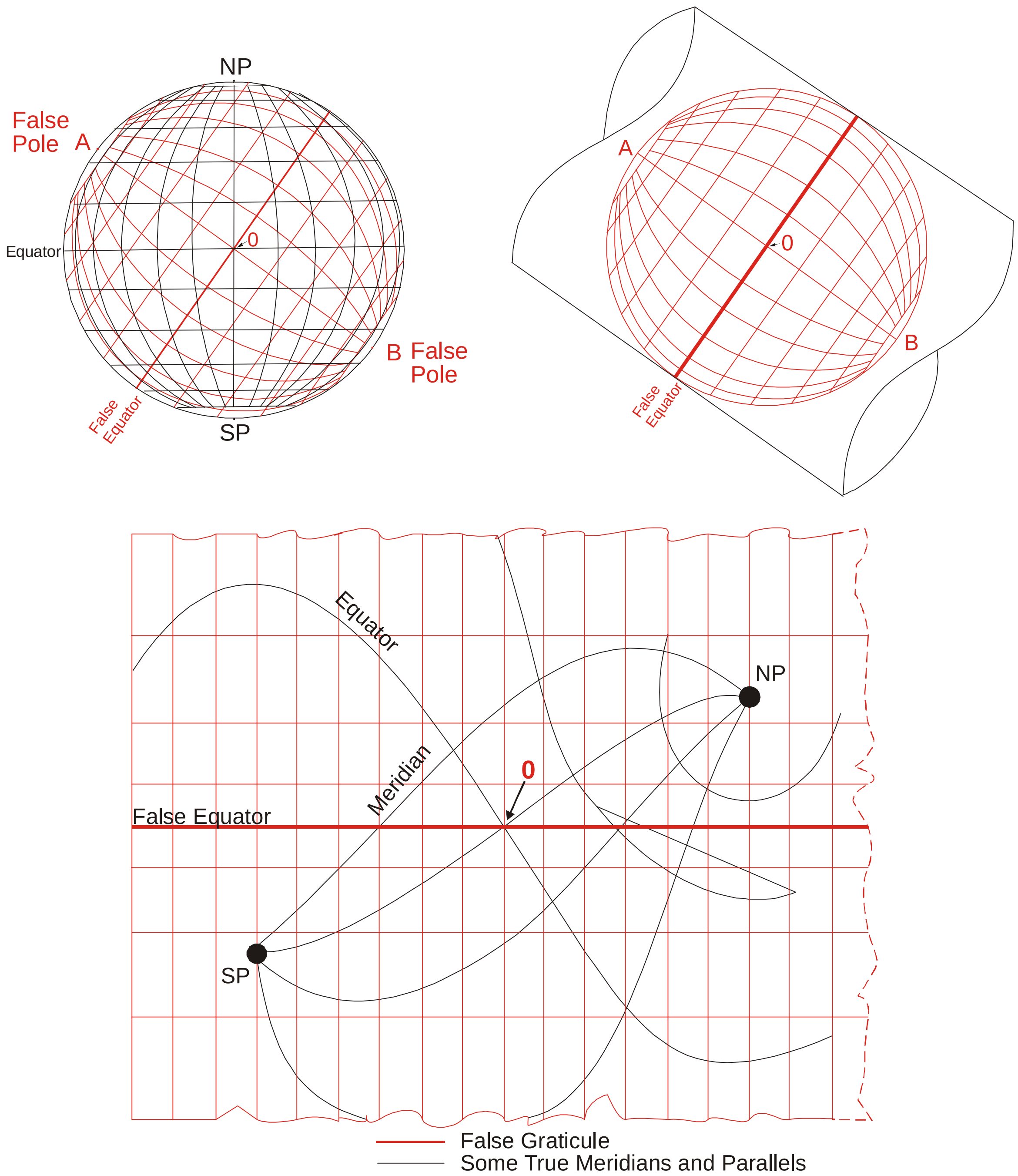
SKEW CYLINDRICALS

Technique of Construction

112. Skew cylindrical projections are the derivatives of the perspective projections which would be obtained using a light source at the centre of the reduced Earth to cast shadows onto cylinders wrapped around it, and tangential at great circles other than the equator. The simplest interpretations of such projections is obtained by erecting a false graticule of meridians and parallels on the reduced Earth; the great circle of tangency becomes the false equator, and false meridians are drawn as great circles at right angles to the false equator. The false meridians intersect at false poles.

113. The false graticule is projected onto the cylinder which is then developed. Some points of intersection of geographical latitude and longitude with the false graticule are computed, plotted on the projection and joined by smooth curves. These are labelled in geographical coordinates and the false graticule erased. The process is illustrated in Fig 37.

9-3 Fig 37 Construction of a Skew Cylindrical



114. The type of projection required will determine the method of transformation of the false graticule onto the flat sheet, but whatever type is required the relationship between points on the geographical graticule and on the false graticule will be the same.

115. The false latitude is measured along the false meridian from the false equator to the point; the false ch long is measured from some convenient datum false meridian (the false meridian through the intersection of the equators is often chosen with the alternative of that joining the false and geographic poles).

116. The skew cylindrical projections which are important in navigation are the Mercator projections of the false graticule. Referred to this graticule they have exactly the same properties as the normal Mercator, but when referred to the geographical graticule the picture changes and extra care is needed. The projections considered here are:

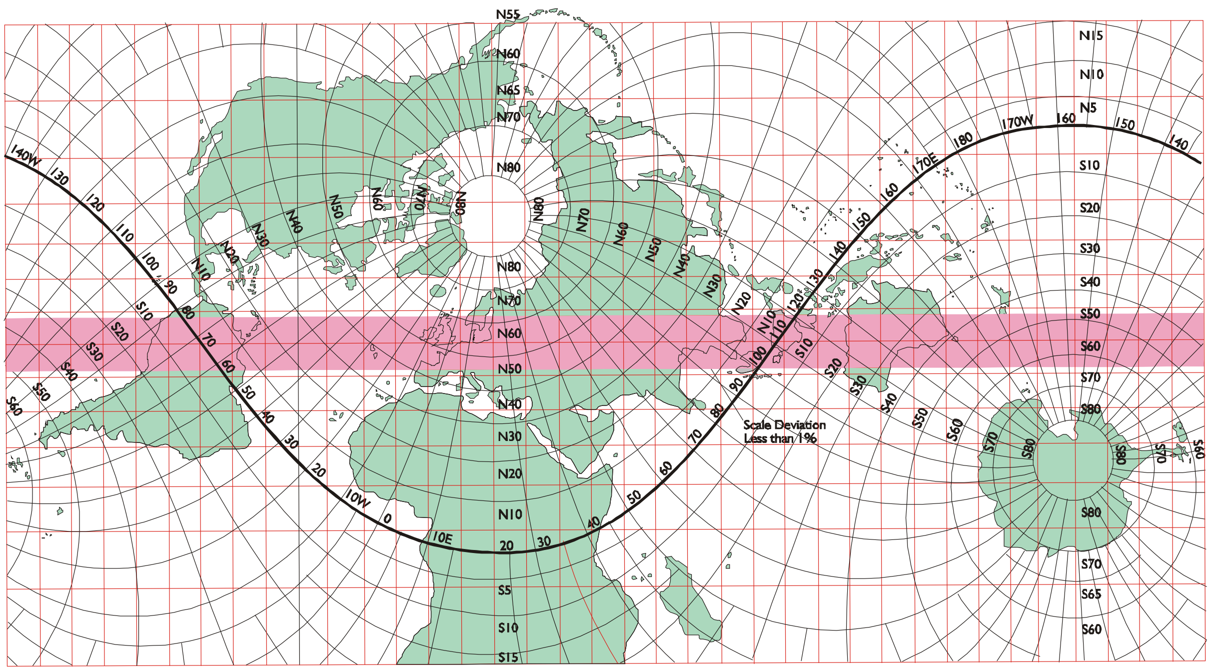
a. The Oblique Mercator.

b. The Transverse Mercator.

The Oblique Mercator

117. A diagram of an oblique Mercator projection is shown in Fig 38. Considering the false graticule, at any point, scale is the same in all directions (scale factor is the secant of the false latitude) and the rectangular spherical graticule is transformed to a rectangular plane graticule. Hence the projection is orthomorphic.

9-3 Fig 38 Oblique Mercator Projection



118. Analogously with the normal Mercator, scale can be considered constant within a false latitude band ± 8° about the false equator (the light red band in Fig 38). Since the false graticule does not appear on the final chart it is more usual to talk of a distance band of 960 nm within which scale is almost constant.

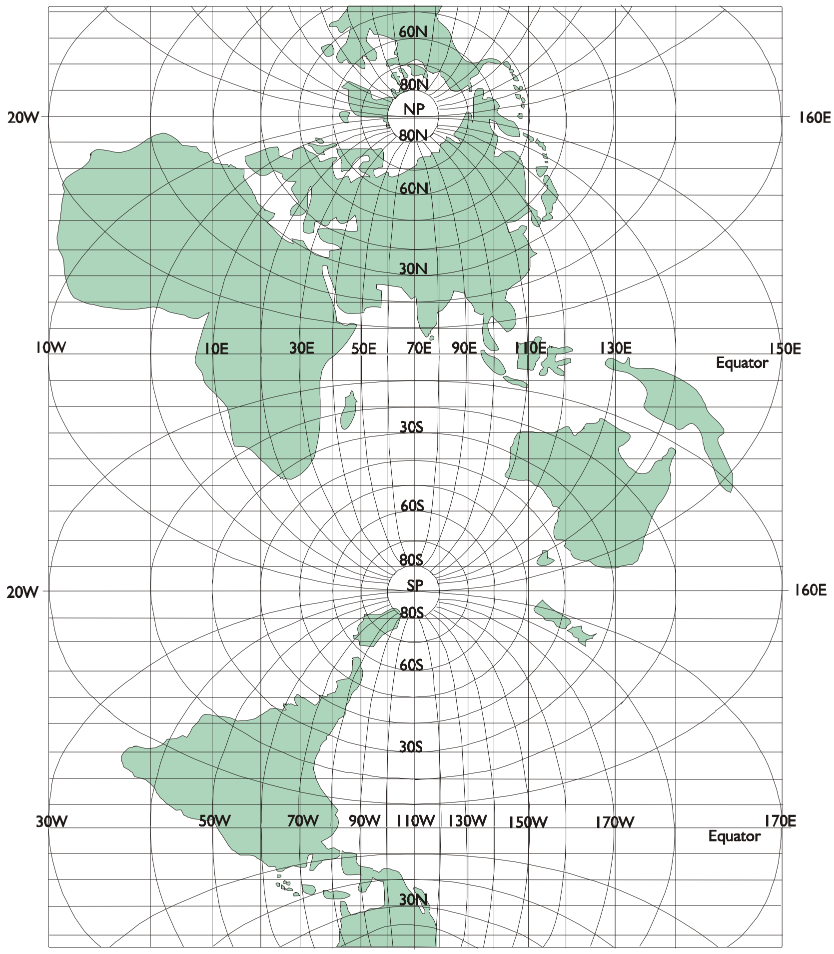
119. Because the projection is almost constant scale in this band, and is in any case conformal, it makes a useful chart for navigation along established great circle routes. Another common use is the mapping of countries of considerable length but of limited width, whose longitudinal axis does not run north/south or east/west. However, the complicated appearance of the geographical graticule, together with the large-scale expansion away from the great circle of tangency, limits the use of this chart.

120. Great circles are curved lines concave to the great circle of tangency, unless they happen to coincide with that great circle or are at right angles to it (false meridians). Rhumb lines are complicated curves. Straight lines on the chart represent lines along which heading measured from the false meridians is constant. Straight lines within about 500 nm of the false equator are roughly great circles.

The Transverse Mercator

121. The Transverse Mercator is the special case of the oblique Mercator in which the great circle of tangency is a meridian. The general appearance of the geographical graticule is less complicated (Fig 39) and it is easier to use for general navigation. The chart is conformal, and the scale expansion varies (for a spherical Earth) with the secant of the false latitude, ie the angular distance east or west of the selected meridian of tangency.

9-3 Fig 39 Transverse Mercator Projection

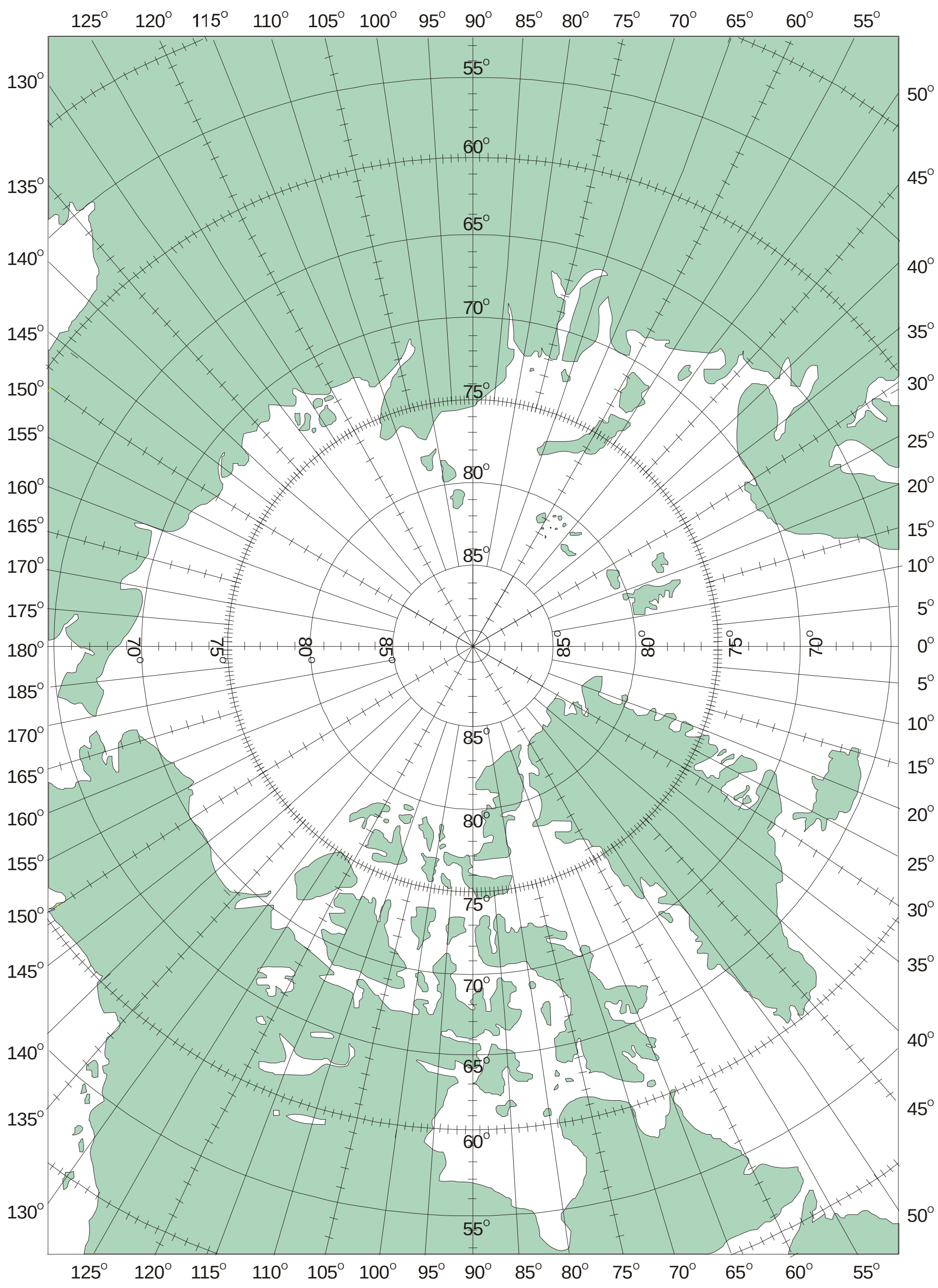


122. The projection is often used to map countries of considerable latitude extent but of little girth. If the meridian of tangency is chosen to be the mean longitude of the country then in a band some 960 nm wide disposed about this meridian, all the useful features of a normal Mercator about the equator appear. In this band the scale deviation does not exceed 1%, great circles are almost straight lines and area distortion is minimal; add these properties to conformality and a fairly regular geographical lattice and the result is an almost ideal chart.

123. The latitude extent which can be projected with these almost ideal properties is not limited. Both geographical poles and the 960 nm 1% scale deviation band about any meridian and its anti-meridian can be projected onto one sheet of paper. Some of the charts in common use are discussed below.

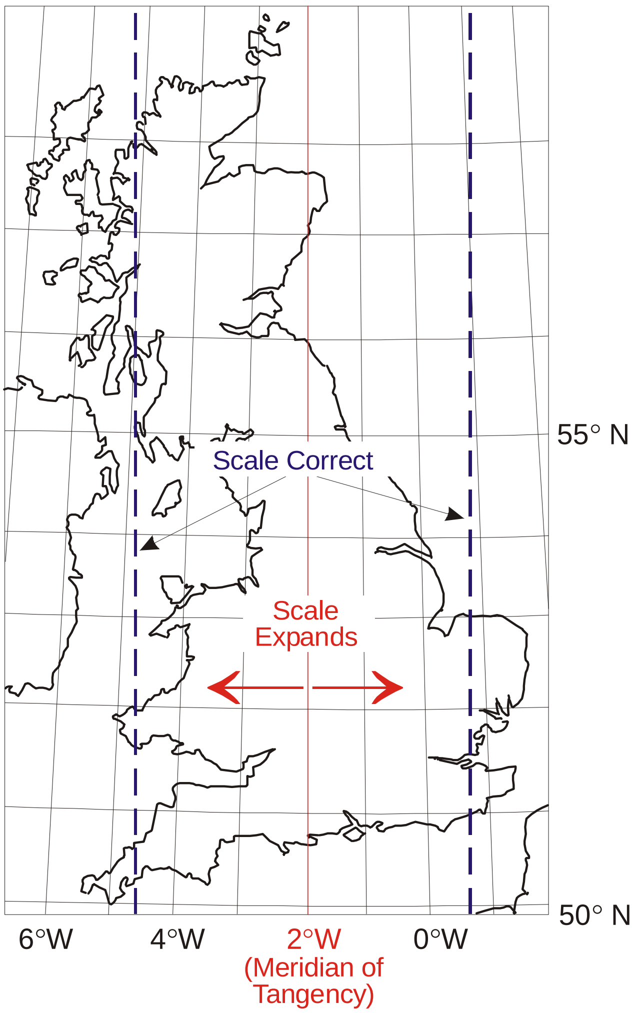
124. **Polar Charts**. Transverse Mercator projections in the polar regions appear very similar to the polar azimuthal charts since near the pole the parallels are nearly circular and the meridians almost straight lines (see Fig 40). Comparison with Fig 39, however, identifies both the parallels and the meridians as elliptic. Polar sheets on this projection are often rectangular, the greater length being provided along the line of tangency; scale errors limit the extent of the sheet at right angles to this direction.

9-3 Fig 40 Polar Chart on Transverse Mercator Projection



125. **Ordnance Survey Maps of UK**. Topographic maps of the British Isles are available at scales of 1:250,000 and 1:50,000 based on the Ordnance Survey (OS) maps. The scales are adjusted so that they are correct, not at the meridian of tangency (2° W), but at some distance on either side of it. The scale at 2° W is 0.9996 of the stated scale; at the east/west extremities of the map cover the scale is about 1.0004 of the stated scale. Had the scale been made correct at 2° W, then scale deviation of the order of 8 parts in 10,000 would have occurred at the east/west extremities; this mean scale device balances the overall scale deviation and hence halves its effective magnitude. The stated scale is correct along two lines parallel to the meridian of tangency, one 180 km east of it, the other 180 km west. The OS map projection is illustrated in Fig 41.

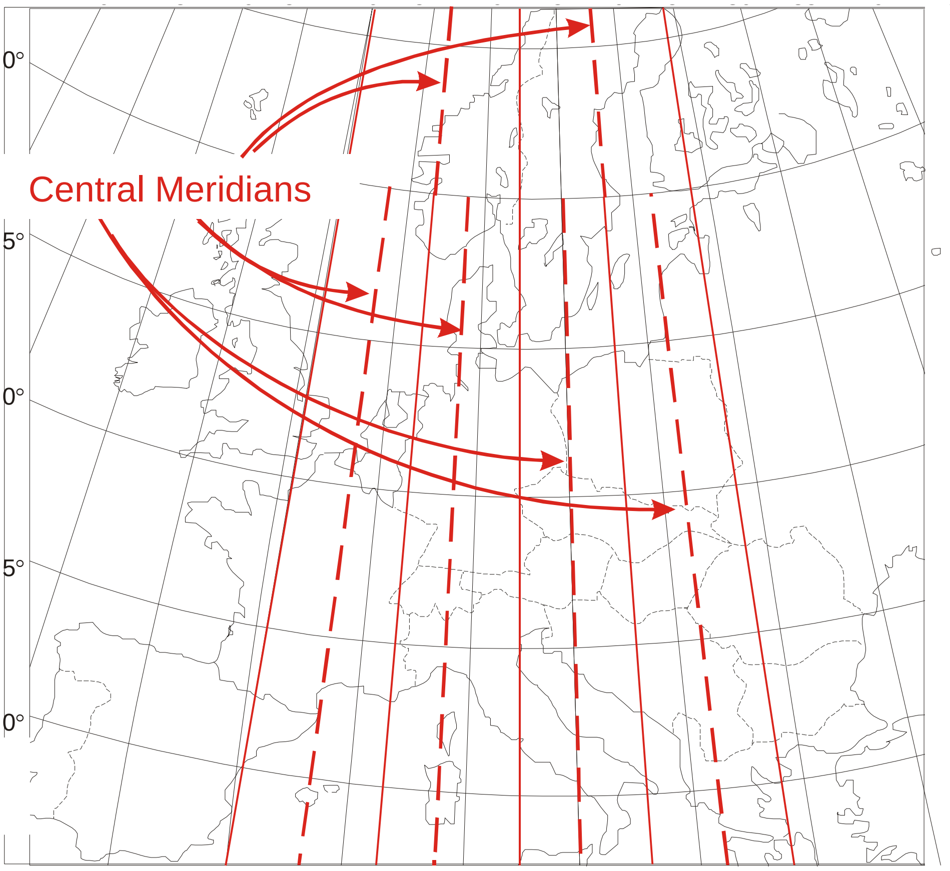
9-3 Fig 41 OS on Transverse Mercator Projection



126. **Joint Operations Graphics**. The 1:250,000 Joint Operations Graphic (JOG) is a series of topographical charts (Fig 42) which provide almost worldwide coverage of the land areas from latitude 80° S to latitude 84° N. Each sheet of the series covers 1° in latitude and between 1.5° to 8° in longitude (depending on latitude) and is constructed on its own individual transverse Mercator projection of the International Ellipsoid with meridian of tangency at the centre of the sheet. The scale deviation of the projected graticule of a sheet does not exceed 0.01%. Adjoining sheets fit exactly along north and south edges and although, in fact, they do not fit exactly along east and west edges the discrepancies are so

small as to be unnoticeable. Charts of this series carry a reference grid, such as the British National Grid or one of the zones of the UTM Grid appropriate to the country or region covered. These reference grids may be based on different projections, ellipsoids or points of tangency but are designed so that the scale deviation is usually less than 0.15% within the grid area. Although, strictly, the projected graticule of a sheet and the projected grid are independent of each other, either may be used for positioning and navigation purposes.

9-3 Fig 42 Joint Operations Graphic (JOG) Projection System



127. **Summary of Properties**. The properties of the transverse Mercator are summarized below.

a. Scale is constant along the meridian of tangency but expands (for a spherical Earth) with the secant of the false latitude.

b. Since the false meridians and parallels are projected by Mercator's method the projection is orthomorphic.

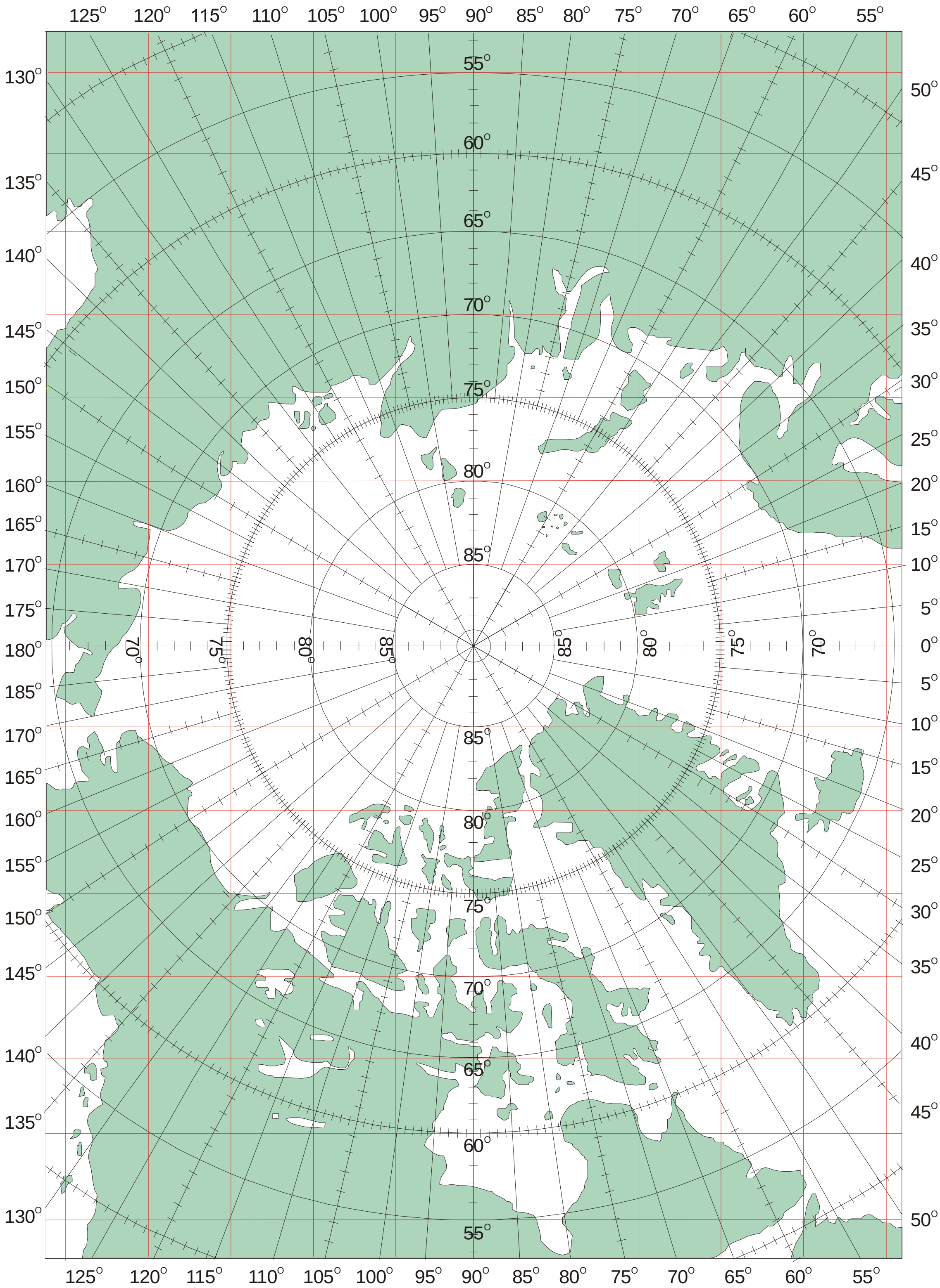
c. The meridian of tangency and all great circles at right angles to it (i.e. false meridians) are straight lines. All other great circles are curves concave to the meridian of tangency.

d. Rhumb lines are curves.

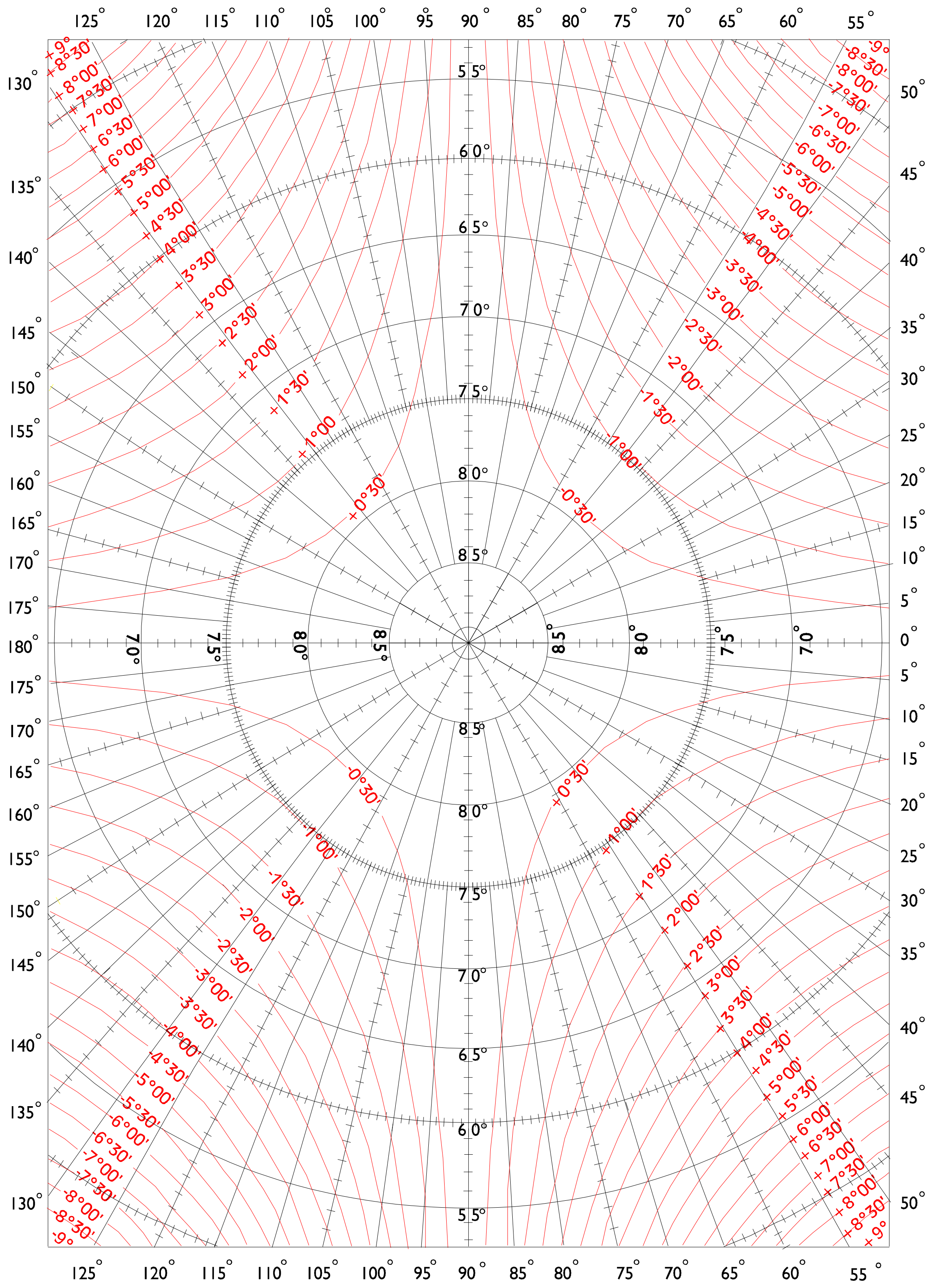
e. Near the meridian of tangency scale is almost constant (1% error 480 nm removed from it), great circles are almost straight lines, area distortion is minimal, and the graticule appearance is regular. Charts do not, of course, fit along east and west edges if based on different meridians of tangency, but provided the separation of these meridians is small (as with the JOG) the discrepancy is not inconvenient.

128. **Gridded Transverse Mercator Charts**. Transverse Mercator charts are often provided with an overprint of the false graticule, to be used with some form of grid navigation. By analogy with the normal Mercator, the grid is of approximately square appearance within about 500 nm of the great circle of tangency. Grid north is the direction of the false pole and a gyroscope device initially aligned with grid north will maintain this datum direction if suitable torqueing terms are applied to it. A word of warning is necessary when convergence is considered. The geographical meridians are curved, even though on a small part of a chart they appear to be straight lines; hence the angle between true north and grid north is not constant along a given geographical meridian (as it is on a gridded conical chart). It is of importance, for example, when converting true heading to grid heading for checking purposes, to apply convergence for the particular position: various tables have been drawn up for this purpose and values are printed on some charts. A gridded polar chart and a convergence correction chart are illustrated in Figs 43 and 44. When using gridded transverse Mercator charts, it is possible, if false north can be accurately defined, to steer false rhumb line track; such a system is the same as navigation on a normal Mercator if false latitude and longitude are substituted for their geographical counterparts.

9-3 Fig 43 Grid on Polar Transverse Mercator



9-3 Fig 44 Convergence Correction Chart



CONICAL PROJECTIONS

Introduction

129. The cylindrical projection is best suited to the representation of a single great circle (such as the equator) and the band of the Earth's surface close to it, while the azimuthal projections depict very well the area surrounding a point. The conic projections fill the gap by best projecting small circles and the bands of surface close to them.

130. From a navigation point of view, the conformal conics are the most important members of the group, and most of this chapter is devoted to them. However, some discussion of perspective conics may be found helpful.

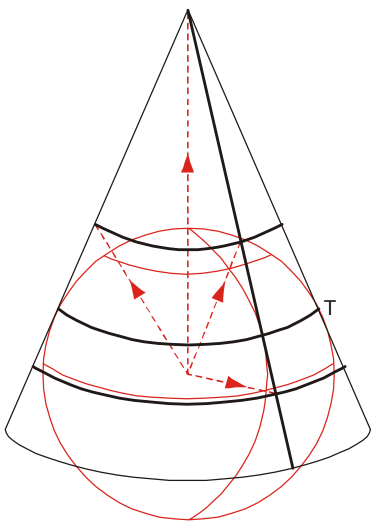
General Description

131. All the conic projections described in detail are normal to the equatorial plane; oblique conics are sometimes drawn but they are not often found to be useful in navigation. The simplest arrangement is that of a cone, tangent at a parallel of latitude (Fig 44a), onto which the meridians and parallels are projected.

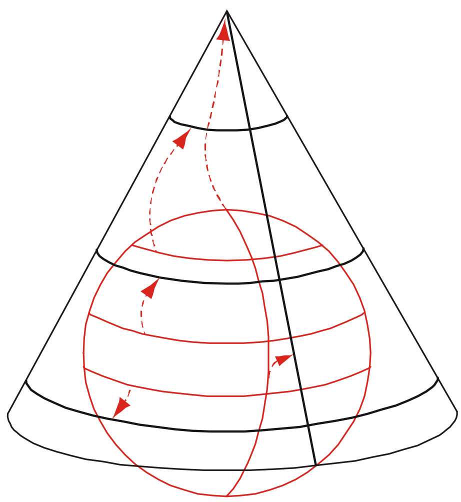
132. The projection can be perspective or non-perspective. In the perspective case, the graticule is a linear projection, usually from the centre of the sphere, as in Fig 45a. In the more general non-perspective case, the graticule is positioned mathematically on a cone which may touch, or cut through, the sphere as shown in Fig 45b.

9-3 Fig 45 Conical Projections

45a – Perspective Projection



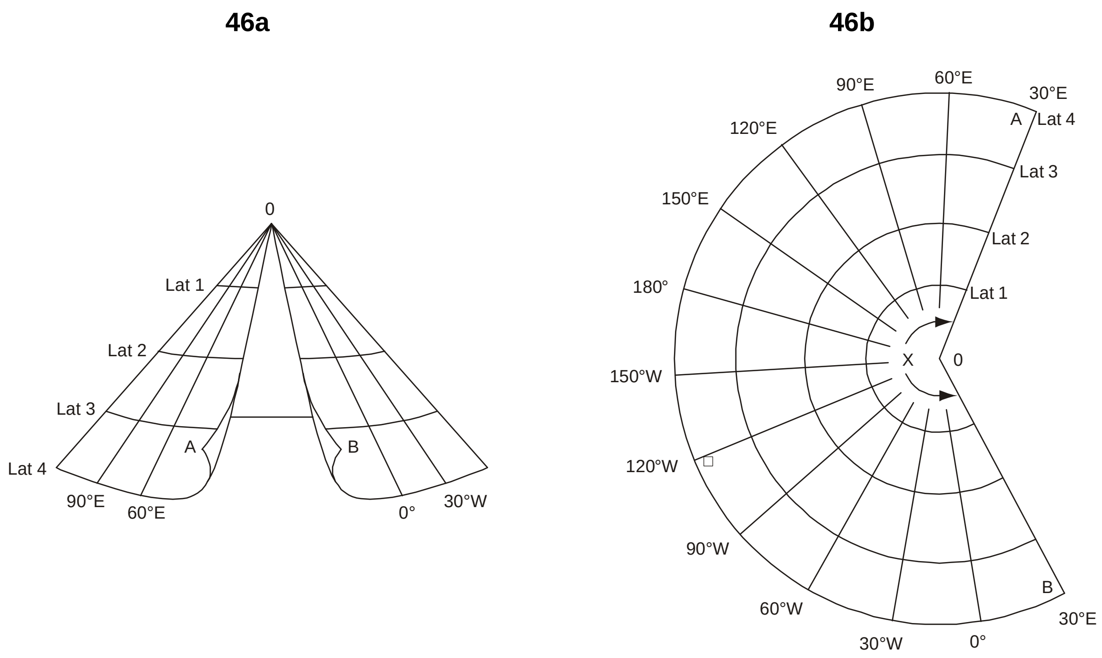
45b – Non-perspective (Lambert's) Projection



133. **Appearance of Graticule**. After projection, the cone is cut and unrolled (Fig 46a). This is known as the development of the cone. The meridians appear as straight lines radiating from a point, which,

in all normal projections, represents the geographic pole. The parallels of latitude are arcs of circles, concentric at this point. The developed cone is illustrated in Fig 46b.

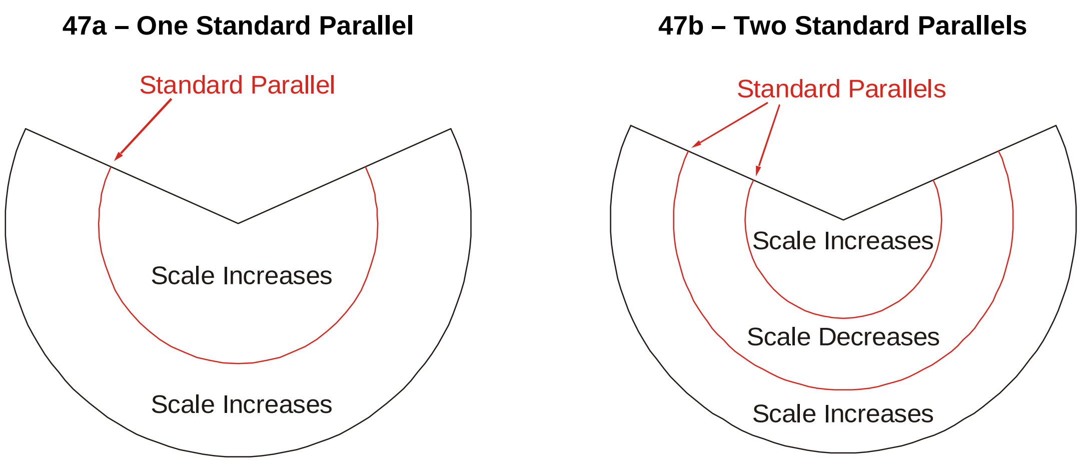
9-3 Fig 46 Development of the Cone



134. **Standard Parallels**. A 'standard' parallel of latitude is one which is projected at reduced Earth scale. It is possible to have more than one standard parallel and one- and two-standard parallel projections are discussed. On a one-standard parallel projection, the standard parallel is also the parallel of origin (λ_0).

135. **Scale Expansion**. On all the conformal conics, and on all the perspective conics, the pattern of scale change is that shown in Fig 47. Scale is correct along the standard parallels and increases away from them; in the two-standard case it decreases between them.

9-3 Fig 47 Conformal Conic Scale



Constant of the Cone

136. When the cone is developed, the reflex angle at the centre of the sector (x in Fig 46b) represents 360° of longitude. The ratio of x° to 360° is known as the 'constant of the cone' (or the convergence factor) and is denoted by n. Its value is normally printed on a conic projection, and chart convergence can be obtained from the formula:

$$n \times \text{ch long}$$

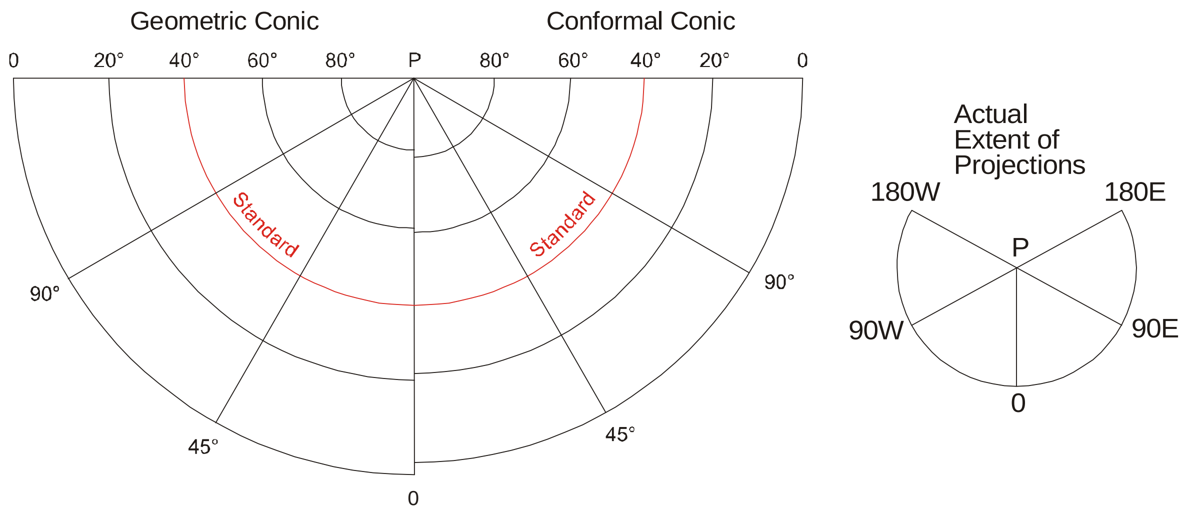
CONFORMAL CONIC PROJECTIONS

Conformal One-Standard Conic Projection

137. A geometric conic is a perspective projection onto a cone at a parallel of latitude, which is the standard parallel for a one-standard conic projection. The point of projection is the centre of the Earth. The conformal version of the one-standard conic is derived from the geometric conic by adjusting the radii of the parallels to make the scale at any point the same in all directions. The standard parallel and the parallel of origin (λ_0) are also coincident on this projection.

138. The projection is non-perspective on to a cone tangent at the latitude chosen as the standard parallel. The meridians are drawn exactly as in the geometric case, but the parallels (see Fig 48) are moved slightly nearer the standard parallel. The pole remains at the apex of the cone and represents the oddity of the projection, for it is not conformal at that point. This is evident from the angle between two meridians; at the pole this angle should be ch long but on the chart it is n × ch long (the projection is everywhere else conformal, even at latitude 89º 59'). Scale factor is 1 on the standard parallel and increases with distance from the standard parallel.

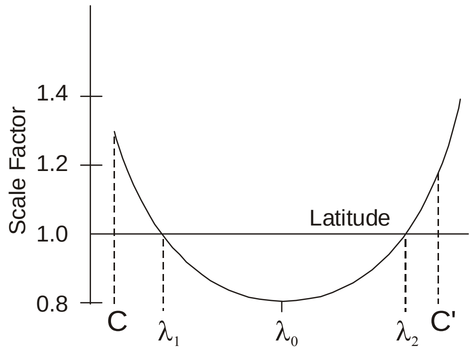
9-3 Fig 48 One Standard Conformal Conic



Lambert Conformal Conic Projection

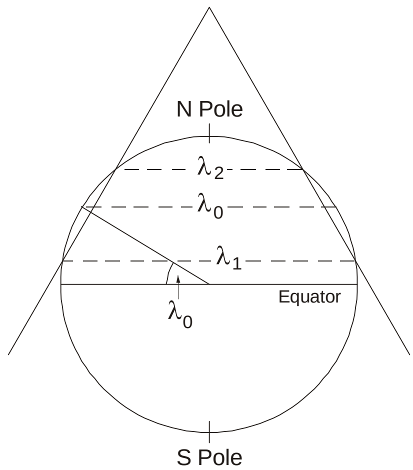
139. The Lambert conformal is a non-perspective projection with two standard parallels. It is obtained by simply declaring the scale to be correct (i.e. equal to reduced Earth scale) along two parallels which are approximately equally spaced about λ_0. The scale factor at these standard parallels is 1, varying at other latitudes, as illustrated in Fig 49.

9-3 Fig 49 Lambert Conformal Scale Factor



140. **Description**. The projection can be regarded as the projection of a slightly larger reduced Earth onto the original cone, which is so placed as to cut it at two parallels, λ_1 and λ_2, as in Fig 50. The meridians are straight lines radiating from the pole and inclined to each other at n × ch long, where n is sin λ_0. For all practical purposes, λ_0 is the mean of the two standard parallels, λ_1 and λ_2, and is, of course, the latitude of minimum scale factor.

9-3 Fig 50 Approximate Projection Description



141. **Advantage of Two Standard Parallels**. The advantage of a projection with two standard parallels is to give an increase of the area of the Earth within which the scale deviation of the projection will not exceed a given amount, i.e. in the example at Fig 49, if a straight edge calibrated to the scale at λ_1 or λ_2 is used, the error is within 20% at λ_0, C and C′. Thus, by choosing a scale factor at λ_0 for the Lambert

projection, all other scale factors can be determined. The scale factor at λ_0 is sometimes called the scale reduction factor (SRF).

142. **Standard Parallel Separation**. The shape of the scale factor graph fixes a relationship between SRF and the distance apart of the standard parallels. The choice of one determines the other. The actual connection depends upon latitude, but over a wide range (up to about 80º N), Table 2 below is a useful guide.

Table 2 Relationship between Standard Parallel Separation and Scale Reduction Factor

Scale Reduction Factor	Scale Deviation at λ_0	Standard Parallel Separation
0.99	1%	16°
0.98	2%	23°
0.97	3%	28°
0.96	4%	32°

143. **Minimizing Scale Deviation on the Chart**. Scale factor increases away from λ_0 in both directions, passing through 1 at the standards, λ_1 and λ_2. If the standard parallels are placed so as to divide the latitude coverage of a chart in the ratio 1:4:1 or 1/6:4/6:1/6, then the best balance of scale deviation is achieved. This is known as the 1/6 rule. Furthermore, if a maximum standard parallel spacing of 14º is observed, then the scale deviation will be limited to <1%. Thus, a Lambert chart can be considered as 'constant scale' if both:

a. The spacing of the standard parallels does not exceed 14º Ch Lat, and
b. The 1/6 rule is observed.

144. **Great Circles**. Near λ_0, great circles are approximately straight lines; away from λ_0 they are curves concave to λ_0. The angle (Δ) between the great circle and the straight line is given by:

$$\Delta = \tfrac{1}{2} \text{ ch long } (\sin \text{ mean lat} - n)$$

Near λ_0, the great circle is very well represented by a straight line and, on most parts of actual charts, the divergence between the two is not noticeable.

145. **Distance Measurement**. When measuring distances on Lambert projections, the mid-latitude scale in the area should be used, but over long tracks, which pass from areas of negative scale error to positive scale error, a straight edge graduated at the stated scale can be used. The amount of care which is required can be assessed from para 142. If the standards are within 16° of each other, then a straight edge can be used everywhere within about 12° of λ_0. If the separation is greater than 16°, then a constant-scale straight edge should only be used when measuring long distances or if the flight is within the band of 1% scale deviation about a standard parallel.

146. **Summary of Properties**. The properties of the Lambert Conformal projection are as follows:

a. The projection is conformal with two standard parallels (where scale factor is 1).

b. Scale factor is at a minimum at the latitude whose sine is n. This latitude is about the mean of the standards.

c. Scale factor change is roughly of the form of the secant of the ch lat from λ_0.

d. The projection is not conformal at the poles and scale factor is very large near the poles.

e. Great circles are curves concave to λ_0. Near λ_0 they are approximately straight lines.

f. Sheets will join only if they are based on the same standard parallels and are at the same scale.

147. **Uses**. Lambert's Conformal charts are in widespread use except for polar latitudes. Examples of current charts are: 1:500,000 Global Navigation Charts (GNC), 1:2,000,000 Jet Navigation Charts (JNC), 1:500,000 Tactical Pilotage Charts (TPC), 1:100,000 Operational Navigation Charts (ONC) and 1:500,000 Low Flying Charts (LFC). The moving map filmstrip used in the Tornado is based on Lambert's charts but modified to a form of equidistant cylindrical projection (Plate Carree) during photography.

NAVIGATION PROJECTIONS - COMPARISON AND SUMMARY

Introduction

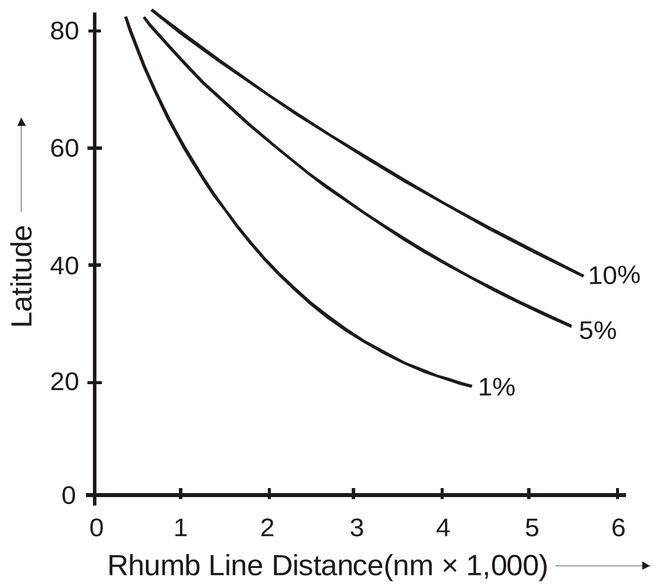
148. In this chapter, the navigation projections are compared, and their properties are summarized.

Great Circles and Straight Lines

149. In general, conformal projections do not portray great circles as straight lines, except the equator and meridians in some cases. It is therefore necessary to provide some guidelines as to when it is worthwhile to plot the great circle rather than the straight line.

150. **Distance**. From a distance-saving point of view, there is usually little to gain in flying true great circle routes on the stereographic projection or on Lambert's projection. The difference between the straight line and the great circle distance for flights of less than 2,000 nm contained within ±25° of the parallel of origin (λ_0) is less than 0.5 % of the distance. Navigation charts based on these projections are usually confined to a much smaller latitude spread, but since this is not the case with the Mercator projection, special care is needed with it. Fig 51 illustrates the penalty, expressed as percentages of great circle distances, in flying east west rhumb line tracks at various latitudes.

9-3 Fig 51 Mercator Projection Distance Penalty

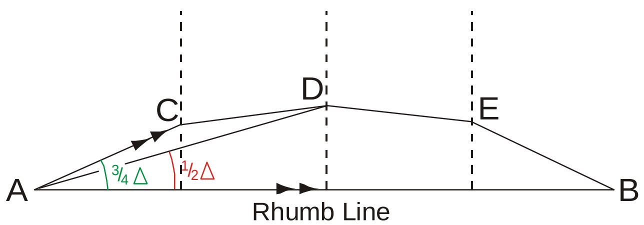


151. **Direction**. The angle between the great circle direction and the straight line is given by:

$$\Delta = \tfrac{1}{2}\ \text{ch long (sin mean lat} - n)$$

approximately on Mercator's and on Lambert's projection, and exactly on the stereographic projection. Use can be made of Δ to sketch in a series of straight lines which will correspond very well with the great circle in most cases. The straight-line distance, AB in Fig 52, is measured in some constant unit and perpendiculars are erected at the quarter, half and three-quarter length points. The line segments AC, CD, DE, EB are then drawn using angles 0.75Δ and 0.5Δ, and 0.25Δ as shown in the diagram to obtain the intercepts C, D and E. The direction is concave to λ_0.

9-3 Fig 52 Approximate Great Circle

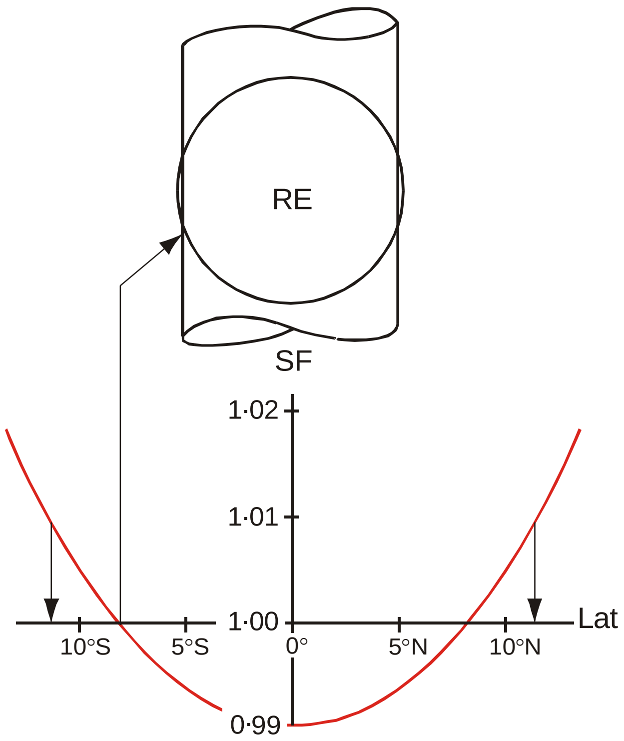


Scale Reduction Factor

152. Scale reduction factor (SRF) was used to develop the Lambert conformal projection from the one-standard conformal conic. It is also the device used in the Ordnance Survey transverse Mercator projection of the United Kingdom to reduce scale deviation. SRF can be used for any conformal projection to produce the same effect.

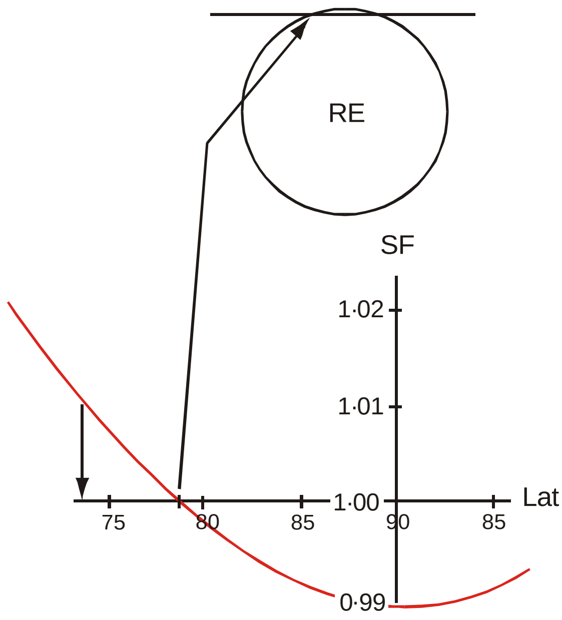
153. If, for example, the scale factor everywhere on a Mercator projection is multiplied by 0.99, two parallels, one at about 8° N and the other at about 8° S, will gain scale factors of 1. The projection will be of the form illustrated in Fig 53, on to a cylinder cutting a larger reduced Earth in these two parallels, and reduced Earth scale can now be used everywhere between about 11.5° N and 11.5° S with a deviation of less than 1%, i.e. with almost constant scale.

9-3 Fig 53 Mercator with Two Standard Parallels



154. The idea can be applied to the polar stereographic. A scale deviation of 1% occurs at about 11.5º from the pole. To enlarge the area of almost constant scale it is necessary to multiply all scales by 0.99. Scale factor becomes 0.99 at the pole and 1 at about latitude 78.5º. Constant scale measurement can be used up to 16º (latitude 74º) from the pole where scale factor is now 1.01. This projection can now be thought of as stereographic on to a plane cutting the Earth at latitude 78.5º (Fig 54).

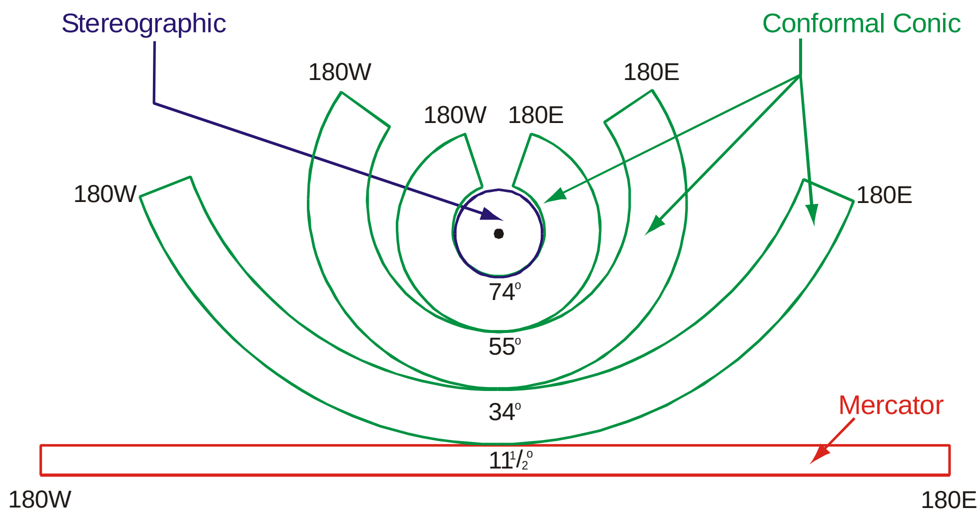
9-3 Fig 54 Modified Stereographic



155. Using the Lambert conformal projection, a scale deviation of 1% can be achieved by placing the standard parallels some 16º apart; an area bounded by parallels approximately 3º or 4º beyond these then has the required maximum scale deviation.

156. The use of scale reduction factor allows conformal mapping of a hemisphere on to five projections with scale deviation everywhere less than 1%. The projections are a Mercator at the equator, polar stereographic and three Lambert conformal conics covering latitude bands shown in Fig 55.

9-3 Fig 55 Conformal Mapping of a Hemisphere



Errors in Distance Measurement

157. On the majority of Lambert conformal charts available for navigation no sensible error is introduced through using the constant scale for distance measurement, but care is needed on any chart on which

the standards are about 16º or more apart. This care is especially necessary when the area of operation is at the centre or at the extremes of the projection.

158. Similarly, no appreciable error will result from using reduced Earth scale in equatorial regions on a Mercator projection, or near the pole on a polar stereographic projection. When there is any doubt, on any projection, the track should be divided into latitude bands of 100 nm to 200 nm and the mean latitude scale at each band used.

PROJECTION SUMMARY

Choice of Chart

159. Choosing the best chart for a particular task may appear at first sight a difficult task, but it is often reduced simply to a choice between only two or three charts and the decision may finally be made by availability. The following summary suggests suitable charts for a number of purposes.

Planning Charts

160. Planning charts are used for display and for route and operational planning. They must, in general, cover large areas with minimal distortion, or have some particular useful property, such as showing great circles as straight lines, or radii of action at constant scale. The scales used for planning charts are necessarily small, in the order of 1:10,000,000 to 1:20,000,000.

161. Without doubt, the best general-purpose display and planning projection is the stereographic. It is conformal, it has the smallest scale expansion, it can display almost the whole world on one sheet, and great circles can be drawn with a minimum of difficulty since they are lesser arcs of circles.

162. For smaller areas the Lambert conformal in middle latitudes, and the Mercator in low latitudes, provide the best working projections.

163. **Summary**. The applicability of the various projections to planning tasks may be summarized as follows:

Task		Projection Most Suited
Large Area	-	Stereographic
Small Area		
Middle	-	Lambert Conformal
Low Latitudes	-	Mercator
Polar Regions	-	Stereographic
Radii of Action	-	Azimuthal Equidistant
Great Circles	-	Gnomonic

Plotting Charts (General)

164. Plotting charts must be conformal. They should also be easy to use, which implies that the scale for distance measurement should be uncomplicated and that the measurement of headings and bearings should be made from a straight-line datum. The simplest form of navigation is constant heading and for this the direction datum should be parallel over the whole chart.

165. If the direction datum is True North, then the Mercator projection fulfils this requirement, but it cannot be used in high latitudes and is not the best projection in medium latitudes since the rhumb line is excessively longer than the great circle. The plotting of chords of the great circle from a gnomonic satisfies the distance difficulty, but it also defeats the object by introducing many changes of direction.

166. The best all-round solution in middle latitudes is the Lambert conformal projection, on which scale is almost constant. A grid can be overprinted, and the corrections to magnetic or other datum direction to indicate grid north are no more difficult to apply than those to obtain True North. In polar regions, the Polar Stereographic is the best chart.

167. **Summary**. The usefulness of the projections for plotting purposes is shown below:

12º S to 12º N	-	Mercator
12º to 74º	-	Lambert Conformal
74º to 90º	-	Polar Stereographic or Transverse Mercator

Plotting Charts (Special)

168. Special plotting charts are available when the area of operation is specified by a great circle and a narrow band around it.

169. If the area of operation extends from polar to equatorial regions the best single projection is the transverse Mercator.

170. If the area is along an inter-cardinal great circle then the oblique Mercator projection provides the best solution. Such strip maps are produced for important high-density routes.

171. **Summary**. The best charts for special plotting uses may be summarized as:

Large ch lat, small ch long	-	Transverse Mercator
Inter-cardinal Great Circle	-	Oblique Mercator

Topographical Charts

172. Topographical charts for navigation must be conformal and have the same properties as other plotting charts. Thus, the Mercator and Lambert projections are usually chosen.

173. However, an additional problem is introduced when large-scale topographical charts of world-wide coverage are considered. Such charts, which are intended primarily for joint air/ground operations, must have very small-scale errors and adjoining sheets must fit north/south and east/west as exactly as possible. These requirements are best met by a sequence of transverse Mercator projections based on close meridians.

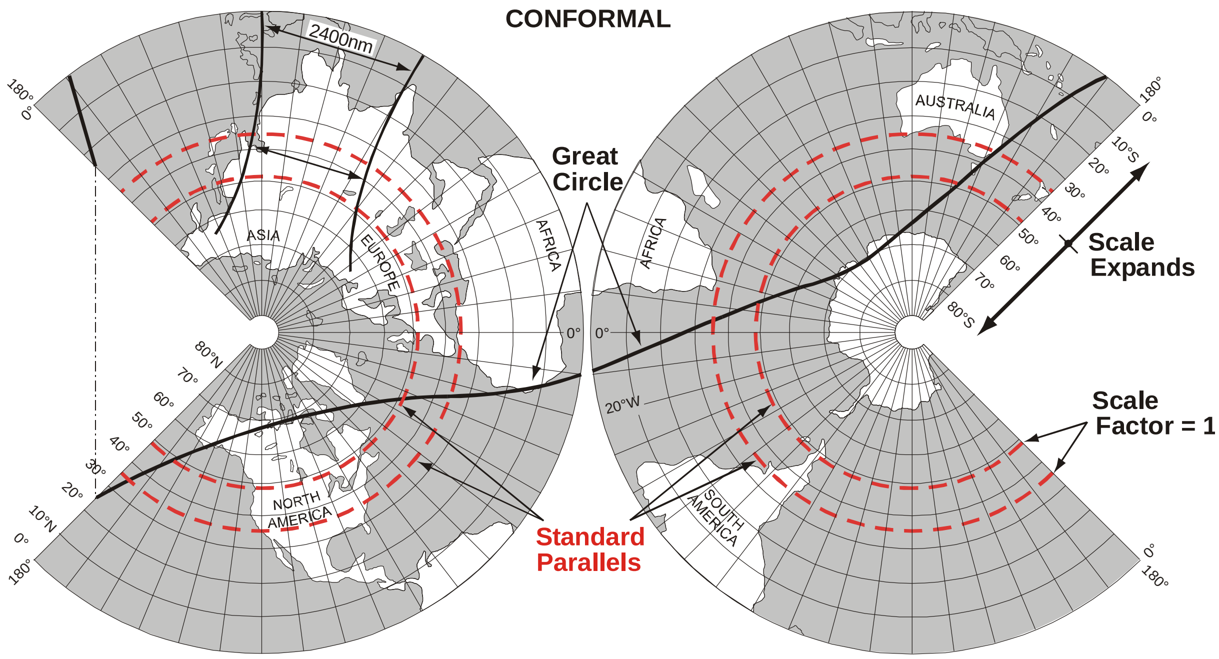
174. **Summary**. The appropriate projections for topographical use are summarized as follows:

General	-	Lambert Conformal
	-	Mercator (Low Latitudes)
World-wide (Large Scale)	-	Transverse Mercator

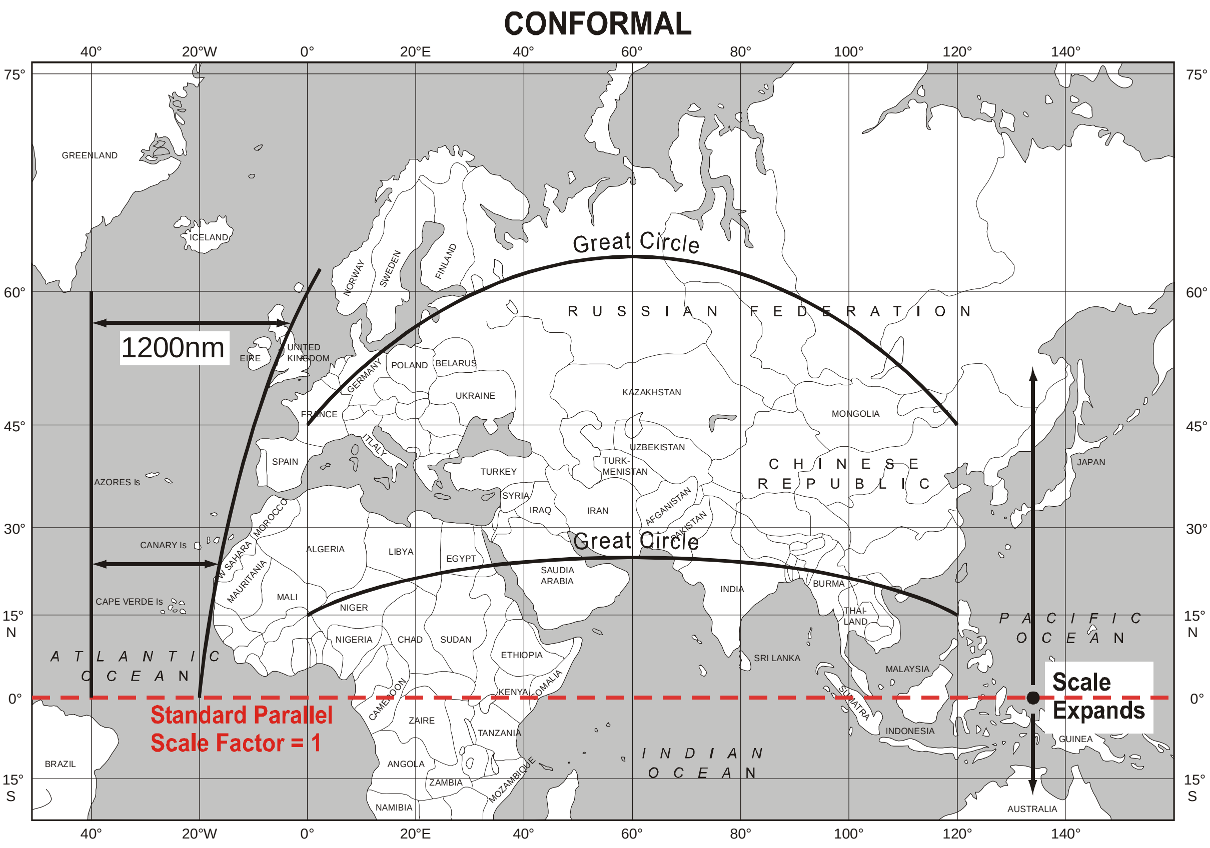
The Navigation Projections

175. The projections of importance in navigation are summarized in Figs 56 to 62.

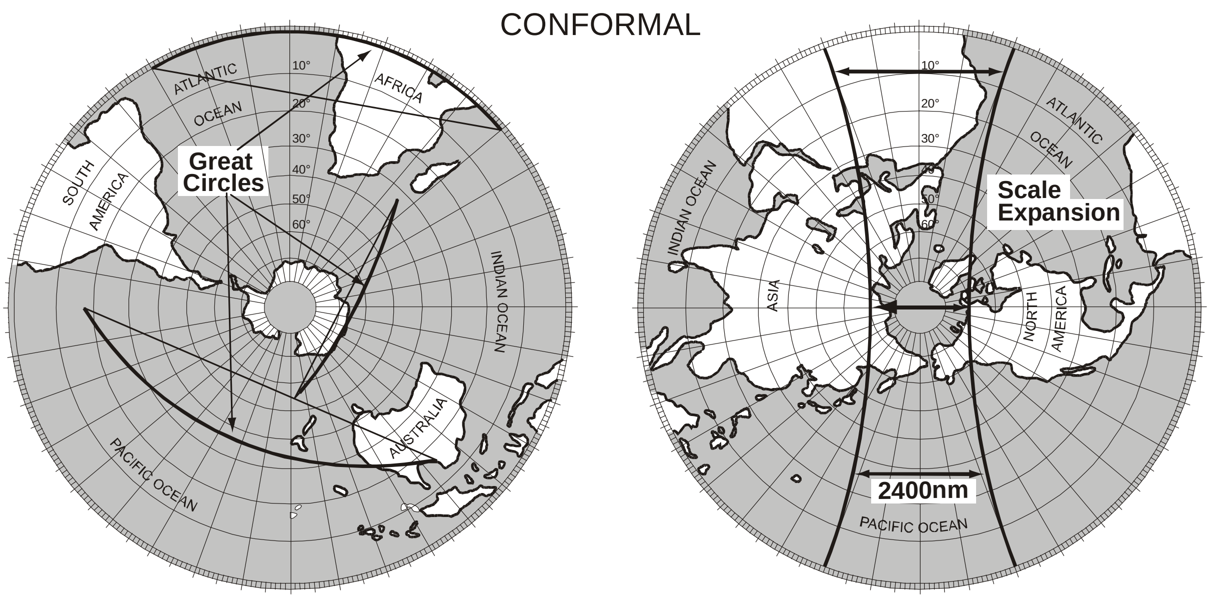
9-3 Fig 56 Lambert Conformal Projection



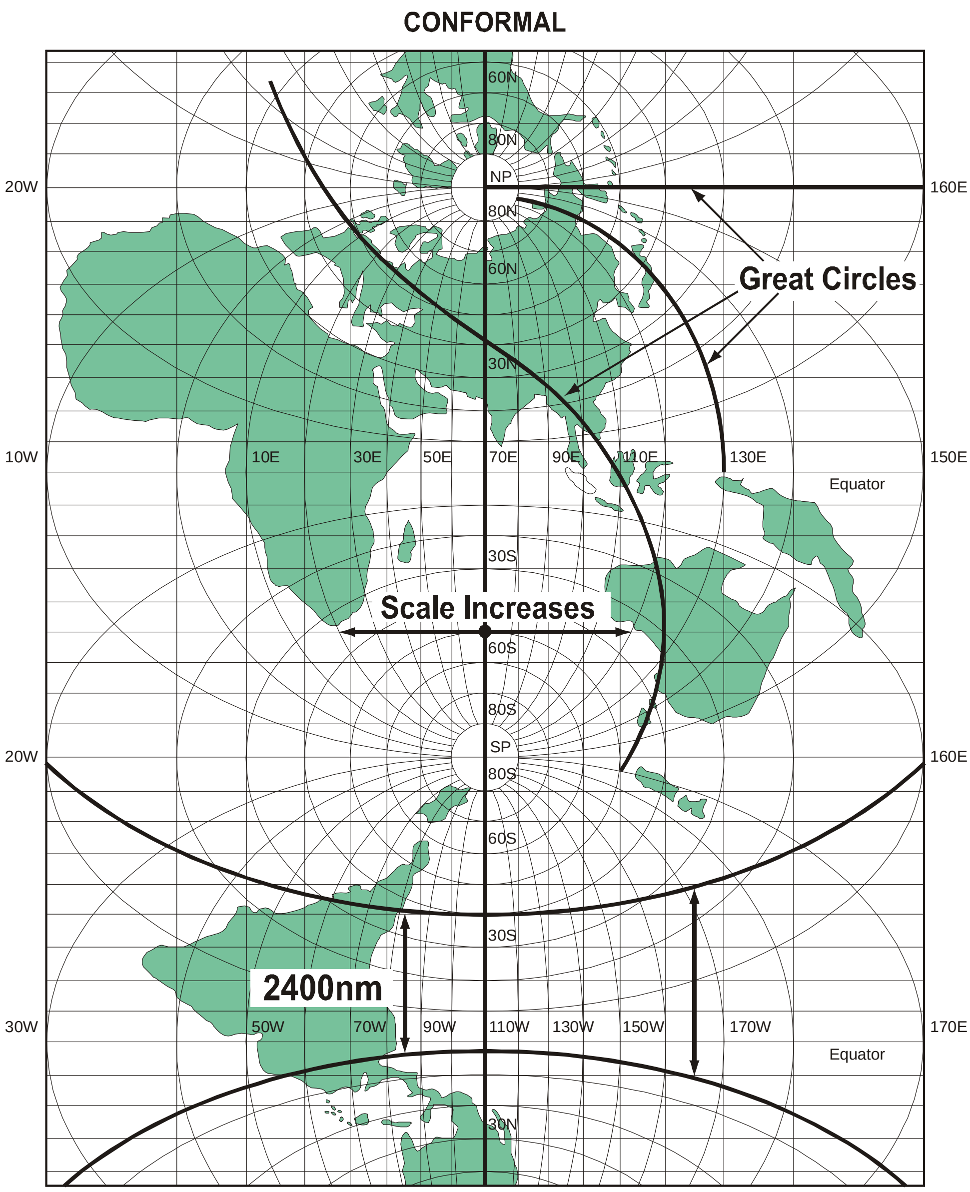
9-3 Fig 57 Mercator Projection



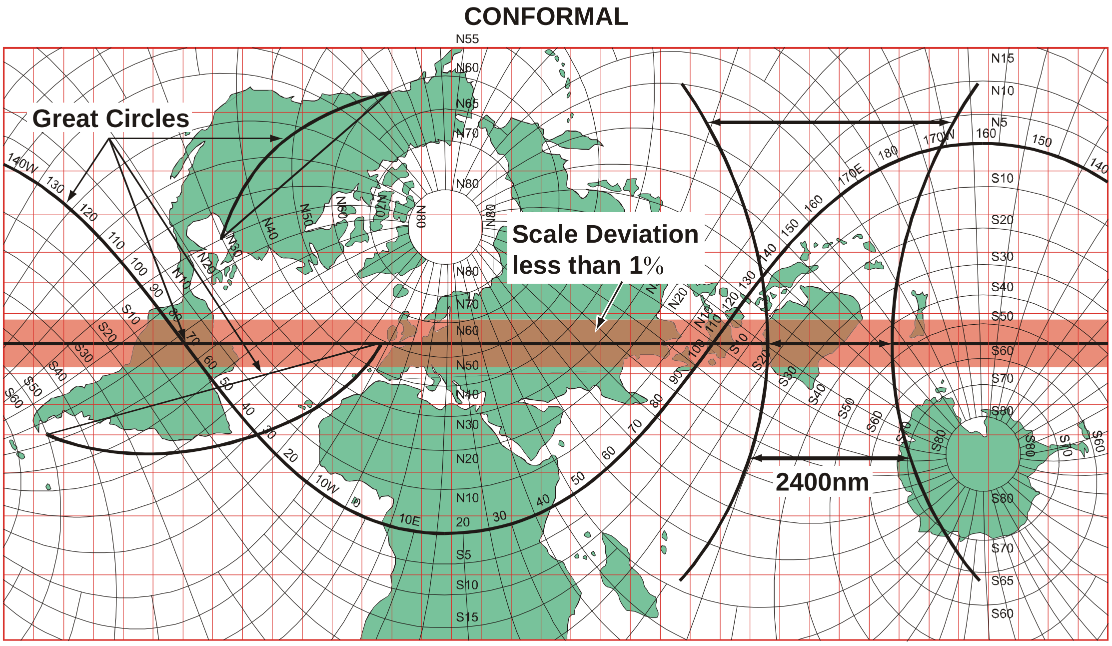
9-3 Fig 58 Polar Sterographic Projection



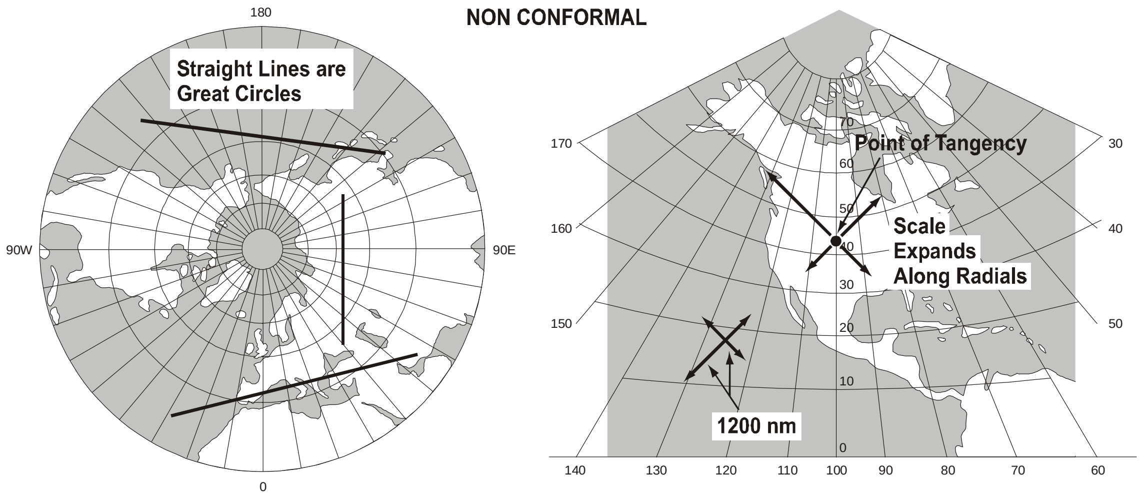
9-3 Fig 59 Transverse Mercator Projection



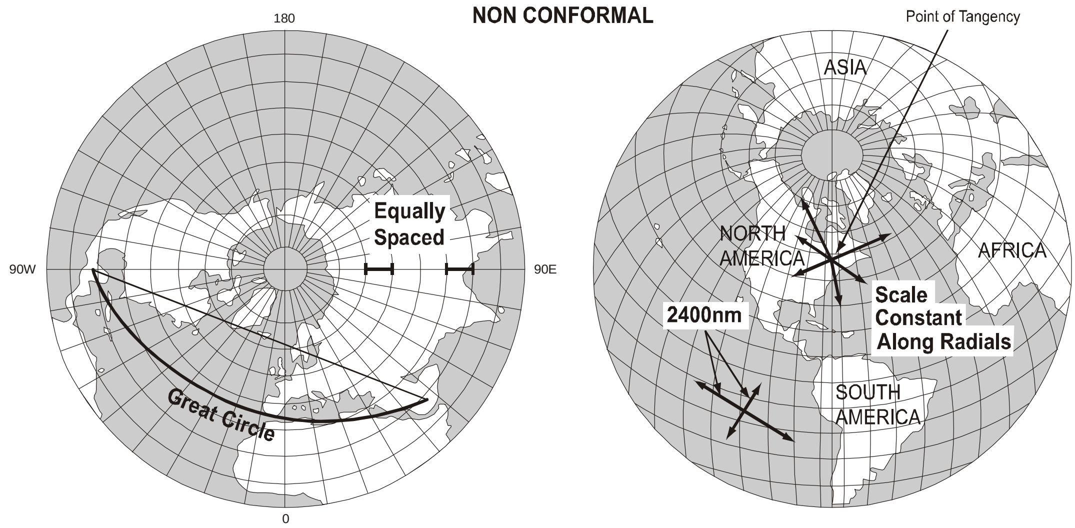
9-3 Fig 60 Oblique Mercator Projection



9-3 Fig 61 Gnomonic Projection



9-3 Fig 62 Azimuthal Equidistant Projection



CHAPTER 4 - THE TRIANGLE OF VELOCITIES - APPLICATION TO NAVIGATION

Speed and Velocity

1. It is important to realize the difference between the meanings of the words 'speed' and 'velocity'. Speed describes only the rate at which an object is moving. The statement that an aircraft has a speed of 400 kt gives no indication of the direction in which the aircraft is travelling, and this direction may be changed without any alteration of speed. Speed is thus a scalar quantity; it has magnitude but no direction.

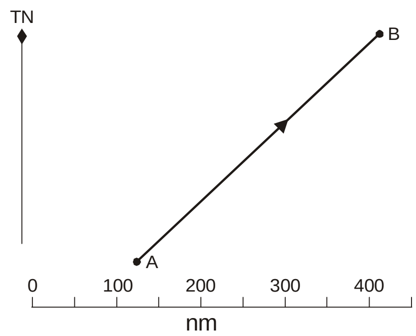
2. Velocity describes speed in a specified direction, it is said to be a vector quantity for it has both magnitude and direction. Thus, an aircraft flying at 400 kt on a heading of 045° (T) has a different velocity from that of an aircraft flying at 400 kt on 090° (T), although their speeds are identical.

Vectors

3. Since a velocity is a speed in a given direction, it may be represented graphically by a straight line whose length is proportional to speed, and whose direction is measured from an arbitrary datum line. Such a straight line is called a vector.

4. The scale used in drawing vectors may be any that is convenient. The datum line for measurement of direction is, by convention, True North, and usually points to the top of the sheet. To indicate the direction and scale of the vector, it is usual to insert the True North symbol at some point in the diagram, and to indicate scale by a graduated scale line. Fig 1 illustrates the vector for an aircraft flying at 400 kt on a heading of 045° (T); the arrowhead indicates the sense of the vector, showing that the direction is 045° and not 225°.

9-4 Fig 1 A Vector



5. The discussion, so far, has concerned an aircraft's velocity relative to the air through which it moves. However, there is another factor which plays an important part in air navigation - the movement of the air itself.

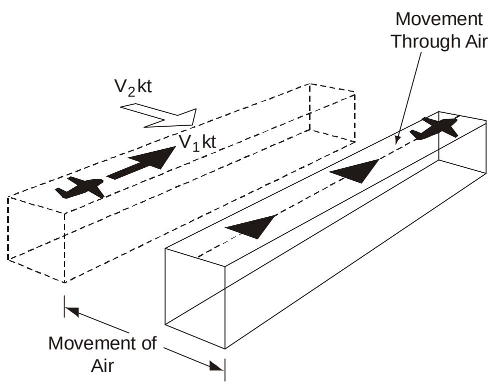
6. **Wind Velocity**. Wind is air in natural motion, approximately horizontal. The direction and speed of that motion defines wind velocity (w/v), and it too can be represented by a vector. It is expressed as a five or six figure group; the first three figures refer to wind direction (the true direction from which it blows); the last two or three figures indicate wind speed in knots. The figures representing direction are separated

from those of speed by an oblique stroke. Thus, a wind velocity of speed 45 knots blowing from the east would be written as 090/45, and one of 145 knots from the same direction as 090/145.

Vector Addition

7. Fig 2 illustrates the basic navigation problem; the aircraft is moving at V_1 kt through an air mass which itself is moving at V_2 kt (w/v). It is necessary to find the resultant of these two component velocities to determine the aircraft's path over the ground.

9-4 Fig 2 Factors Affecting the Path of an Aircraft

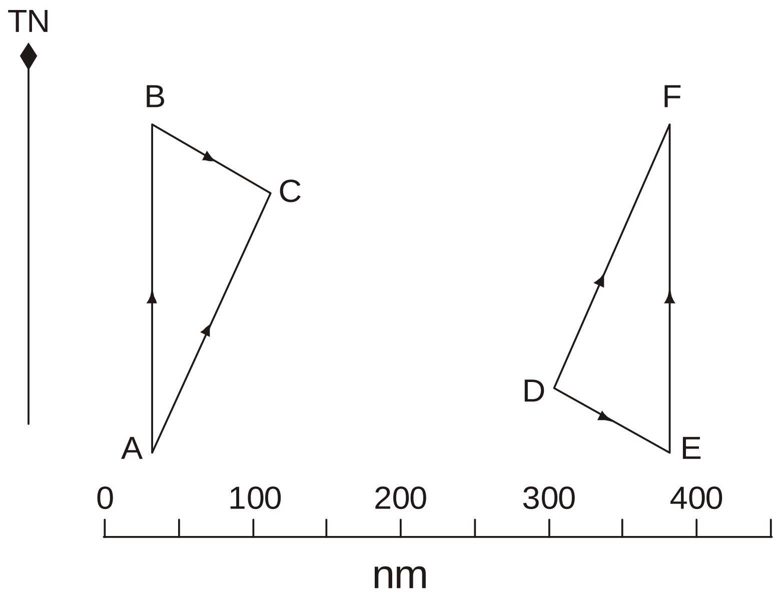


8. If the component velocities act in the same direction (i.e., the aircraft flies directly upwind or downwind), the resultant velocity is the algebraic sum of the aircraft speed and wind speed, along the aircraft heading. However, when the component velocities do not act in the same line, the resultant velocity is an intermediate speed in an intermediate direction. In such cases, it is possible to find the resultant by constructing a vector diagram, or triangle of velocities.

Triangle of Velocities

9. If the vectors (see Fig 3) of the aircraft's velocity (AB or EF) and wind velocity (BC or DE) are drawn (using the same scale), such that their sense arrows follow each other, then the resultant velocity vector is the third side. The sense of this vector is such that its arrow opposes the arrows of the component velocities around the triangle. Thus, in Fig 3, the vector of the resultant velocity is AC or DF.

9-4 Fig 3 Triangle of Velocities



10. It can be seen that AC and DF are identical in magnitude and direction; it does not matter in which order the initial component vectors are drawn as long as their sense arrows follow each other.

NAVIGATION COMPONENTS OF THE TRIANGLE OF VELOCITIES

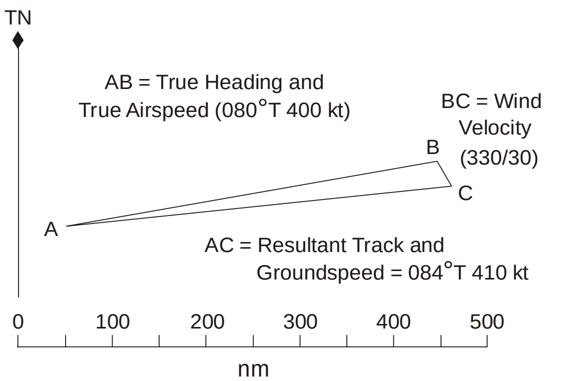
General

11. Using the triangle of velocities to solve the basic navigation problem, the component vectors represent the aircraft's velocity (true heading and true airspeed) and wind velocity; the resultant vector represents the aircraft's true track and groundspeed (see Fig 4a).

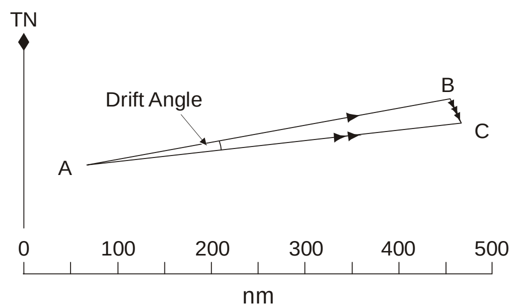
12. In addition to these vectors, the other important quantity in navigation is the angle between the aircraft's velocity vector and the resultant; this is the drift angle (see Fig 4b).

9-4 Fig 4 Navigation Vectors

a Component Parts of the Triangle of Velocities



b Arrow Convention



13. **Arrow Convention**. The vectors are not normally labelled as in Fig 4a but are identified merely by the number of arrows on the vector. The convention, illustrated in Fig 4b, is:

a. The true heading and true airspeed vector carries one arrow, pointing in the direction of heading.

b. The track and groundspeed vector carries two arrows, pointing in the direction of track.

c. The wind velocity vector carries three arrows pointing in the direction in which the wind is blowing.

14. In para 11, several new terms were introduced, eg true airspeed, track, and groundspeed. These will now be examined in more detail.

Airspeed

15. The speed of an aircraft measured relative to the air mass through which it is moving is termed true airspeed (TAS). It is emphasised that, because of wind velocity, this speed will differ from that measured by an observer on the Earth. Airspeed is independent of wind and is the same regardless of whether the aircraft is flying upwind or downwind.

16. An aircraft's airspeed is usually measured by an airspeed indicator (ASI). The ASI reading is termed indicated airspeed (IAS), but this does not equal true airspeed. The difference between these quantities is caused by a number of inaccuracies which, broadly speaking, stem from two sources, the ASI itself and the atmosphere.

17. If IAS is corrected for the inaccuracies of the ASI (instrument and pressure errors), the result is called calibrated airspeed (CAS). At higher speeds (normally above about 300 kt), a correction to CAS is necessary to take into account the compressibility of air; this correction varies with altitude and speed. The speed after this correction is termed equivalent airspeed (EAS). ASIs are calibrated in relation to the International Standard Atmosphere and at mean sea level. At all other altitudes, EAS and CAS are less than TAS because the air is less dense than at sea level. CAS or EAS may be corrected to TAS by using graphs, tables, digital computers or analogue computers (such as the Dead Reckoning Computer Mk 4A).

Mach Number

18. An alternative method of quoting TAS is to express it as a fraction of the local speed of sound; this fraction is known as the Mach Number (M) and is given by:

$$M = \frac{V}{C}$$

Where V = True Airspeed

C = Speed of Sound (in the same air conditions)

Mach Numbers are expressed as decimals e.g.:

V = 440 kt and C = 580 kt, then M = 0.76; or
V = 725 kt and C = 580 kt, then M = 1.25.

19. There are aerodynamic problems which occur at a certain fraction (depending on the aircraft type) of the speed of sound. Although this fraction is fixed, it may be represented by widely varying values of CAS (depending on altitude) and varying values of TAS (depending on temperature). It is more convenient, therefore, in high-speed flight to display the aircraft's speed as a Mach Number rather than as IAS or TAS. A Machmeter computes and displays this quantity.

20. The speed of sound varies as the square root of the absolute temperature. Thus, the calculation of TAS from Mach Number is much simpler than, say, from CAS, for the only variable is temperature.

Groundspeed

21. Since air navigation is concerned with the movement of an aircraft over the Earth, it is necessary to know the speed at which the aircraft is moving relative to the Earth; this is termed groundspeed, and, like airspeed, it is measured in knots.

22. Groundspeed is usually determined by one of the following methods:

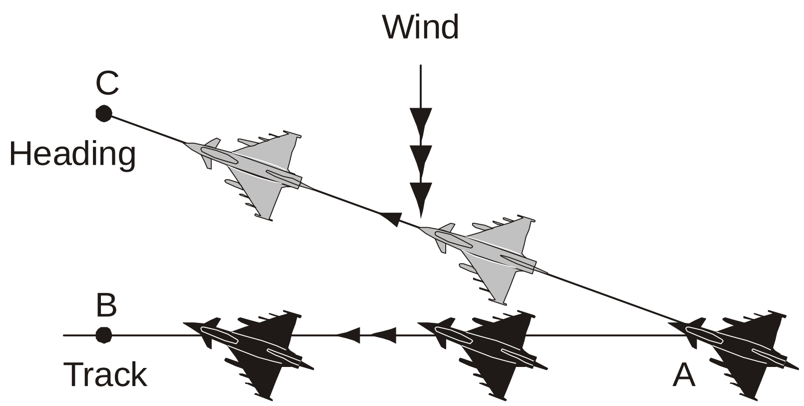
a. Calculating the effect of wind velocity on the aircraft, ie by solving the triangle of velocities.
b. Measuring the time taken to travel a known distance between two positions on the ground.
c. The use of Doppler equipment.
d. The use of inertial navigation systems.

Track

23. The direction of the path of an aircraft over the ground is called its track. If an aircraft flies directly upwind or downwind, or in still air, its path over the ground lies in the same direction as its heading. In all other cases, wind will cause the aircraft to move over the ground in a direction other than that which is in line with its fore and aft axis, and to an observer on the ground it will appear to move crab-wise rather than straight ahead. In such cases the aircraft's heading and track are not the same.

24. In Fig 5, an aircraft at A is flying on a heading of 290° (T). As it maintains this heading, a northerly wind carries the aircraft from the path it would have followed in the absence of the wind ie AC. Sometime later the aircraft passes over B; AB then represents the track and the aircraft is said to have 'tracked' from A to B.

9-4 Fig 5 Heading and Track

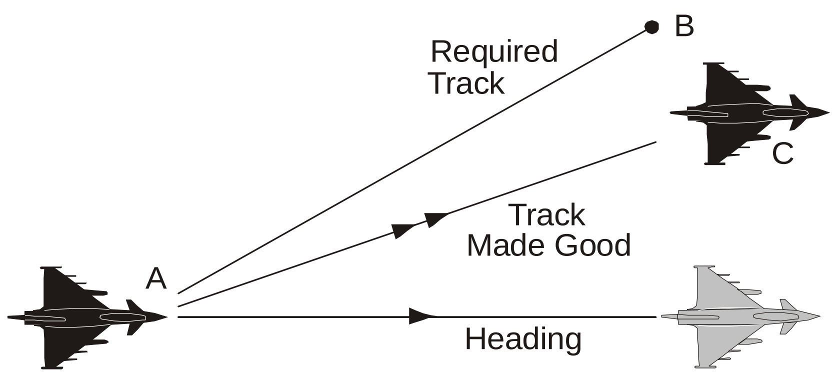


25. The line joining two points between which it is required to fly is known as the required track.

26. In flying from one point to another, the path which the aircraft actually follows over the ground is called its 'track made good'. When track made good coincides with required track, the aircraft is said to be 'on track'; when track made good and required track are not the same the aircraft is said to be 'off track'.

27. Fig 6 illustrates the difference between required track and track made good. An aircraft attempting to go from A to B finds itself sometime later at C. AB is therefore the required track and AC the track made good.

9-4 Fig 6 Required Track and Track Made Good



28. Any two points on the Earth's surface may be joined by a rhumb line and by a great circle. It follows, therefore, that the required track may be either a rhumb line track, which follows the rhumb line between two points, or a great circle track, which follows the great circle between the points. By definition, the rhumb line track maintains a constant direction relative to true North and is therefore, in many cases, the easier to make good.

29. Track is measured in degrees and is expressed (like heading) as a three-figure group eg 045°. Track may be measured relative to true North, magnetic North or grid North and is annotated (T), (M) or (G) accordingly.

Drift

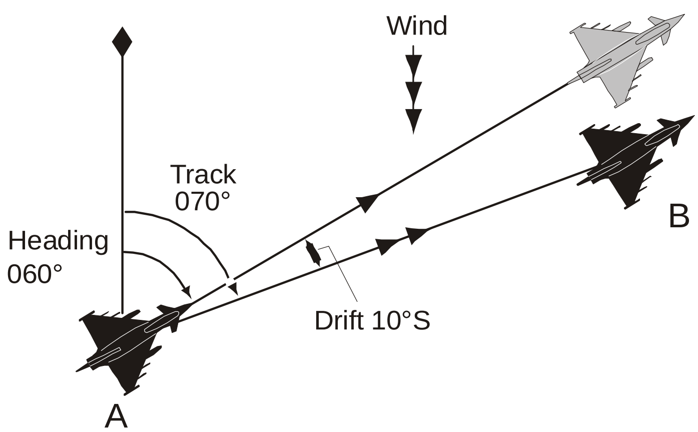
30. The angle between the heading and track of an aircraft is called drift. Drift is due to the effect of the wind and is the lateral movement imparted to an aircraft by the wind. An aircraft flying in conditions of no wind, or directly upwind or downwind, experiences no drift. In such cases, track and heading coincide. Under all other conditions, track and heading differ by a certain amount, referred to as the drift.

31. Drift may be measured manually by observing the direction of the apparent movement of objects on the ground below the aircraft (Track) and comparing this direction with the fore and aft axis of the aircraft (Heading) to obtain the angular difference (Drift). Many aircraft are fitted with automatic systems that calculate drift continuously by electronic means eg Doppler or inertial systems.

32. Drift is expressed in degrees to port (P) or starboard (S) of the aircraft's heading. An aircraft experiencing port drift is said to drift to port, and its track lies to port of its heading. Thus, knowing the heading of the aircraft, the track can be determined by proper application of drift to heading. If drift is to port, track angle is less than heading; if to starboard, track angle is greater than heading. Automatic systems can continuously apply drift to heading to give a direct indication of track.

33. The direct measurement of track, i.e. from knowledge of actual ground position, enables drift to be determined, provided the heading is known. Thus, an aircraft whose track is measured from a map as 070° (T) while flying on a heading of 060° (T) is drifting 10° to starboard. This relationship is shown in Fig 7.

9-4 Fig 7 Drift



APPLICATION OF THE TRIANGLE OF VELOCITIES IN NAVIGATION

General

34. Having discussed the triangle of velocities and its components, it is now possible to review its application in the solution of navigation problems.

35. The triangle of velocities may be considered to have six parts; each of its three sides representing a speed and a direction. A knowledge of any four of these parts enables the remaining two parts to be found. In navigation, the types of problem solved by this method are:

a. Finding the length and direction of one side eg finding track and groundspeed, wind velocity or, occasionally, heading and airspeed.

b. Finding the length of one side and the direction of another, eg true heading and groundspeed.

In practice, the triangle of velocities can be continuously resolved by automatic navigation systems. However, graphical methods may still be used during planning and in flight, using the transparent plotting disc of the DR Computer Mk 4A or Mk 5A. The following examples, employing basic pencil-on-paper vector plotting, are therefore intended to provide a thorough understanding of the underlying principles, rather than to illustrate a practical method of solving navigation problems.

Rules for Plotting

36. In plotting the vector triangle, there are a number of points to note. The same datum direction, and a uniform unit of measurement, must be used for all vectors, otherwise the diagram will be distorted. Furthermore, one must ensure that true airspeed is measured only along true heading and that similar relationships for track and groundspeed, and wind direction and wind speed are maintained.

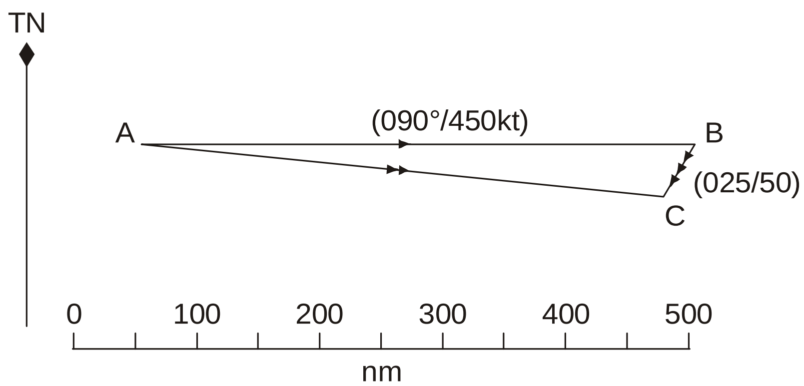
Finding the Length and Direction of One Side

37. **To Find Track and Groundspeed**.

Example: An aircraft flying at TAS 450 kt, on a heading of 090° (T), experiences a w/v of 025°/50 kt. What is its track and groundspeed?

Solution (Fig 8):

9-4 Fig 8 Calculating Track and Groundspeed



a. Draw AB, the heading and airspeed vector.

b. From B, lay off the wind vector BC.

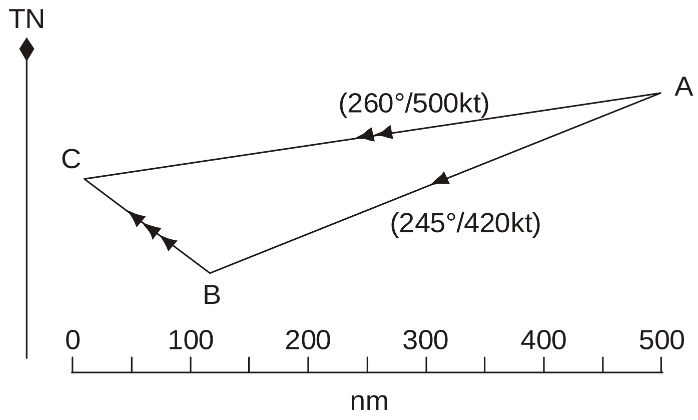
c. Join AC and measure its direction and length. Track and groundspeed are found to be 096° (T) and 432 kt respectively.

38. **To Find Wind Velocity**.

Example: The groundspeed of an aircraft is 500 kt on a track of 260° (T); its true airspeed is 420 kt on a heading of 245° (T). What is the wind velocity?

Solution (Fig 9):

9-4 Fig 9 Finding Wind Velocity



a. Plot AB, the heading and true airspeed vector.

b. From A, lay off AC, the track and groundspeed vector.

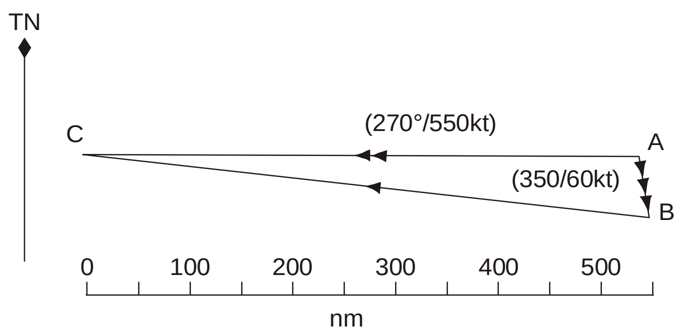
c. Join BC and measure its direction and length. Wind velocity found is 129°/145 kt.

39. **To Find True Heading and True Airspeed**.

Example: In order to maintain a schedule, it is necessary to fly a track of 270° (T) at a groundspeed of 550 kt. The wind velocity is 350°/60 kt. What true airspeed and what true heading must be flown to achieve these conditions?

Solution (Fig 10):

9-4 Fig 10 Finding True Heading and Airspeed



a. Plot AB, the wind vector.

b. From A, lay off AC, the track and groundspeed vector.

c. Join BC to obtain the heading and airspeed vector. Heading and airspeed are 276° (T) and 563 kt respectively.

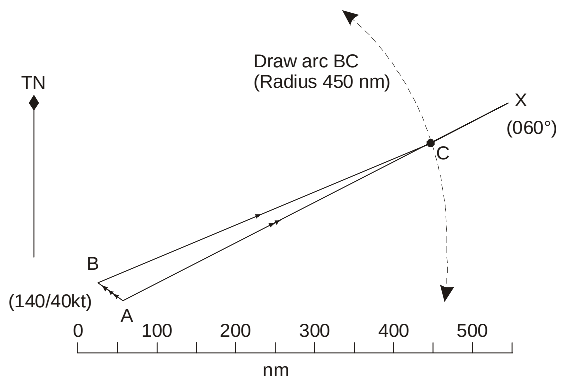
Finding the Length of One Side and the Direction of Another

40. **To Find Heading and Groundspeed**. The determination of the heading to make a given track, and the resultant groundspeed, is probably the most common navigation problem:

Example: It is necessary to make good a track of 060° (T) whilst flying at a TAS of 450 kt. Wind velocity is 140°/40 kt. What heading must be flown and what groundspeed will be achieved?

Solution (Fig 11):

9-4 Fig 11 Finding Heading and Groundspeed



a. Draw line AX of indefinite length in a direction 060° (T) to represent required track.

b. From A, lay off AB, the wind vector.

c. With centre B, and radius true airspeed, describe an arc to cut AX at C. The direction of BC, 065° (T), is the heading required to make good a track of 060° (T); AC represents groundspeed, which is measured as 441 kt.

CHAPTER 5 - DETERMINATION AND APPLICATION OF WIND VELOCITY

DETERMINATION

Introduction

1. Wind velocity plays a major part in navigation calculations. If wind velocity was constant, one measurement would suffice for all calculations and workloads would be considerably reduced. However, wind velocity is seldom constant; it varies in direction and speed with height, time, and place. Consequently, a knowledge of the expected wind velocities is required in order to plan a flight, a knowledge of the wind effect actually being experienced in flight is necessary to calculate position and a knowledge of present wind velocity is needed to calculate alterations of heading. Because of its continual variation, it is normally necessary to measure wind velocity frequently if accurate navigation is to be accomplished.

Mean and Local Wind Velocities

2. Measured wind velocities may be divided into mean and local winds, the division depending upon the interval over which the wind is determined. A mean wind velocity is one which has been found over a fairly long-time period and usually over a large area; it represents the mean effect of all the different wind velocities experienced by the aircraft during that time. However, should the wind velocity have changed during the period of measurement, the mean wind velocity may be quite different from the actual wind velocity affecting the aircraft at the end of the period. Consequently, although a mean wind velocity is ideal for calculating position, it is not usually suitable for calculating alterations of heading, because it may not represent the wind velocity that will affect the aircraft to its next turning point or destination.

3. A wind velocity found instantaneously, or over a comparatively short period of time, is known as a local wind velocity. It represents the wind velocity affecting the aircraft at that time and as such is usually the best available wind velocity for use in calculating alterations of heading.

4. In practice, it is usually necessary to compromise between mean wind velocities found over long periods of time and the more quickly calculated local wind velocity. Whereas the former are of limited value for future application, the latter tend to be less accurate because the time interval in which they are measured is small. The actual period of time that will provide a reasonable value of wind velocity is a matter of judgement. For example, if the wind velocity was required in order to calculate a change of heading, it would be inappropriate to use a time period during which there had been a significant change in height or during which a weather front had been crossed. In normal circumstances, wind velocities found over time periods between 18 minutes and 40 minutes are used.

5. Modern navigation systems provide an instantaneous readout of local W/V which can be used to compare against the forecast W/V or to calculate required heading changes if necessary. Although manual plotting techniques are rarely practised nowadays, where they are used, several methods of determining W/V can be employed, and the following paragraphs may provide a useful background to

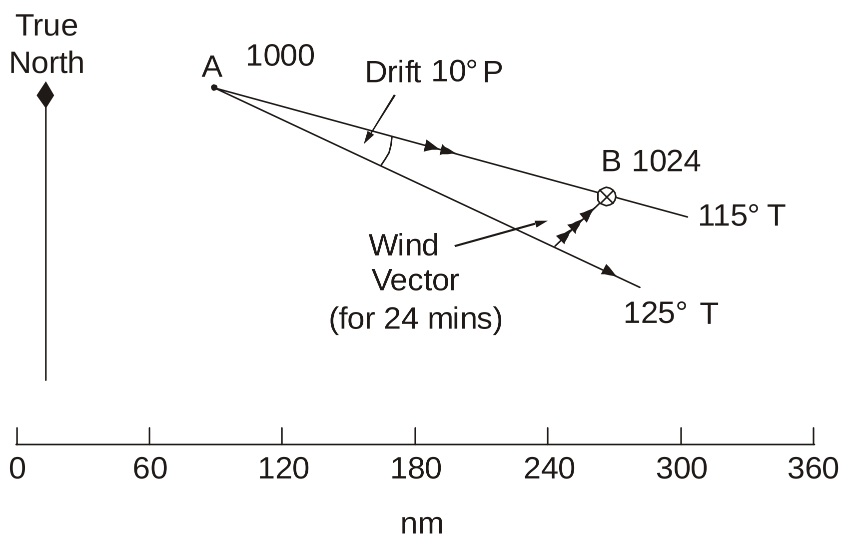
the basic understanding of navigation. It should be appreciated that the results obtained by each method described in the following paragraphs will be different.

Track and Groundspeed Method

6. The track and groundspeed method is that solution of the vector triangle which determines the length and direction of one side of the triangle (the wind vector), given the length and direction of the other two sides (the heading and track vectors). The wind velocity so found may be a mean wind velocity, or a local wind velocity, depending upon the time interval chosen.

7. The principle of the method is illustrated in Fig 1. An aircraft leaves point A at 1000 hours, on a heading of 125º T and with a TAS of 420 kt. At 1024 hours, the aircraft's ground position is found to be at point B, which bears 115º T from A, at a distance of 180 nm. The aircraft's ground speed can thus be calculated as 450 kt and the drift as 10º P. Heading, TAS, drift and groundspeed can be set on to a DR computer and wind velocity found as 231º/82 kt.

9-5 Fig 1 Track and Groundspeed Wind Velocity



8. When using this method, no alterations of heading or airspeed can be tolerated between the fixes used in determining the track and groundspeed. An alteration of heading between the two fixes will result in the measurement of an erroneous track and groundspeed and consequently an incorrect wind velocity. Similarly, an alteration of airspeed will cause errors because the resultant changes in drift and groundspeed will be attributed to the wind effect.

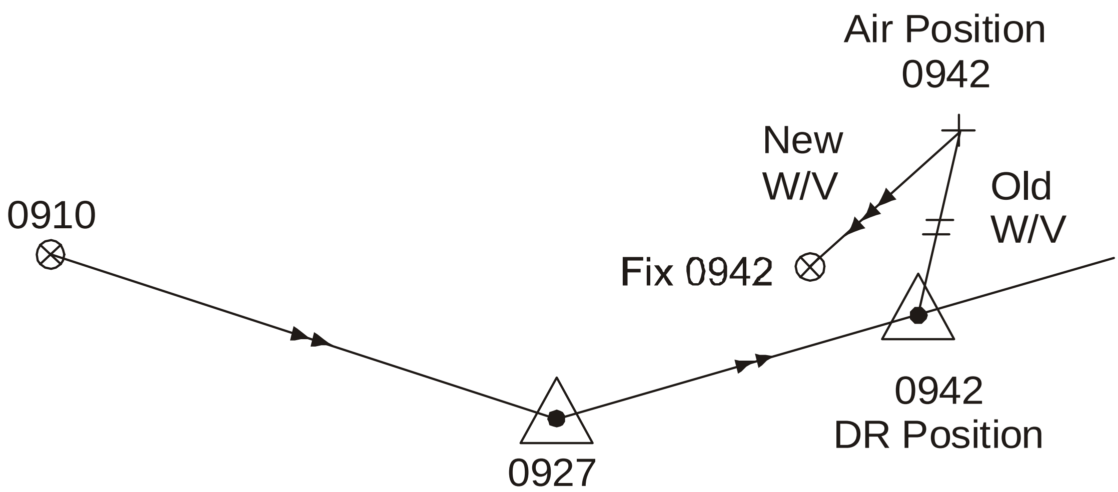
9. The track and groundspeed method of finding wind velocity eliminates the plotting and measurement of wind vectors, which is often a major source of error, and so its accuracy depends primarily on the accuracy of, and measurement between, the fixes used to determine the track and groundspeed. Other pertinent factors are the accuracy to which true heading is known, the accuracy of timing and computation, and the pilot's ability to maintain a constant heading and airspeed.

10. **Automated Wind Velocities**. None of the limitations mentioned in paras 8 and 9 apply to wind velocities found from the continuous outputs of drift and groundspeed provided by automated navigation equipments. These quantities may be applied to true heading and true airspeed to find the local wind velocity. The advantages of this method are that the wind velocity currently affecting the aircraft can be quickly, easily and continuously determined, consequently there is little restriction on tactical freedom.

Track Plot Wind Method

11. When keeping a track plot, winds are normally found by the track and groundspeed method. If, however, a fix is found from which neither groundspeed nor track can be calculated, the wind velocity may be determined by back plotting vectors in the following manner. In Fig 2, a fix has been found shortly after a change of heading. A DR position, using the old wind velocity is plotted for the time of the fix. The reciprocal of the old wind velocity is laid off from this DR position, making the length of the vector proportional to the time that has elapsed since the start of the track plot, to produce an air position. The new wind velocity for the same period of time is given by joining this air position to the fix. Alternatively, by joining the fix to the DR position for the same time, a correction vector for the old wind velocity may be obtained.

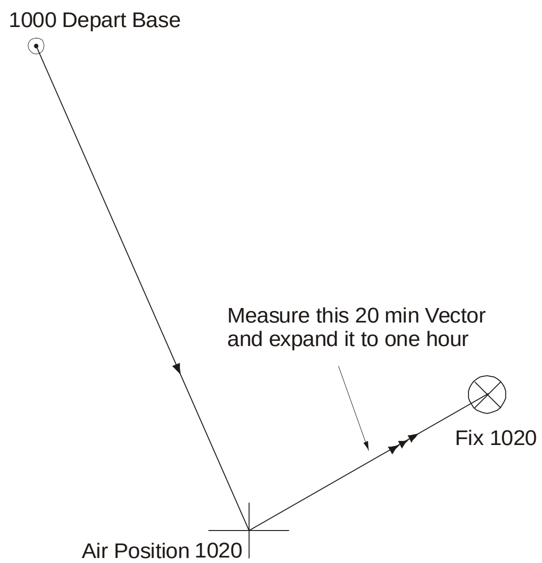
9-5 Fig 2 Track Plot Wind Vectoring



Air Plot Wind Method

12. The air plot method does not rely on the measurement of track and groundspeed, instead the wind vector, ie the displacement between a fix and its corresponding air position, is measured directly (Fig 3). The wind vector measured is of course proportional to the period of time that the air plot has been running and must be converted mathematically to nautical miles per hour (ie a wind velocity in knots).

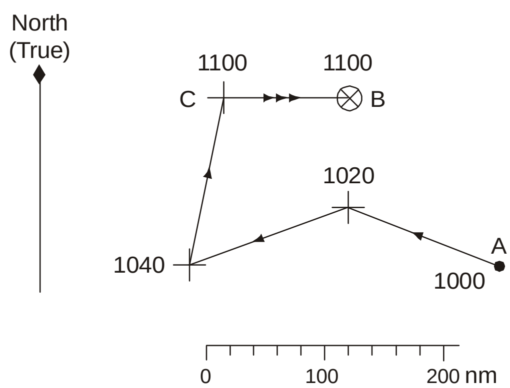
9-5 Fig 3 Air Plot Wind Velocity



13. Whereas the track and groundspeed method of finding wind velocity cannot be used if there is any alteration of heading or airspeed between the fixes, this restriction does not apply to the air plot method. Wind velocities can be measured, regardless of heading and airspeed flown, provided that an accurate log of air positions is maintained for each change of heading or airspeed. The plot must be restarted whenever a fix is obtained, and the navigation equipment updated.

14. As an example, in Fig 4, an aircraft flying at a true airspeed of 420 kt leaves point A at 1000 hours and flies for 20 minutes on each of three headings, 290º T, 250º T, and 010º T. At 1100 hours the aircraft's position is fixed at point B, and from the log of heading and airspeed, an air position for the same time can be established at point C. The vector CB is the wind effect for an hour, and it represents the average of the wind velocities which have affected the aircraft over the hour; it can be measured as 269º/105 kt.

9-5 Fig 4 Air Plot Wind Velocity Incorporating Changes of Heading



15. The accuracy of the air position, which depends on the accuracy of the start fix and the knowledge of headings and airspeed flown, together with the accuracy of the final fix, dictates the accuracy to which the wind velocity can be determined.

16. An air plot wind is the mean wind velocity over the period since the air plot was started and thus its validity for future calculations must be considered carefully. It is usually necessary for this reason to limit the period over which air plot winds are found in order to obtain an approximation to the local wind.

17. Conversely, if air plots winds are found over very short intervals, the resultant vectors are often so short that accurate measurement is difficult. Errors in measuring vectors, representing short periods of wind effect, cause large errors in the wind speed found, e.g. an error of 1 nm in a vector representing a 6-minute period will result in a 10-knot inaccuracy. Usually the most satisfactory period for wind finding is between 18 minutes and 40 minutes.

Visual Wind Assessment

18. When flying at low level, in sight of the surface, it may be possible to make an assessment of the wind direction, and with experience also of the wind speed, by observing its effect on smoke plumes from factories, power stations and other miscellaneous fires. It should be remembered that close to the surface there may be local wind channelling and eddies, and the apparent wind direction may not be a true representation of the mean wind over a broader area or at the aircraft's height. Despite these shortcomings, such clues can be helpful where there is little better information, or where it is required to confirm a forecast wind velocity. Over open water, the wind causes a pattern of parallel lines or streaks formed by foam or spray. These streaks, called wind lanes, are aligned with the wind direction and are usually clearly visible from the air.

APPLICATION

Introduction

19. Generally speaking, wind velocities found by the methods described in the previous paragraphs are used directly in the calculation of future headings, and DR groundspeed. It is, however, sometimes necessary to apply corrections to the wind found before it is used in further navigation calculations. The occasions requiring such corrections are dealt with in the following paragraphs.

Change of Meteorological Zones in Flight

20. Where the meteorological forecast for a particular flight is divided into a number of zones, it will be necessary to take into account the change in wind to be expected on crossing the boundary between zones. This is done by comparing the wind velocity found with that forecast, for the zone in which the aircraft has been flying. The arithmetical difference in both direction and speed is then applied to the wind forecast for the next zone.

> Example. A met forecast for zones 1º E to 5º E and from 5º E to 10º E gives wind velocities of 250º/20 kt and 270º/30 kt respectively. Approaching 5º E from the west, the wind is found as 235º/15 kt. The difference between the met forecast and the wind found in the first zone is therefore

–15º and –5 kt. This correction factor is applied to the forecast wind for the second zone, giving a wind to be used as 255º/25 kt.

21. This procedure is applicable to navigation in areas where few fixes are available, whereas in rapid-fixing areas local wind velocities found regularly over relatively short periods would be used without corrections.

Change of Height in Flight

22. The method of selecting a wind velocity for use after the aircraft has changed height is similar to that outlined above. A correction factor, being the difference between the forecast and found winds at the height flown, is applied to the forecast wind velocity for the new height to be flown.

23. In the event of the aircraft making a long climb, it may be necessary to alter heading while ascending, and therefore to select a wind velocity for that part of the climb from the DR position at the time of altering heading to the limit of the ascent. Wind velocities found whilst climbing are mean wind velocities (apart from those found by automated equipments) and the height at which they are considered to be operative is ascertained by the application of simple rules which depend upon the rate of climb of the aircraft.

24. If the rate of climb is constant throughout the period in which the wind velocity is found, the wind velocity is said to apply to the mean height for the period. If the rate of climb is decreasing during the period in which the wind velocity is found, the wind applies at two-thirds of the height band ascended during the period.

Example. A wind velocity of 240º/30 kt is found whilst an aircraft is climbing from 7,000 ft to 16,000 ft, and during that time the rate of climb decreases. Therefore 240º/30 kt is the wind velocity applicable to a height at two-thirds of the ascent from 7,000 ft to 16,000 ft, ie 13,000 ft.

25. Two-thirds is an arbitrary fraction designed to take some account of the fact that the aircraft, with a decreasing rate of climb, spends more time in the higher layers of air and is therefore affected to a greater degree by wind velocities at the higher levels.

26. Having established, in the above example, that the wind velocity at 13,000 ft is 240º/30 kt, it is necessary to select a wind velocity for the remainder of the climb, say to 22,000 ft. Since the rate of climb continues to decrease with height, the two-thirds rule is again applied, and a wind velocity is therefore required for 20,000 ft, ie two-thirds of the ascent from 16,000 ft to 22,000 ft. The procedure for selecting this wind is as described in paras 24 and 28.

Wind Velocity for Flight Planning a Climb or Descent

27. The wind velocity to be used when flight planning a climb or descent is the mean of the wind effects which will be experienced by the aircraft as it ascends or descends through the various layers of air. The

selection of this wind velocity, in practice, depends upon the change of wind speed and direction with height, and upon the rate of climb or descent of the aircraft. Where the wind velocity changes regularly with height and the rate of climb or descent is constant, the wind velocity at the mid-level would be used; where the rate of climb reduces with altitude the level chosen would need to reflect the longer time spent at the higher altitudes and the two-thirds rule will normally suffice, although this may need to be amended for certain aircraft types and payload. Where there is an intermediate fix (or fixes), in the climb or descent, an appropriate wind velocity for each section can be used.

28. Example. Consider an aircraft which is to climb from 2,000 ft to 27,000 ft at a constant rate of climb. The forecast wind velocities are as follows:

2,000 ft	220º/15 kt
5,000 ft	230º/25 kt
10,000 ft	240º/30 kt
15,000 ft	260º/40 kt
20,000 ft	290º/50 kt
30,000 ft	350º/70 kt

29. These wind velocities vary regularly with height, and since the rate of climb is constant, the wind for the mean height of the climb would be used, ie that effective at 12,500 ft - 250º/35 kt.

30. If the aircraft was to climb from 2,000 ft to 27,000 ft at a reducing rate of climb, the two-thirds rule would be applied to determine the appropriate height, ie 18,500 ft in this case, giving a wind velocity of 280º/47 kt to be used. In practice, the 20,000 ft wind velocity would probably suffice to avoid interpolation.

31. A further adjustment may be necessary in the situation where the wind velocity does not vary uniformly with height, but exhibits a marked change at some level, perhaps due to a jet stream. In any event the wind velocity that is used will inevitably be an approximation, and even the simple case of a constant rate of climb or descent may be disrupted by Air Traffic Control restrictions.

CHAPTER 6 - ESTABLISHMENT AND USE OF POSITION LINES

Terminology

1. A position determined without reference to any former position is called a fix. This is a generic term and is often qualified to indicate the fixing method, e.g. GPS fix, radar fix, visual fix etc.

2. Instantaneous fixes can be obtained from electronic navigation systems or the visual identification of the aircraft position vertically beneath the aircraft. Electronic rapid fixing facilities are not infallible, and position lines can be used to enhance confidence in them. While position lines are not generally plotted on charts nowadays, some operators may still use such traditional navigation techniques.

3. It is possible to fly over an identifiable feature, e.g. a motorway, without knowing the precise point of crossing; all that can be said is that at that particular time the aircraft was somewhere on the line of the motorway. This is known as a position line (P/L) and two or more such lines can provide a fix.

POSITION LINE TYPES

General

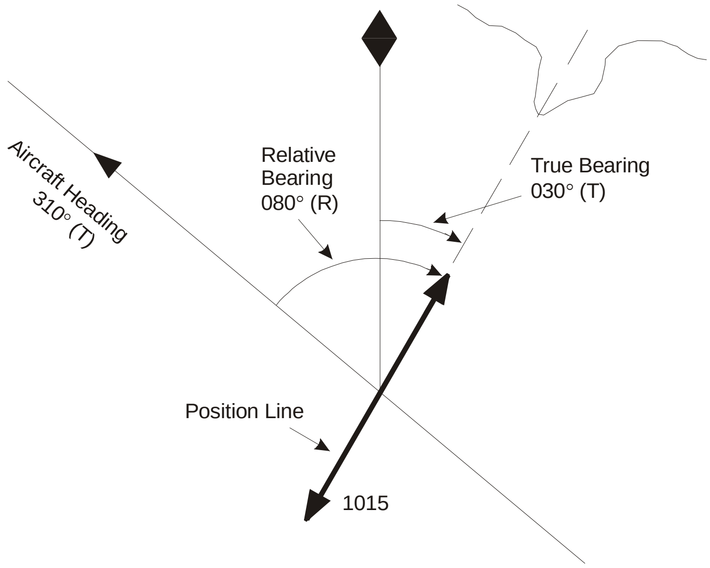
4. Position lines can be straight or curved, depending on the information they convey. Bearings are straight position lines representing the angular relationship between the aircraft and a known position, or the orientation of a line feature. Circular position lines represent the aircraft's range from a position, the radius of the curve being equal to the range. Both forms of position line and their sub-classifications are discussed below.

Bearings

5. **Relative Bearings**. A bearing may be taken relative to the fore and aft axis of the aircraft, normally by using a radio compass tuned to a radio beacon or by visual or radar observation of a feature. To obtain the true bearing of the beacon or feature, the true heading of the aircraft must be added to the relative bearing (either directly or by offsetting the azimuth scale of the measuring instrument). The reciprocal of this true bearing plotted from the beacon or feature gives the position line for the time of observation. It is essential that the true heading applied to the relative bearing is obtained at the precise time of the observation.

> Example. At 1015 hours, while on a heading of 310° T, a prominent headland is observed on a bearing of 080° relative (see Fig 1).

9-6 Fig 1 A Relative Bearing



∴True bearing of headland from aircraft = 080° + 310° = 030° T

Plot reciprocal: 030° T + 180° = 210° T.

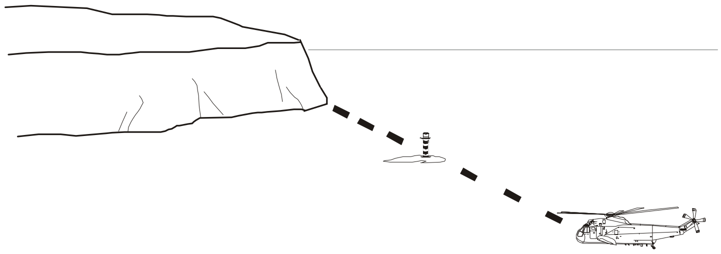
At 1015 hours, the aircraft was therefore at some point along that position line.

6. **Transit Bearings**. A line drawn on a chart through two features observed to be in line, i.e. in transit, must pass through the aircraft's position at the time of sighting. This line, a true bearing, is therefore a position line.

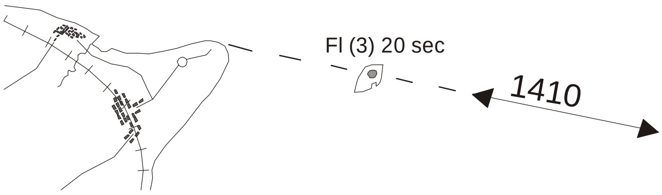
Example. A lighthouse and a promontory of land are sighted in transit at 1410 hours (see Fig 2a). The position line is drawn as in Fig 2b, though the dotted portion need not be plotted. Greater accuracy is obtained when the distance between the objects in transit is large in relation to the distance between the aircraft and the nearer object.

9-6 Fig 2 A Transit Bearing

2a



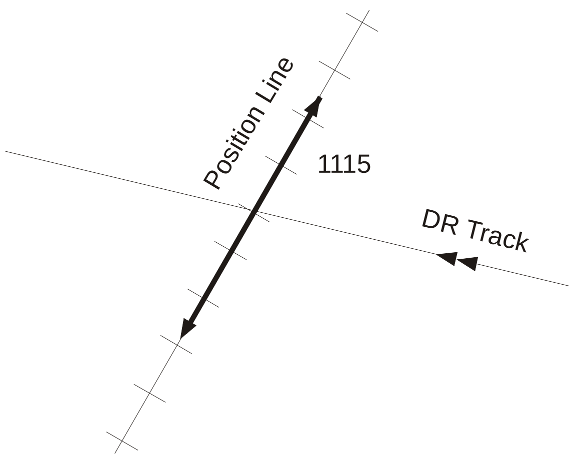
2b



7. **Line Features**. Stretches of coastline, road, railway or river, though lacking prominent features suitable for pinpoints, may be used as position lines provided that they are marked on the charts in use.

Example. An aircraft crosses a straight stretch of railway at 1115 hours. The railway thus becomes the position line as shown in Fig 3.

9-6 Fig 3 Use of Line Features



8. **Position Lines from Ground D/F Stations**. A position line may be obtained by a direction-finding ground station taking a bearing on an aircraft's radio transmission. The bearing is passed to the aircraft by radio, usually in the form of either the true bearing of the aircraft from the station, or as the magnetic track that the aircraft must make good to reach the station. The form is decided by the initial call: "request true bearing" or "request QDM" (magnetic heading to facility (zero wind)). In order to use the latter information, the magnetic variation, measured at the station, must be applied, so obtaining the true track to the station; the reciprocal is then plotted. The other information which can be provided by the ground D/F station is the magnetic heading to fly to reach that station; this is termed a 'steer'. Using a

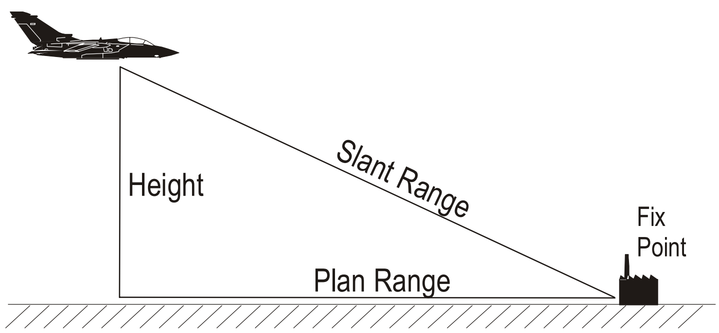
local wind velocity, the ground operator assesses the drift and applies this to the QDM measured, to calculate the steer for the aircraft. Ground D/F facilities are provided on VHF and UHF within the UK, but the service may be available on other bands elsewhere.

9. **TACAN and VOR Bearings**. TACAN and VOR beacons both transmit a signal which, when interpreted by the aircraft equipment, gives the magnetic bearing of the aircraft from the beacon. The position line is obtained by taking the reciprocal of the reading of the indicator needle.

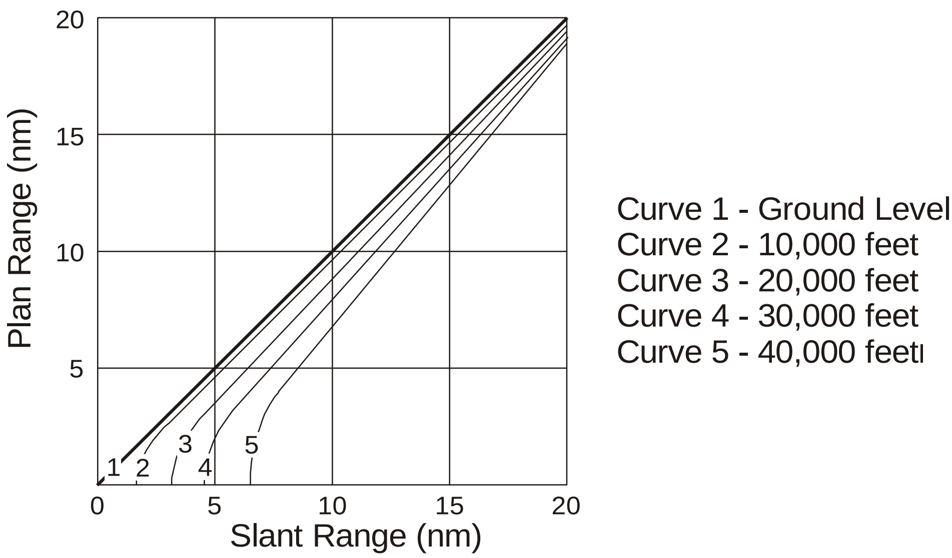
Circular Position Lines

10. **Radar Range Position Lines**. The range from a ground TACAN or DME beacon can be obtained using transmitter/responder equipment. The range displayed is a slant value (Fig 4), which should be converted to plan range before plotting. Fig 5 shows a typical slant range to plan range conversion graph. The circular position line is drawn with the plan range as radius and with the beacon as the centre. Range position lines may also be obtained by ground mapping radars, in some of which the range is automatically converted to plan range. However more simple equipments, such as cloud warning radars, give slant range only which should be corrected in the same way as TACAN and DME ranges.

9-6 Fig 4 Slant Range



9-6 Fig 5 Slant to Plan Range Conversion



USE OF SINGLE POSITION LINES

Introduction

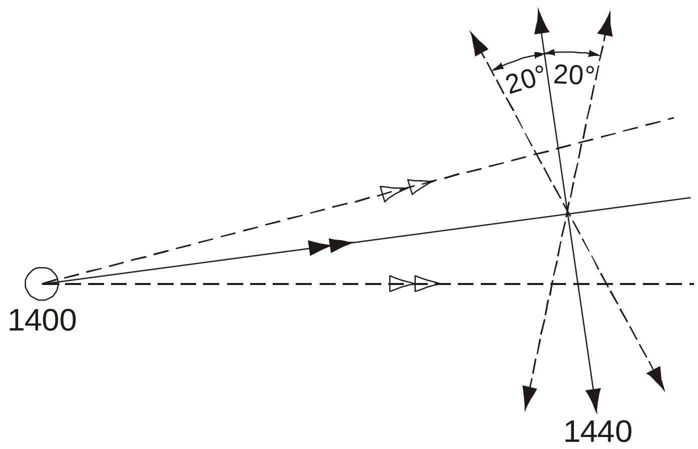
11. A single position line can be used to provide navigation data in one or more of the following ways:

a. As a check on groundspeed.
b. As a check on ETA.
c. As a check on track made good.
d. As a means of homing to an objective.

Groundspeed Check

12. For a groundspeed check, a position line is required which lies as nearly as possible perpendicular to the aircraft's track (see Fig 6).

9-6 Fig 6 Position Line used forGroundspeed Check



13. The distance between the last fix and the position line is measured along the DR track, and so, knowing the time that has elapsed, the groundspeed can be calculated. If the position line is within ±20° of the perpendicular to track, then errors in DR track (represented by the broken track lines in Fig 6) will produce little difference in the distance measured and therefore no significant error in the groundspeed calculated.

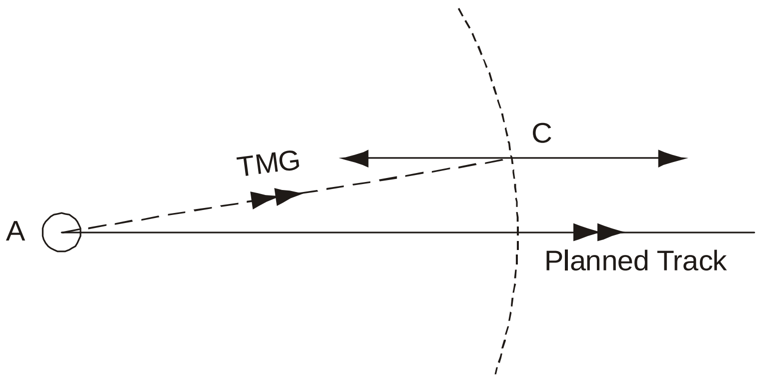
ETA Check

14. A position line near the perpendicular to track may provide a check of ETA at the next turning point by enabling the distance to run to be measured accurately.

Track Check

15. To check track made good, a position line is required which is parallel or nearly parallel (±10°) to DR track (see Fig 7).

9-6 Fig 7 Position Line used for Track Check



16. In Fig 7, an arc equal in radius to the ground distance flown since the last fix (position A), calculated using the latest groundspeed, is described from that fix to cut the position line at C. AC then represents the track made good. Errors in the groundspeed used will cause an error in the position of C along the position line, but this error will have little effect if the limits of para 15 are observed.

Homing Check

17. Homing to a destination along a position line, whose origin is the destination, is a simple matter, since the direction of the position line is the same as that of the required track. The aircraft is turned on to a heading which will make good this track and tracking can be checked against further position lines obtained from the destination.

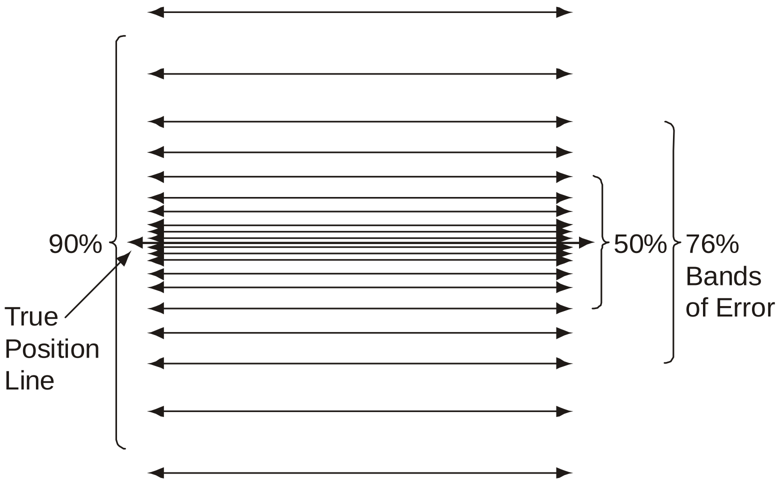
Accuracy of Position Lines

18. When a position line is obtained, it is assumed, for the purposes of navigation, that the aircraft's position is on that line at that particular time. However, in practice, the aircraft is very seldom exactly on that line at the time it was obtained. All position lines are subject to errors, the magnitude of which depends upon the type of position line, i.e. whether it is a visual bearing or an electronically derived bearing, and the conditions under which it is obtained.

19. If a large number of position lines of the same type could be taken from an aircraft in the same known position, and operating under identical conditions, the position lines when plotted would be found to lie in a band about the aircraft's true position. They would be found to be concentrated in the area about the aircraft's position and would become more widely dispersed with distance away from the aircraft.

20. This dispersion of results is due to a variety of reasons, eg slight errors in timing and observation, approximations in calculations. It is possible to carry out a statistical analysis on a set of accuracy figures for position lines of any type, and from this, to define the width of the band about the true position which would enclose a certain proportion, say 50%, 70% or 90% of all the position lines considered (see Fig 8).

9-6 Fig 8 Statistical Distribution of Observed Position Lines



21. The bands are known as bands of error in navigation terminology, and the 50% and 76% bands are those normally considered. Extensive trials have been carried out on the accuracy of position lines and as a result it has been possible to produce a table which defines, for convenience, half the width of bands of errors for various types of position lines (see Table 1).

Table 1 Position Line Bands of Error

Type of Position Line		Band of Error (Half - Widths)	
		50%	**76%**
Transit Bearing		0.5°	0.9°
TACAN Bearing		2°	3.5°
TACAN/DME Range		0.2 nm	0.5 nm
VOR		3°	5°
ADF		1.5°	2.5°
Cloud Warning Radars:	a. Range b. Bearing	2 nm 3°	3 nm 5°

22. Taking the 50% band as an example, this band encloses 50% of all possible position lines, and there is, therefore, only an even chance of being somewhere inside the band of error. The 76% band is wider since it must contain a larger number of possible position lines and if this band is plotted there is a 76% chance of being somewhere inside it. To cover every possible case the 100% band of error would need to have infinite width, since gross errors would inevitably occur in a few cases in the

calculating and plotting of a large number of position lines. It is clearly impracticable to work at very high levels of probability and, indeed, a position line that falls a considerable distance from its expected position should be treated with circumspection and its accuracy should be verified by other means if possible.

CHAPTER 7 - PLOTTING POSITION LINES

Introduction

1. Position lines are not generally plotted onto charts nowadays but where they are used, this chapter will provide the necessary information to allow the user to employ them correctly. The line of sight between two points lies along the shortest path between them. The corresponding radio wave also follows the same path. Consequently, visual and radio bearings are great circles, and this complicates plotting for none of the common plotting charts portray all great circles as straight lines.

2. The divergence (Δ) between the straight line joining two points on the chart, and the corresponding great circle varies according to:

a. The projection.
b. The bearing and distance between the two points.
c. The area of operation.

3. **The Projection**. The path represented by a straight line on a chart depends upon the projection employed in the chart's construction. On some projections, the straight line approximates to a great circle, while on others it is very different. Consequently, the magnitude of the angular divergence between the straight line and the great circle is a function of the projection being used. Loosely speaking, ignoring both the effect of the relative orientation of the two points and the area of operation, the divergence is greater on the Mercator projection than on the other common projections: the polar stereographic, the Lambert's conformal, the oblique and transverse (skew) Mercators. On the Mercator projection, the straight line represents the rhumb line.

4. **The Relative Orientation of the Two Points**. A straight line can represent more than one path on a projection. For example, on the Mercators, Lamberts and polar stereographic projections, the meridians, which are great circles, appear as straight lines. On the skew Mercators, with the exception of the meridian through the vertex (oblique Mercator) and the central meridian, anti-meridian and meridians at 90º (transverse Mercator), the meridians appear as curves (although the curvature is small in the best areas of cover). With some exceptions, it is fair to say that the greater the departure from the point or line of origin of the chart, the more the straight line departs from representing a great circle; the longer the straight line the greater this discrepancy.

5. **Area of Operation**. The various chart projections have been devised to provide the most accurate representation of the Earth within limited areas. It is possible to represent the hemisphere accurately using five projections. If this plan were rigidly adhered to, the divergence (Δ) between the great circle and the straight line over distances of 500 nm and less would be very small. However, conditions may result in projections being used outside of the optimum areas and for this reason it is necessary to study the methods of plotting visual and radio position lines.

The Angular Divergence (Δ) Between the Straight Line and Great Circle

6. A general expression for the magnitude of Δ is given by:

$$\Delta = \tfrac{1}{2} \text{ ch long (sin mean lat} - \text{n)}$$

Ch long and mean lat refer to the change of longitude and latitude between the DR position and the bearing source; n is the constant of the cone which is treated in Volume 9, Chapter 3. For the purposes of this chapter it is sufficient to know that:

a. On the Mercator and skew Mercator projections, n = 0.

b. On the Lambert's conformal projection n may lie between 1 and 0, the precise value being a function of the parallel of origin. The GNC and JNC series of charts which are based on this projection, covering the latitude bands (approximately) of 0º to 40º and 32º to 76º, have values of n of 0.3118 and 0.785 respectively.

c. On the polar stereographic projection, n = 1.

7. **General Conclusions**. Assuming a small change of longitude along the bearing, the following deductions for each projection, based on the information above, can be made:

a. **Mercator**. At low latitudes, since the sine of a small angle is small and n = 0, Δ is small.

b. **Lambert's Conformal**. n is of the same order as the sine of the latitude for temperate latitudes, thus Δ is generally small in these areas. However, at the limits of a Lambert's projection there can be a considerable difference in the sine of the mean latitude and n, depending on the standard parallels selected and therefore the parallel of origin, where n = sin lat and divergence is nil.

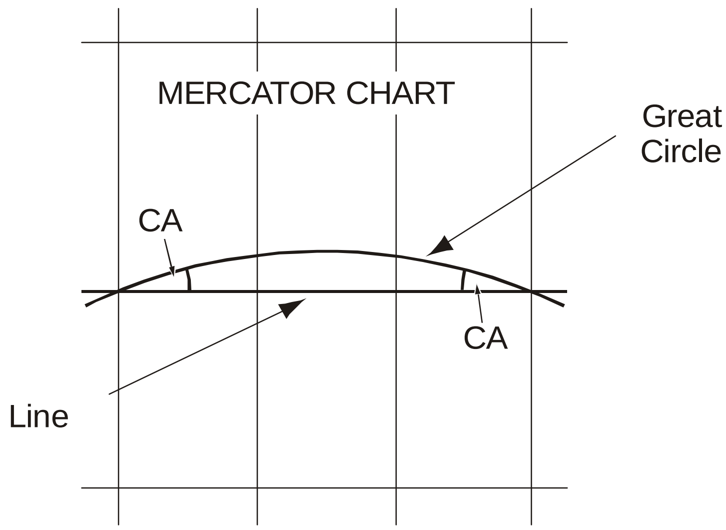
c. **Polar Stereographic**. In high latitudes, the sine of the mean latitude approaches 1, thus on a polar stereographic projection where n = 1, Δ is small.

PLOTTING PRACTICE WHEN BEARINGS ARE MEASURED AT A GROUND STATION

Mercator Projection

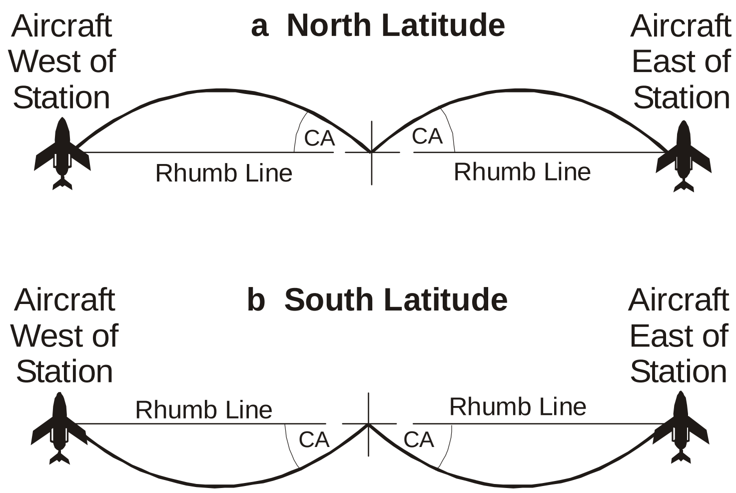
8. On a Mercator chart the straight line represents the rhumb line, while the great circle appears as a curve concave to the equator and, particularly outside of the Mercator's optimum latitude band of 12.5º S to 12.5º N, this difference must be considered when plotting bearings. The angle between the great circle and the rhumb line bearing between two points is known as conversion angle (CA, see Fig 1).

9-7 Fig 1 Great Circle and Rhumb Line on a Mercator Chart



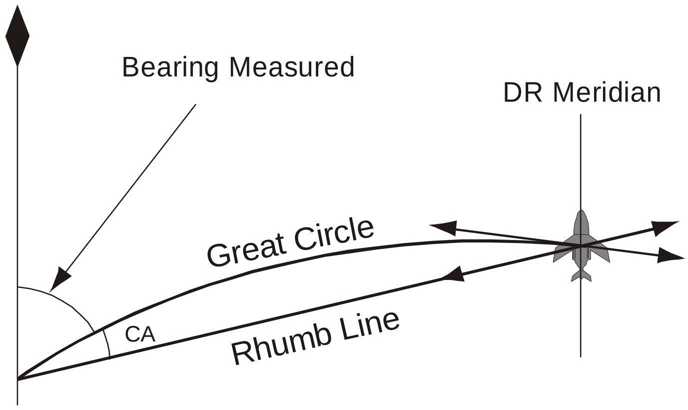
9. Although it is the great circle bearing which is measured by the direction-finding equipment, it is the rhumb line bearing which is initially plotted since this is a straight line. This bearing is obtained by applying CA to the great circle bearing such that, in the northern hemisphere, the rhumb line lies nearer 180º T. In the southern hemisphere the CA is applied in the opposite sense, so that the rhumb line lies nearer 000º T (see Fig 2). For example, if in the northern hemisphere a true bearing of the aircraft is measured as 070º T and the conversion angle is 2º, the rhumb line bearing is 072º T.

9-7 Fig 2 Conversion of a Great Circle Bearing to the Corresponding Rhumb Line



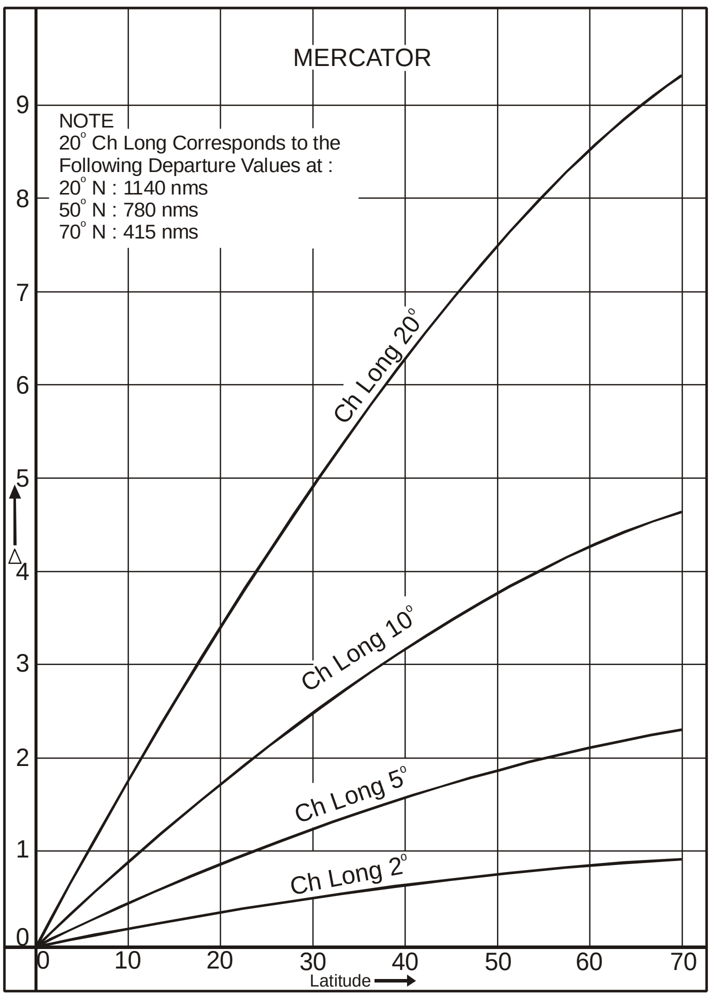
10. From Fig 3 it can be seen that, to plot the portion of the great circle bearing in the vicinity of the DR position, in this case, the rhumb line bearing should now be turned towards 180º T (in the northern hemisphere) at the DR meridian, through an angle equal to CA. In practice the value of the conversion angle would have to be quite large before there was any appreciable difference between the rhumb line and the great circle in the vicinity of the DR meridian, and the rotation of the rhumb line to lie along the great circle at the DR meridian can usually be ignored.

9-7 Fig 3 Plotting the Great Circle Position Line



11. **Calculation of Conversion Angle**. Conversion angle can be deduced from a graph (Fig 4), a nomogram (Fig 5), or from the formula which, since n = 0, reduces to CA = ½ ch long × sin mean lat. For practical purposes ½ × sin mean lat, which is called the conversion angle factor, can be reduced to six values to cover the hemisphere as shown in Table 1. CA is then the product of ch long and the conversion angle factor.

9-7 Fig 4 Conversion Angle Graph



9-7 Fig 5 Conversion Angle Nomogram

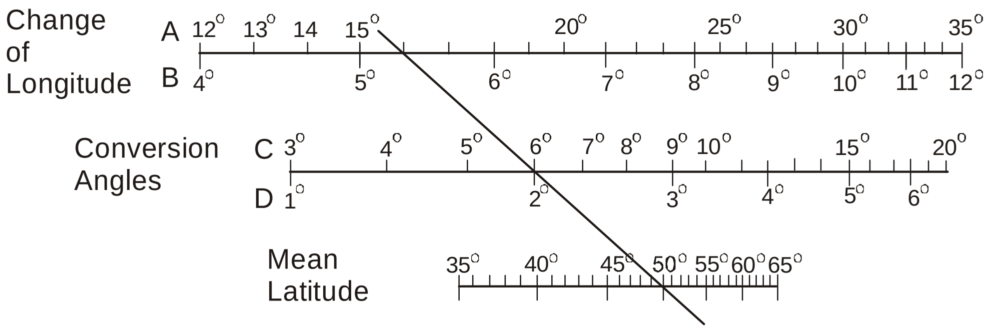


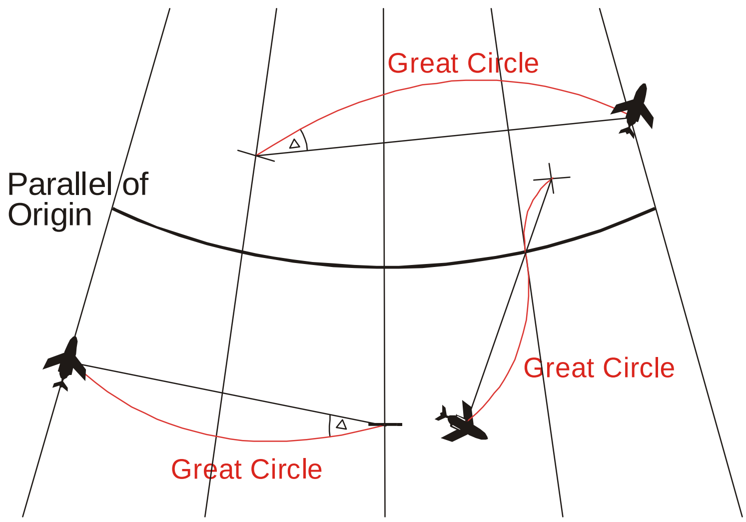
Table 1 Conversion Angle Factor – Mercator

Mean Lat	Conversion Angle Factor
0	
	0.0
6	
	0.1
18	
	0.2
30	
	0.3
45	
	0.4
65	
	0.5
90	

Lambert's Conformal Projection

12. Depending on the relative magnitude of the sine of the mean latitude and n, Δ may be positive or negative. The area of operation on a particular Lambert's projection will determine on which side of the straight line the great circle lies. If the mean latitude is greater than that of the parallel of origin, then the great circle will be closer to the pole than the straight line, and vice versa (see Fig 6). It should be remembered that the straight line on a Lambert's projection is not a rhumb line.

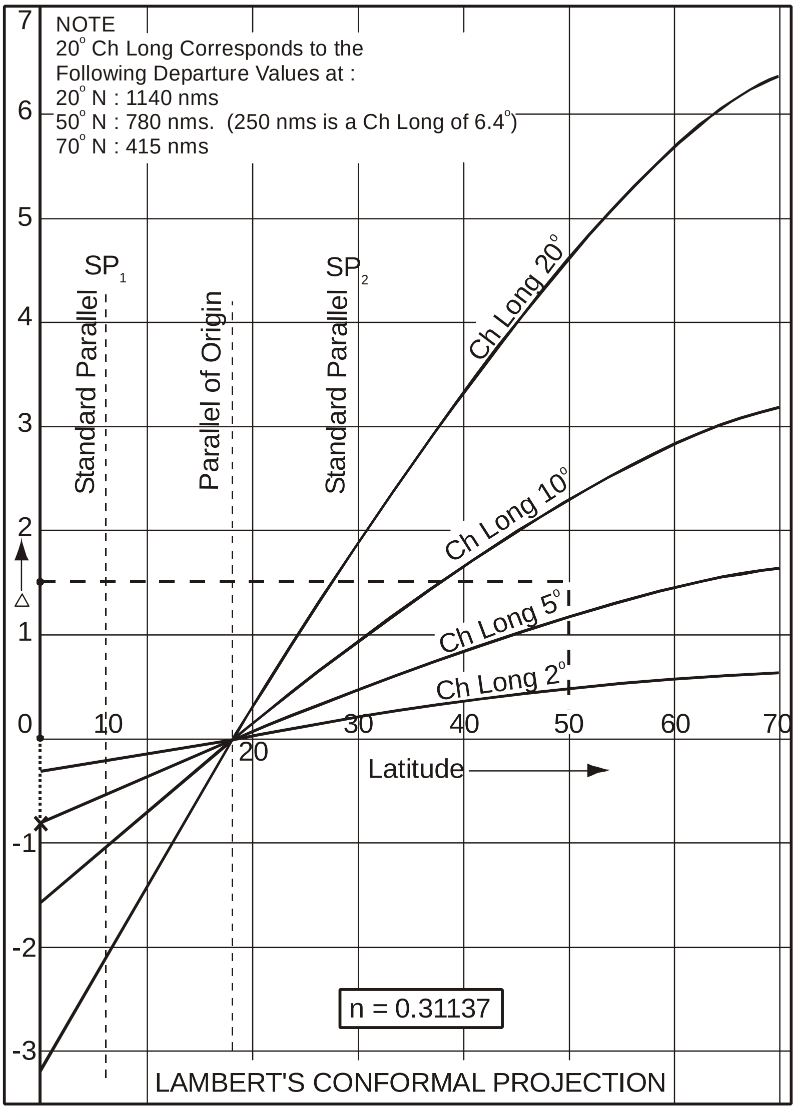
9-7 Fig 6 The Great Circle and the Straight Line on a Lambert's Conformal Projection



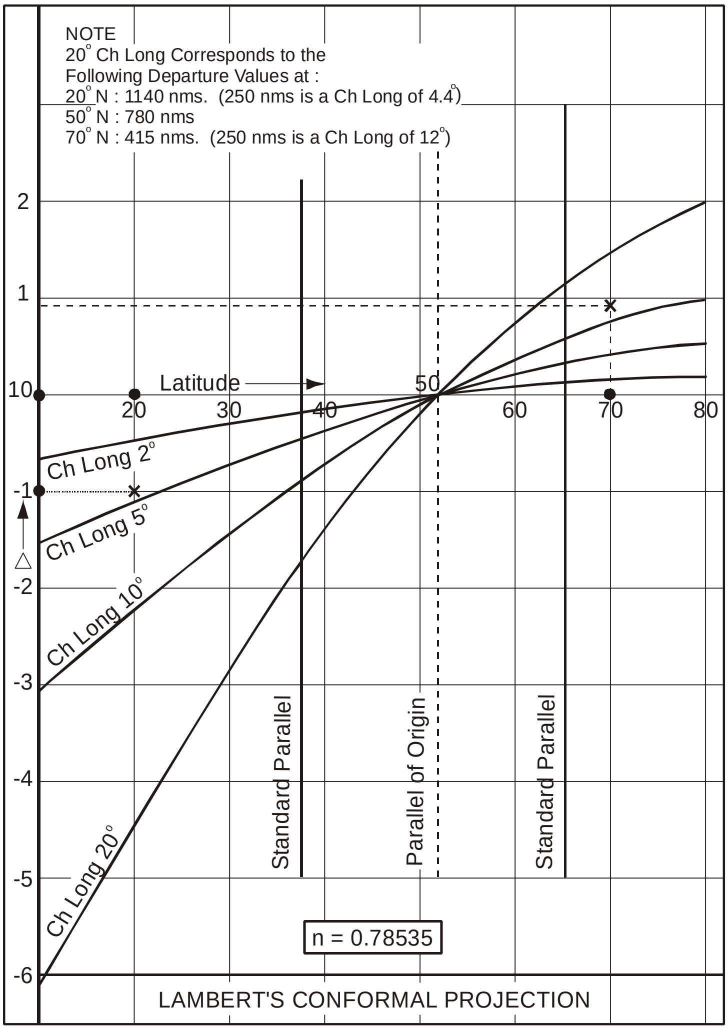
13. Theoretically, the problems of plotting a great circle on a Lambert's projection are essentially the same as those for the Mercator. The great circle is converted to the straight-line equivalent by applying Δ, and this line is then rotated at the DR meridian through an angle Δ to give the tangent to the great circle. The application of Δ, in both cases, is such as to make the bearings nearer 180º if the mean latitude is greater than the parallel of origin, and nearer 000º if less than this parallel.

14. Graphs of mean latitude against Δ are shown at Figs 7 and 8 for values of n of 0.31137 and 0.78535 respectively. For a radio position line obtained over a range of 250 nm, Δ varies from (approx) –0.6º to +1.5º in Fig 7 (at latitudes 0º and 50º), and from □1º to +1º in Fig 8 (at latitudes 20º and 70º). These are the maximum values in the circumstances as it is assumed that the aircraft and station are at the same latitude. If they were at any other position the ch long would be smaller over the given distance. Thus, in the majority of circumstances the great circle can be plotted directly as a straight line with only minimal error.

9-7 Fig 7 Graph of Δ Against Mean Latitude (n = 0.31137)



9-7 Fig 8 Graph of Δ Against Mean Latitude (n = 0.78535)

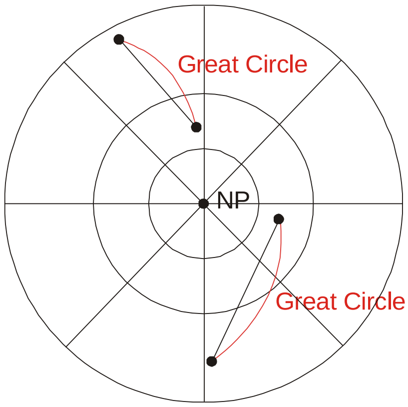


Polar Stereographic Projection

15. On the polar stereographic projection, the great circle lies nearer the equator than does the straight line (see Fig 9), i.e. Δ is negative.

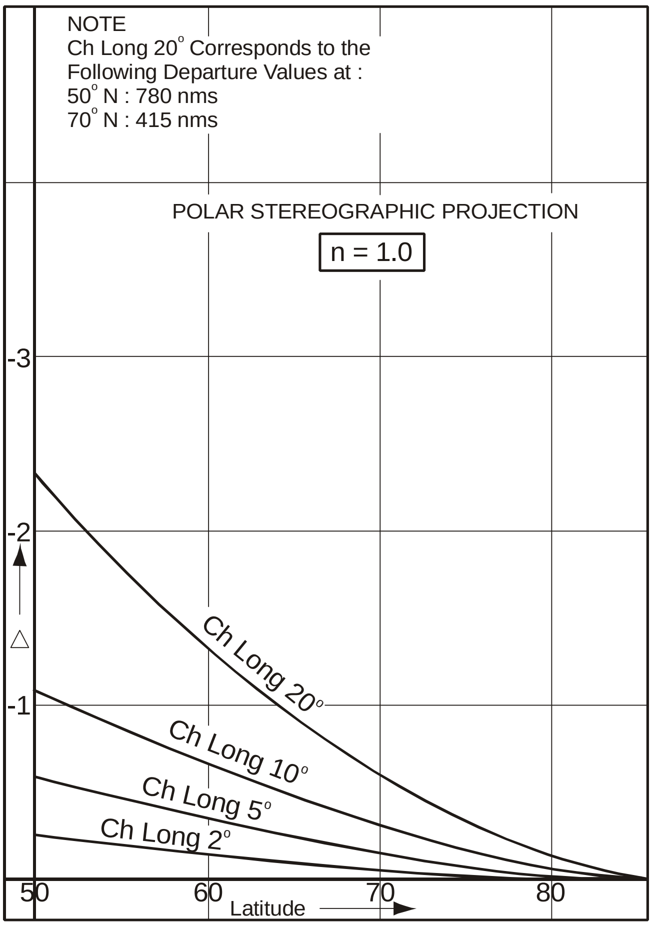
16. Although the procedure for plotting the great circle bearing is similar to that outlined for the Mercator and Lambert's projections, in practice, the value of Δ is so small that for all practical purposes in Polar Regions the great circle and straight line can be regarded as coincident.

9-7 Fig 9 The Great Circle and Straight Line on a Polar Stereographic Projection



17. A graph of Δ against mean latitude is plotted for various values of ch long at Fig 10. In the lower latitudes, at the extremes of the projection's useful cover, Δ can become significant and in this situation the conversion of the great circle to the equivalent straight line becomes necessary.

9-7 Fig 10 Graph of Δ for the Polar Stereographic Projection



Skew (Oblique and Transverse) Mercator Projections

18. Divergence on skew Mercator charts causes the great circle to be concave to the false equator/central meridian. For a 250 nm long line, divergence is unlikely to exceed 0.5º on the oblique

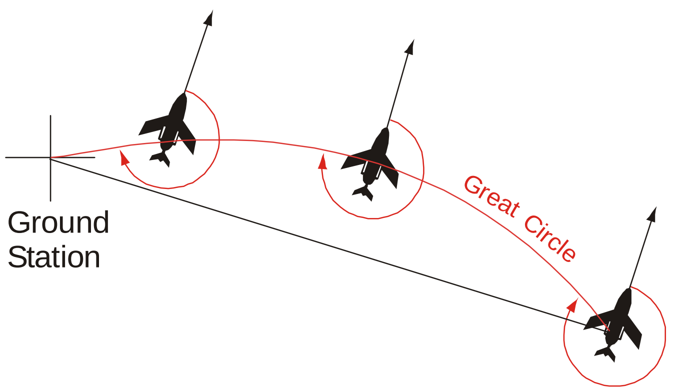
Mercator and 1.2º on the transverse Mercator. For both charts, if the bearing is measured at the ground station, the bearing is plotted from the meridian through the ground station.

PLOTTING PRACTICE WHEN BEARINGS ARE MEASURED AT THE AIRCRAFT

Introduction

19. The bearing measured at a ground D/F station will be the same for all aircraft transmitting from positions on the same great circle; consequently, that great circle is the position line. The converse is not true; aircraft flying the same heading and lying on the same great circle through the station will not measure the same relative bearing from the ground beacon's transmission (Fig 11). Thus, where the bearing is measured at the aircraft, the great circle is not the position line. However, in most circumstances the difference is not significant. This outcome is the result of meridian convergence on the Earth and is not a function of any particular map projection.

9-7 Fig 11 Relative Bearings



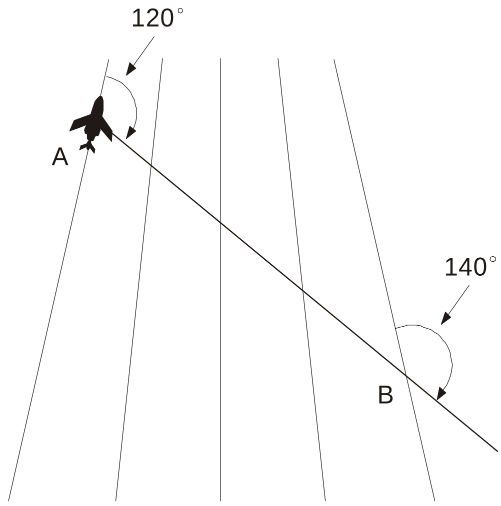
Plotting Relative Bearings on the Mercator Projection

20. Having measured the true bearing of the great circle between the aircraft and the station (i.e. relative bearing + true heading), the corresponding rhumb line can be obtained by applying conversion angle to the great circle such that, in the northern hemisphere, the rhumb line lies closer to 180º. The reciprocal is then plotted from the station. It should be emphasized that CA is applied to the true bearing of the great circle and not to the relative bearing. Rotation of the rhumb line at the DR meridian to account for meridian convergence is usually ignored in practice, bearing in mind the range of MF beacons and the latitude band in which the Mercator projection is used.

Plotting Relative Bearings on the Lambert's Conformal Projection

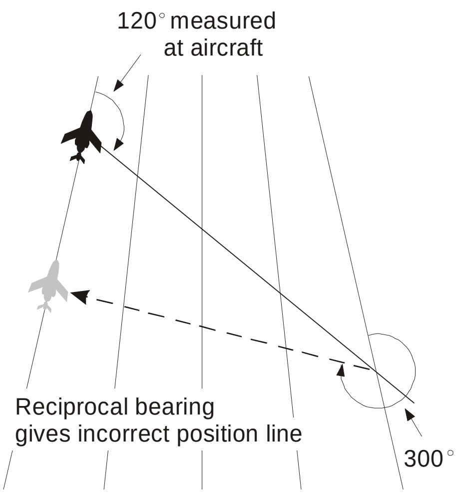
21. The effect of meridian convergence is very apparent on the Lambert's conformal projection. From Fig 12 it can be seen that the bearing of the great circle at A differs from that at B, the difference being Earth convergence.

9-7 Fig 12 The Effect of Convergence



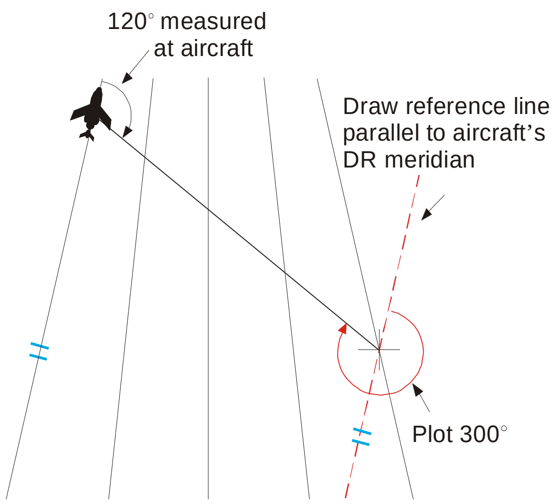
22. In attempting to plot the great circle bearing measured at the aircraft (eg relative bearings such as ADF or radar azimuth), it would be wrong merely to plot the reciprocal from the source. If this were done the bearing plotted would not cut the DR meridian at the measured angle (see Fig 13) but at the measured angle ± convergence.

9-7 Fig 13 Reciprocal Bearing (not allowing for Convergence)



This problem is overcome by plotting the reciprocal from the source with reference to a line parallel to the DR meridian (Fig 14).

9-7 Fig 14 Reciprocal Bearing (corrected for Convergence)



As with the Mercator chart, over the distances travelled by UHF, VHF, and MF radio waves, rotation of the position line at the DR meridian is normally unnecessary.

Plotting Relative Bearings on the Oblique Mercator Projection

23. The procedure for plotting on the oblique Mercator is the same as that used on the Lambert's conformal, ie the DR meridian is paralleled through the beacon (see Fig 14).

Plotting Relative Bearings on Polar Charts

24. The polar stereographic and polar transverse Mercator charts are invariably used with a grid overlay and used with grid navigation techniques. The plotting procedure for a relative bearing obtained while using a grid technique is very simple. Relative bearing + grid heading gives the required grid bearing and the reciprocal is then plotted from the origin. This procedure applies equally to Lambert's charts if a grid technique is being used.

SUMMARY

General

25. The methods used to plot position lines are a compromise between precision and expeditious plotting; the speedier and simpler approximation is normally to be preferred. Although it is not possible to state an invariable rule, consideration should usually be given to converting the great circle bearing to the straight-line equivalent, whereas the need to rotate the position line at the DR meridian is normally ignored. The characteristics of the various common projections are summarized below.

26. **The Mercator**. The divergence between the straight line and the great circle varies directly as the sine of the mean latitude along the great circle. Since this projection is often used over a wide latitude

band, significant values of Δ may be encountered. The need to calculate the straight line equivalent therefore often arises on the Mercator chart.

27. **The Skew Mercator**. Provided the skew Mercator is restricted to the optimum band of cover, i.e. ± 8º of false latitude, the values of Δ are small. If the chart is not gridded, then relative bearings must be plotted with reference to the DR meridian and not the meridian through the ground station.

28. **The Lambert's Conformal Projection**. The standard parallels on these charts can be widely spaced. Consequently, at the limits of cover, Δ can be significant. Thus, although the great circle and the straight line can be considered coincident over the greater part of the projection, this should not be assumed near the limits of cover. When plotting relative bearings, an allowance for convergence must be made, most simply by paralleling the DR meridian through the ground station.

29. **The Stereographic Projection**. Values of Δ on the stereographic projection are very small and, over the distances that bearings are taken, the straight line and great circle may be considered coincident.

30. **VOR and TACAN Bearings**. Although VOR and TACAN bearings are intercepted at the aircraft, the bearing information is encoded at the ground station. On all charts, TACAN and VOR radials should be plotted as originating from the appropriate ground station and orientated with reference to magnetic North at the beacon. Where necessary, divergence should be applied.

CHAPTER 8 - DEAD RECKONING COMPUTER, MARKS 4A AND 5A

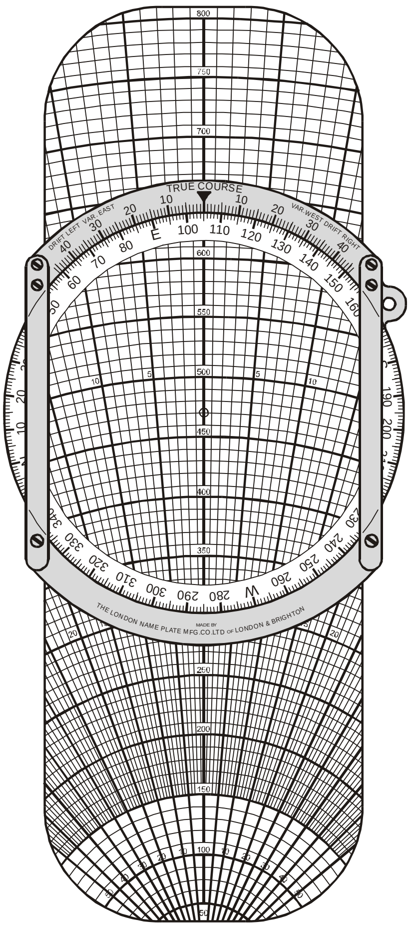
Introduction

1. The Dead Reckoning Computer (Mks 4A and 5A) is designed for solving the vector triangle problems of air navigation. The Mk 5A is a reduced size version of the 4A, produced for helicopter use. Both Mks include an airspeed computer and a circular slide rule.

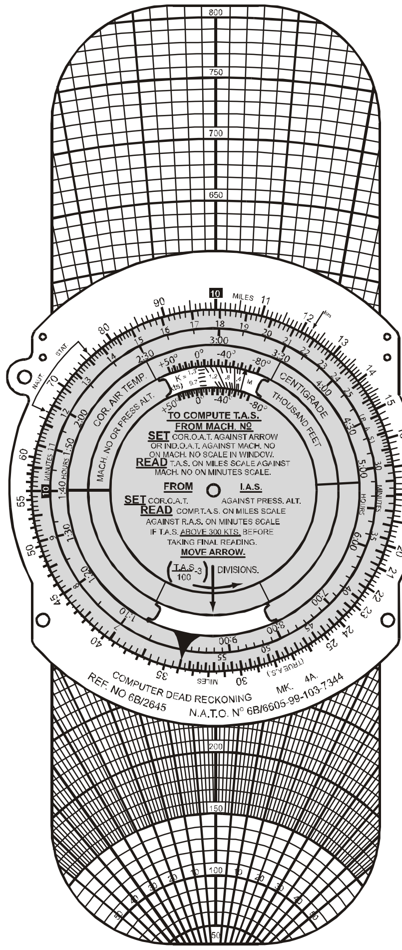
Description

2. The face and reverse of the Mk 4A computer are illustrated in Figs 1 and 2. The computer consists of a metal frame carrying, on one side, a transparent plotting disc in a graduated compass rose, and on the other, a circular slide rule which is also used for airspeed computation. A reversible sliding card printed with concentric speed arcs, radial drift lines, and a rectangular grid, moves under the plotting disc. One side of the sliding card is graduated from 50 to 800 speed units, while the other bears a range from 80 to 320 speed units together with a square grid graduated from 0 to 80. The units can represent whatever is required (e.g. kt, mph, kph), provided that the chosen unit is used consistently. Similarly, one side of the Mk 5A computer is graduated from 30 to 200 speed units and carries a square grid graduated from 0 to 100, while the other side is blank (but older versions may bear graduations from 20 to 120 and markings for helicopter jump navigation once used with the Wessex 1). The examples in this Chapter use the Mk 4A version.

7-14 Fig 1 DR Computer, Mk 4A – Face



7-14 Fig 2 DR Computer, Mk 4A - Reverse



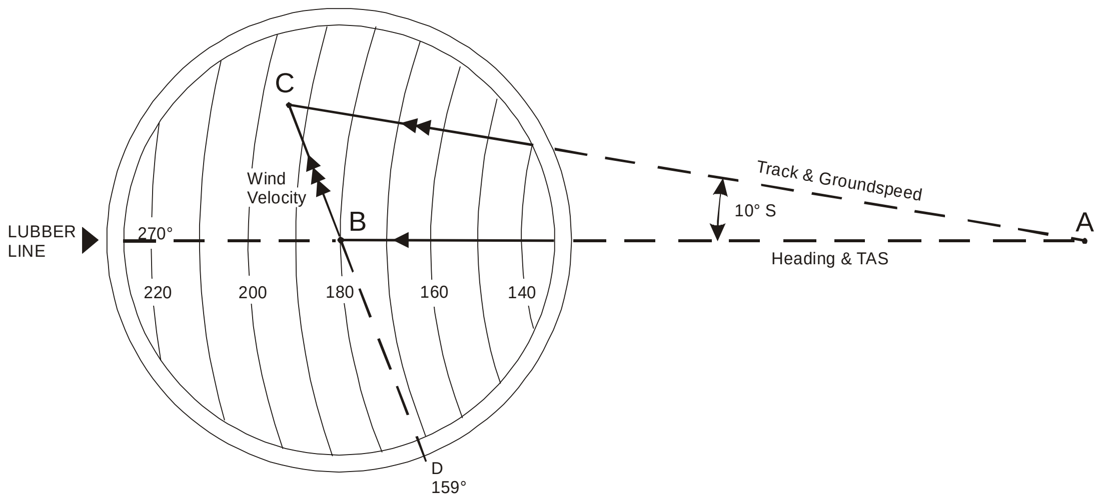
VECTOR TRIANGLE SOLUTION

Principle

3. The DR Computer reproduces, within the rotatable compass rose, that part of the triangle of velocities which is of prime concern, i.e. it shows the wind vector applied between the heading/true airspeed and the track/groundspeed vectors.

4. The principle is illustrated in Fig 3, in which ABC is the vector triangle. The compass rose (or bearing plate) is orientated to register the direction of the heading vector AB, i.e. 270° T, against a lubber line (marked TRUE COURSE on the computer). In doing this, the compass rose is orientated with respect to the other vectors. Thus, the wind vector BC is laid off down wind from B. The wind is therefore from D, i.e. 159° T. The direction of the track is shown as degrees to port or starboard of heading, e.g. in Fig 3 the drift is shown as 10° starboard which, when applied to heading, gives a track of 280° T. In Fig 3, if AB (airspeed) is 180 kt and BC (windspeed) 36 kt, then AC (groundspeed) is 196 kt.

7-14 Fig 3 Principle of DR Computer Mk 4A



5. It is unnecessary to have the whole of the vector triangle shown on the DR Computer. Therefore, only the essential part of the triangle, that containing the wind vector, is shown. The computer may be used over a range of speeds by adjusting the sliding card so that the curve corresponding to the true airspeed lies under the centre of the compass rose.

6. Thus, the transparent disc acts as a plotting dial on which only the wind vector is drawn, the heading vector being represented by the centre line on the sliding card and the track vector by the appropriate radial (drift) line. The centre of the disc is shown by a small circle which normally marks the end of the heading vector.

Operation

7. Wind Speed and Direction*.* To draw the wind vector when the speed and direction of the wind are given, the wind direction is set against the lubber line and the wind vector is drawn from the centre along the centre line in a direction away from the lubber line. The length of the line relative to the card scale represents the wind speed. The end of the vector so plotted is called the wind point. Conversely, if the wind point has been found by other means, the wind speed and direction may be measured by rotating the plotting dial until the wind point lies on the centre line, on the opposite side of the centre circle to the lubber line. The wind direction is now read against the lubber line, while the distance of the wind point from the centre measured against the speed scale of the card gives the wind speed.

Note. The wind vector is always drawn away from the heading pointer because wind direction is conventionally quoted as the direction from which the wind is blowing. Headings and tracks are specified as the direction towards which the aircraft is going. It should be noted also that the scales on the two sides of the card are different so that a wind drawn using one scale must not be used with the other.

8. Airspeed and Groundspeed*.* Airspeed is always set, or read, on the centre line of the card under the centre of the plotting dial. Groundspeed is indicated by the speed circle under the wind point.

9. Variation and Drift. Although the plotting dial is normally orientated with respect to true north, a variation scale marked on either side of the lubber line can be used to convert true directions to magnetic and vice versa. This scale may also be used to obtain track by applying drift to heading, and vice versa.

Examples of Use

10. The examples which follow illustrate the versatility of the DR Computer in solving problems graphically, although only the first two are common in everyday practice. It should be remembered that, as noted in para 7, the wind always blows outwards from the centre of the computer. Animated diagrams are also provided to help explain the various calculations.

11. To Find Track and Groundspeed (Fig 4). The problem is to find track and groundspeed, given:

Click here to view an animated diagram.

Heading	-	185º T
TAS	-	420 kt
W/V	-	105°/39 kt

It is first necessary to ensure that the appropriate side of the sliding card is uppermost. The following steps are then carried out:

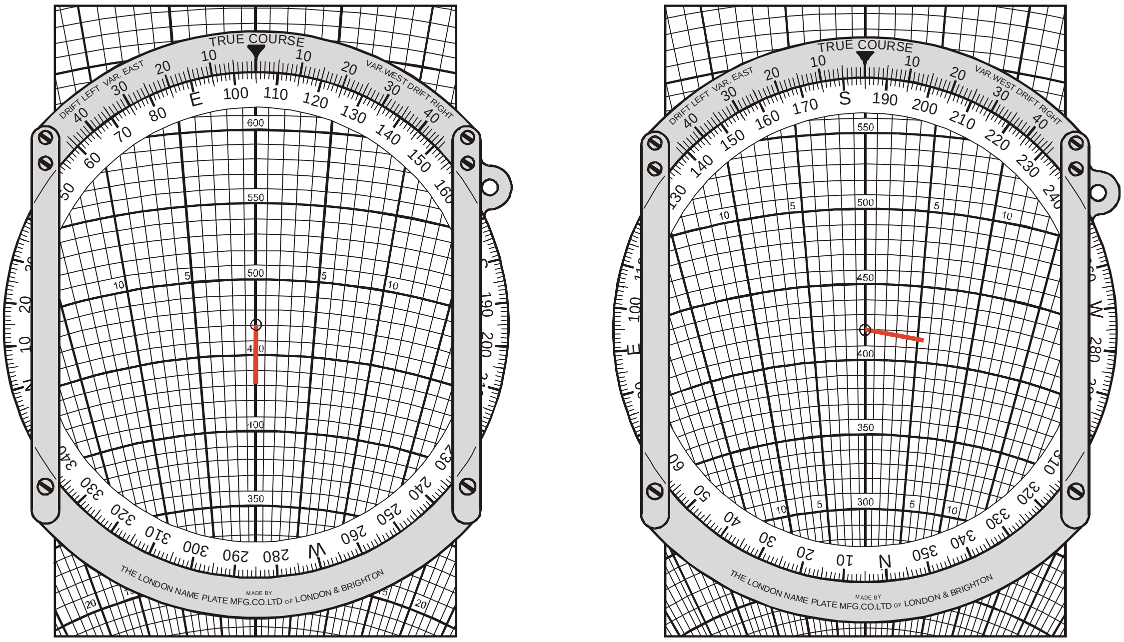
a. Set the W/V. The plotting dial is rotated until 105° on the compass rose is against the lubber line and a line is drawn from the centre of the plotting dial, away from the direction set, equal in length to 39 units on the scale (Fig 4a). Once familiarity with the use of the instrument has been gained, it will be found necessary only to plot the wind point, ie the end of the wind vector, rather than the complete line.

b. Set Heading and TAS. The plotting dial is rotated until 185° is against the lubber line, and the card is adjusted until the 420 speed arc lies under the centre of the plotting dial (Fig 4b).

c. Read Off the Solution Under the Wind Point. From Fig 4b, it will be seen that the wind point is on the 5° S drift line. Track can therefore be calculated as 185° T + 5° = 190° T, or it can be read off on the compass rose against the 5° mark on the drift scale. The groundspeed is given by the speed arc under the wind point, i.e. 415 kt.

7-14 Fig 4 Finding Track and Groundspeed

a Setting the W/V **b Reading the Solution**



12. To Find Heading and Groundspeed (Fig 5). The problem is to find the heading and groundspeed, given:

Track Required	-	300º T
TAS	-	320 kt
W/V	-	195º/45 kt

It is first necessary to ensure that the appropriate side of the sliding card is uppermost. The following steps are then carried out:

a. Set the W/V. This is carried out in the manner described in para 11a.

b. Set TAS. TAS is set by adjusting the card until the 320 speed arc lies under the centre of the plotting dial.

c. The plotting dial is rotated until the required track is registered against the lubber line (Fig 5a). The drift indicated by the wind point (7½° S) is noted; this represents the drift that would be experienced if a heading of 300° T were steered.

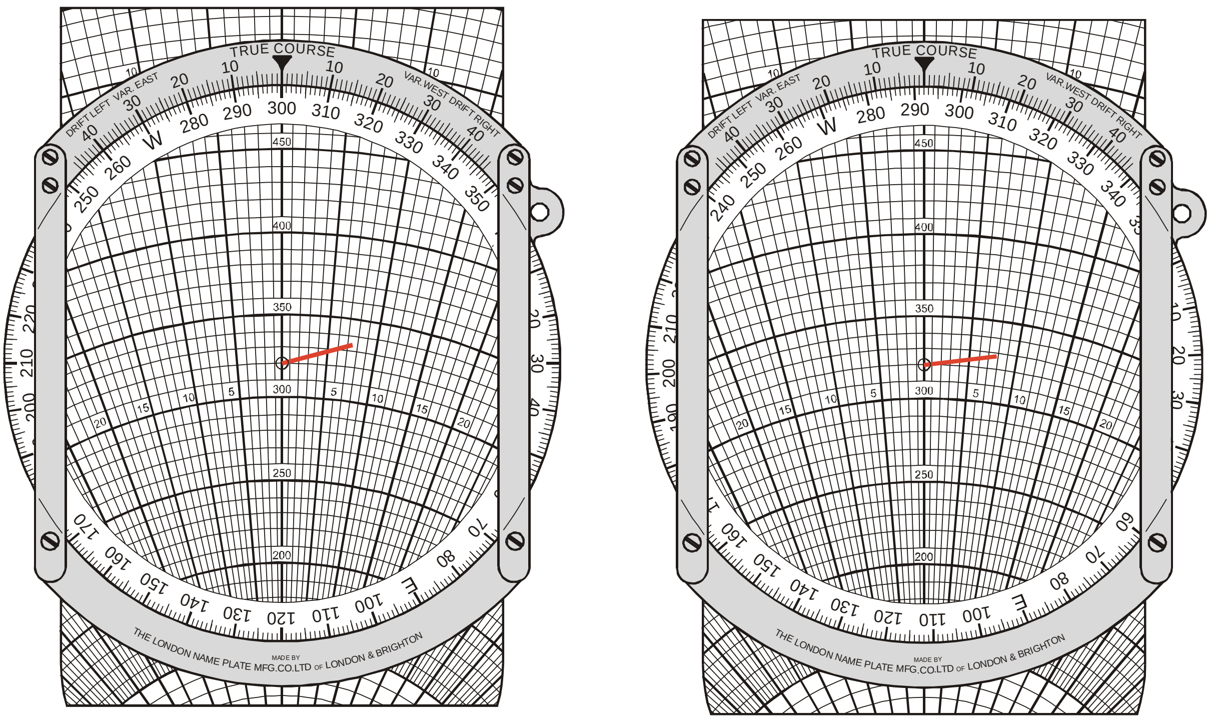
d. The required track is now set against the drift scale mark equivalent to the drift found in para 12c, i.e. 7½° S.

e. It is possible that the wind point will now indicate a slightly different drift value (Fig 5b). If this is the case, the plotting dial is adjusted until the required track is against this new value of drift on the drift scale; (8° S in this example).

f. The required heading (292° T) is read on the plotting dial against the lubber line, and the groundspeed (329 kt) is indicated by the speed arc lying under the wind point (Fig 5b).

7-14 Fig 5 Finding Heading and Groundspeed

a Setting Track and Reading Drift | **b Setting Track against Drift Scale and Reading Solution**



13. Finding W/V by the Track and Groundspeed Method (Fig 6). The problem is to find the W/V given the following data:

Heading	-	120º T
TAS	-	230 kt
Track Made Good	-	112º T
Groundspeed	-	242 kt

It is first necessary to ensure that the appropriate side of the sliding card is uppermost. The following steps are then carried out:

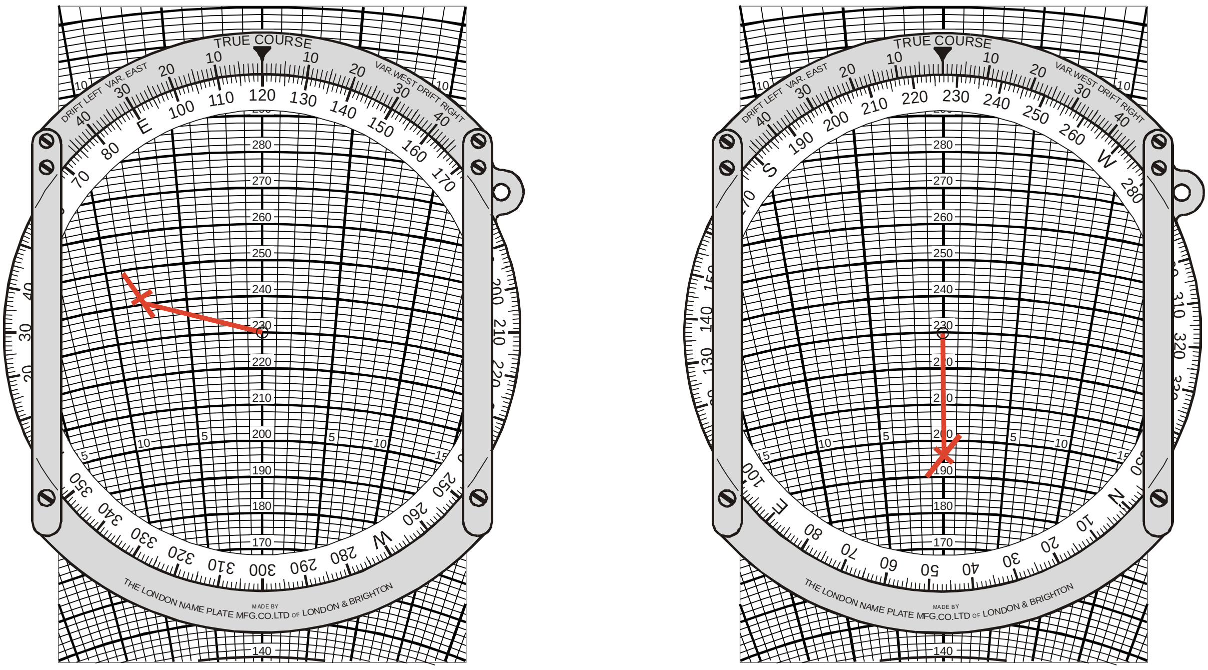
a. The heading and TAS are set as described in para 11b.

b. Set the Track Made Good and the Groundspeed. Firstly, the drift is calculated as the difference between heading and track, in this example 120° – 112° = 8° Port (P). A pencil mark is now made on the plotting dial (Fig 6a) where the drift line (8° P) intersects the speed arc representing the groundspeed (242 kt).

c. A line drawn from the centre of the dial to this point represents the wind vector. In order to measure it, the dial is rotated until the vector is aligned exactly with the centre line and running from the dial centre away from the lubber line (Fig 6b). The wind direction can now be read off against the lubber line (227º T), and the wind speed can be determined by measuring the length of the vector against the speed arcs (34 kt).

7-14 Fig 6 Finding W/V by Track and Groundspeed Method

a Plotting Drift and G/S and Drawing the Wind Vector **b Reading the W/V**



14. Correcting a W/V by Finding the Error in a DR Position (Fig 7). It is possible to find a new wind velocity by applying a correction vector to the wind velocity in use, given a simultaneous DR position and fix. As an example, suppose that the wind velocity that has been used is 345º/30 kt, and that, after 20 minutes of flight, the aircraft's position is fixed at a position which bears 220º T/5 nm from a DR position. The procedure is as follows:

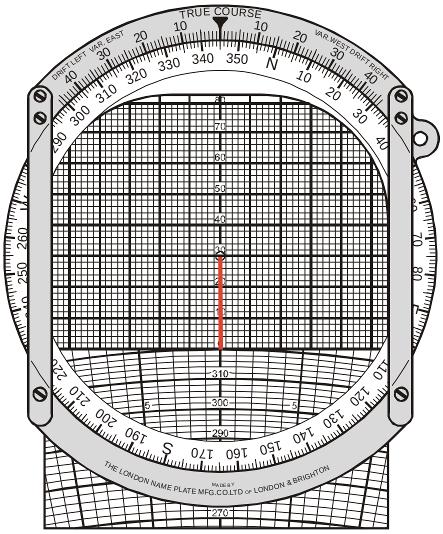
a. The card is adjusted until the square-ruled section is under the dial. The wind direction is set against the lubber line and the wind vector in use is drawn on the dial using a convenient scale, e.g. one large square = 10 nm (Fig 7a).

b. The error per hour is calculated (an error of 5 nm in 20 minutes is equivalent to 15 nm per hour). The dial is rotated until the bearing of the fix from the DR position is against the lubber line. A correction vector is then drawn from the end of the wind vector, parallel to the grid lines and towards the lubber line. The correction vector is of a length equal to the hourly error at the chosen scale (Fig 7b).

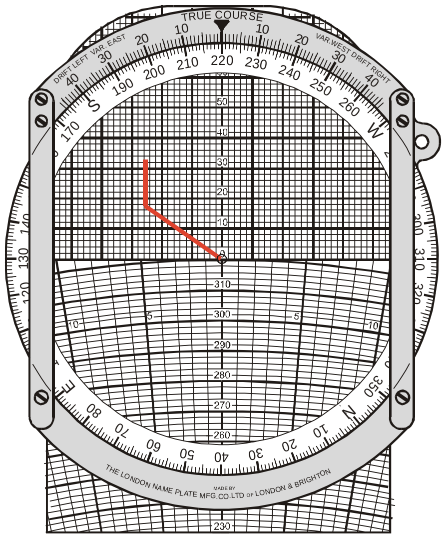
c. The line from the centre dot to the end of the correction vector represents the new wind vector. It can be measured by rotating the dial until the vector is aligned with the centre line and then reading the direction from the lubber line and measuring the speed against the chosen scale of the square ruled section of the card (Fig 7c). In the example, the new wind is 003º/40 kt.

7-14 Fig 7 Correcting a W/V

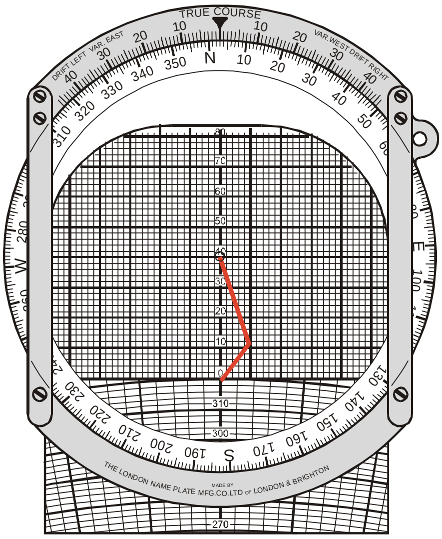
a Drawing the Wind Vector



b Drawing the Correction Vector



c Constructing a New Wind Vector and Reading the Solution



15. Interception (Fig 8). Interception problems concerning a slow-moving target, such as a ship, can be solved satisfactorily on the DR computer. It is easier to deal with the problems in two steps. The first step is to find the relative wind velocity, while the second is to determine the heading to make good the relative track and the groundspeed along it, i.e. the speed of closing along the line of constant bearing. As an example, consider the following data:

W/V	-	060º /15 kt
TAS	-	140 kt
Ship's track	-	000º T
Ship's speed	-	25 kt

Ship's position from aircraft - 80 nm on a bearing of 330º T.

a. To Find Relative W/V.

(1) Adjust the card until the square-ruled part is under the dial.

(2) Set the W/V on the dial using any suitable scale (Fig 8a).

(3) Turn the dial until the ship's track (000º T) is registered against the lubber line.

(4) From the end of the wind vector, draw a line equal to the ship's speed to scale (25 kt) parallel with, but away from, the lubber line (Fig 8b). This is the vector of the ship's track and speed reversed.

(5) Join the centre of the plotting dial to the end of this second vector to obtain the vector of the relative W/V (Fig 8c). It measures 022º/35 kt.

b. To Find Heading to Intercept and Speed of Closing.

(1) Proceed as in para 11, to find the heading to steer and G/S to make good a track of 330º in a W/V of 022º/35 kt with a TAS of 140 kt.

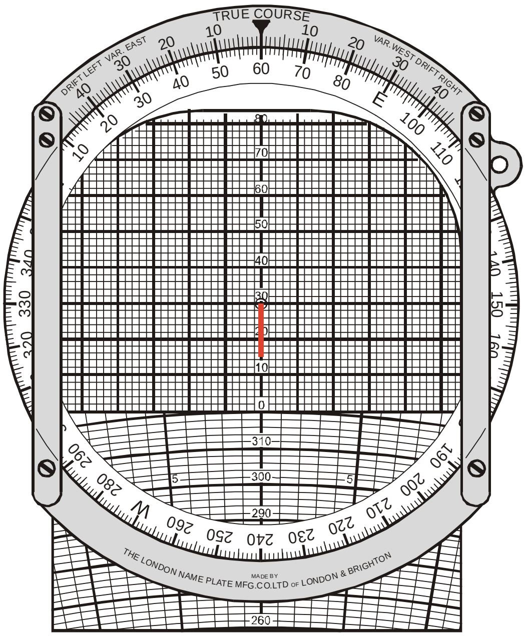
(2) The heading is found to be 341º T.

(3) Although a G/S of 117 kt is found, the figure actually represents the speed of closing along the relative track, or line of constant bearing. Thus, the ship will be intercepted after 41 minutes of flight.

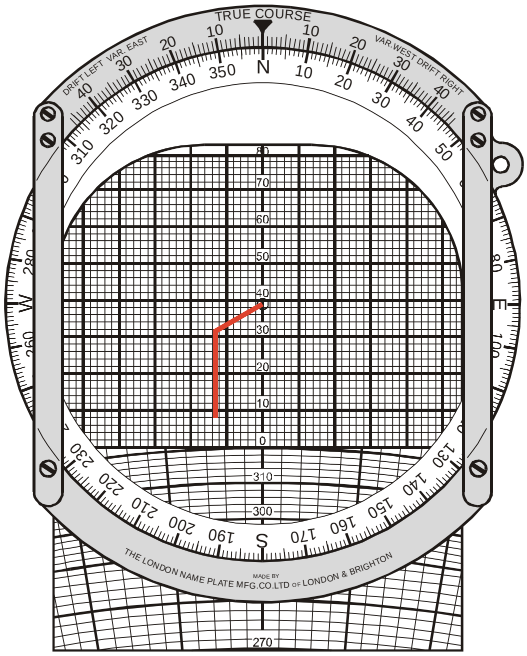
Note. If the relative W/V is found using the same basic scale as represented by the concentric arcs, there is no need to measure the relative W/V. The second step can then be taken immediately the first two vectors of the first step are drawn.

7-14 Fig 8 Interception

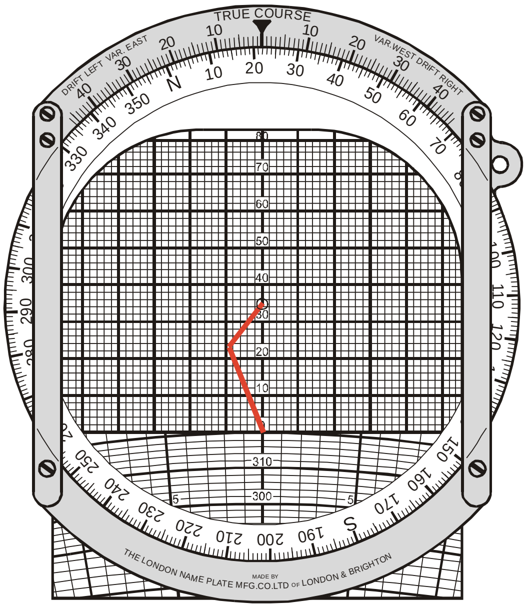
a Setting the W/V



b Setting Ship's Speed



c Drawing and Reading the Relative W/V



16. To Calculate Convergence (Fig 9). Convergence may be determined using the following procedure:

a. Set the compass rose with North against the lubber line.

b. Set the zero point of the squared portion of the slide under the centre of the plotting disc.

c. Mark ch long upwards from the zero point, on the squared section, using any convenient scale (Fig 9a).

d. Rotate the compass rose to set Mean Lat against the lubber line (Fig 9b).

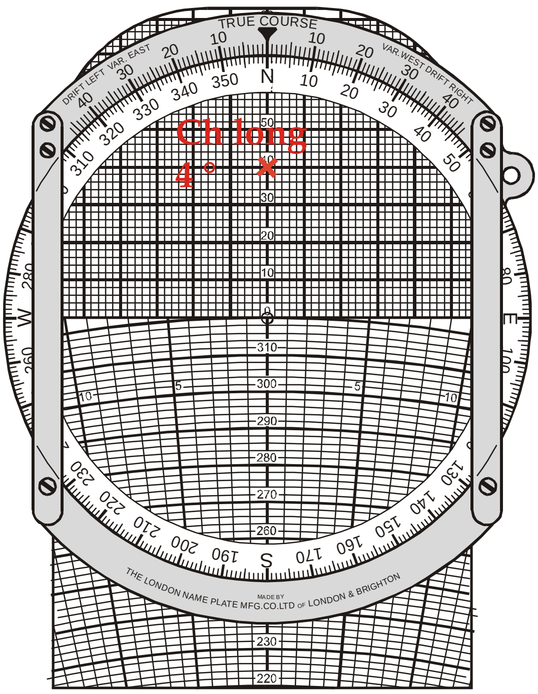
e. Measure convergence horizontally on the squared grid (Fig 9b).

Example: Ch long 4º, Mean Lat 30º

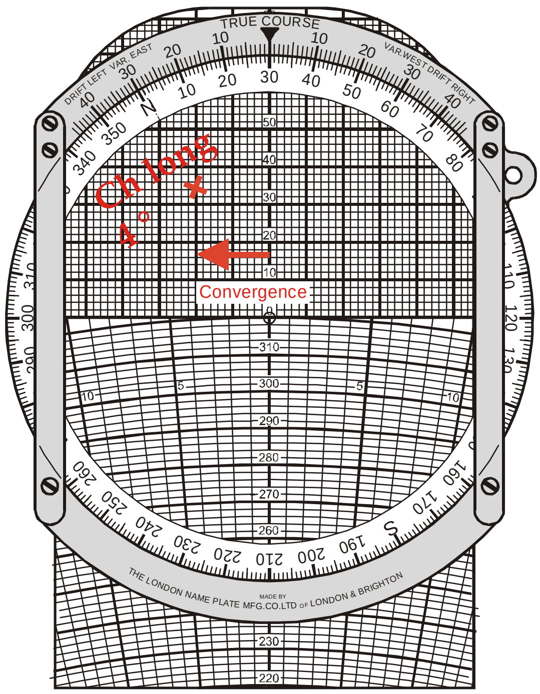
Convergence = 2º

7-14 Fig 9 Calculating Convergence

a Marking Ch Long



b Setting Mean Latitude and Reading Convergence



AIRSPEED COMPUTER

Description

17. The airspeed computer works on the slide rule principle and has scales for the following applications:

a. Computation of TAS from CAS, corrected outside air temperature (OAT) and pressure altitude, with an ancillary scale to allow compressibility corrections to be made to TAS above 300 kt. (Note: CAS is annotated as RAS on inner scale.)

b. Inter-conversion of TAS and Mach Number.

c. Proportion problems.

Use for Airspeed Computations

18. The procedure for calculating TAS from inputs of CAS, corrected OAT, and pressure altitude is as follows:

a. The inner disc is rotated so that the value of corrected OAT is set against the value of altitude, in thousands of feet, in the window (Fig 10a).

b. The value of computed TAS can now be read on the outer scale against the value of CAS on the inner scale (Fig 10a).

c. If the computed TAS is above 300 kt, an additional correction must be made for compressibility error. The correction scale appears in the window, below the altitude window, and the correction is made by rotating the inner disc anti-clockwise so that the reading of the correction scale, against its index, is increased by the value of:

$$\frac{\text{Computed TAS}}{100} - 3 \text{ divisions}$$

d. The corrected TAS is now read off on the outer scale against the original CAS on the inner scale.

Note: To obtain the most accurate results from the computer, pressure altitude and corrected OAT should be used for all airspeed computations. Even so, when computing TAS for altitudes, particularly above 30,000 ft, noticeable, but navigationally insignificant, errors are produced when compared with results using the mathematical formula.

19. Example. As an example, consider the calculation of TAS from the following data:

Pressure Altitude	-	48,000 feet
Corrected OAT	-	– 56º C
CAS	-	210 kt

The procedure is as follows:

a. Set –56° against 48 in the altitude window (Fig 10a).

b. Against 210 on the inner scale, read the computed TAS on the outer scale - 500 kt (Fig 10a).

c. As the computed TAS exceeds 300 kt, a compressibility correction must be made. The current value of the correction scale is 25½. This must be adjusted by:

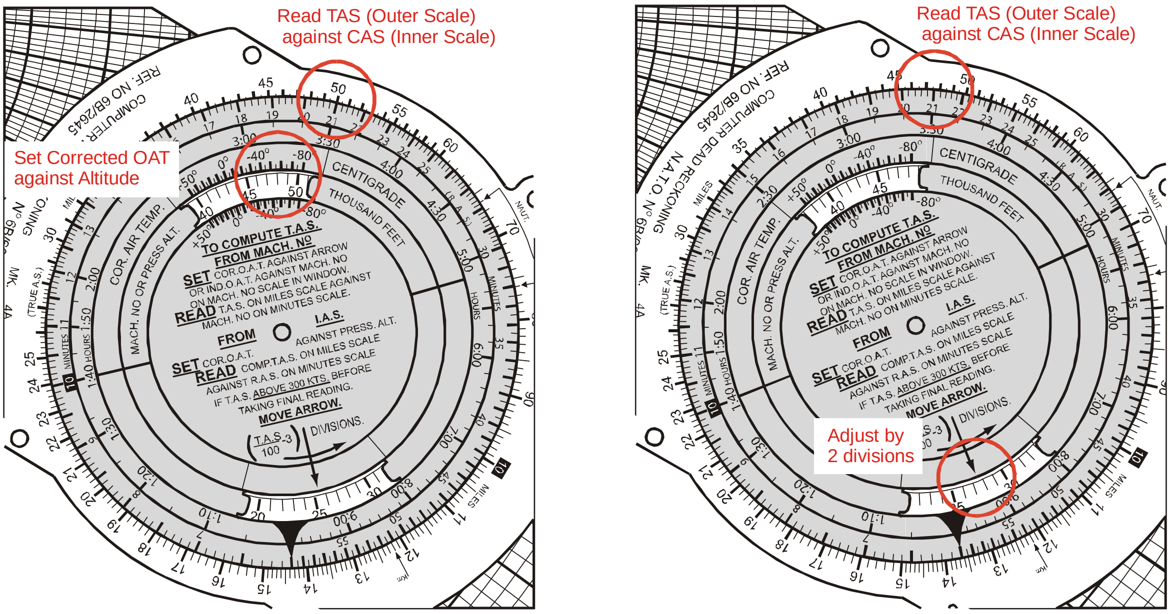
$$\frac{\text{Comp TAS}}{100} - 3 = \frac{500}{100} - 3 = \ 2 \text{ divisions}$$

d. The correction scale is therefore made to read 27½ against its index (Fig 10b).

e. The corrected value of TAS is now read on the outer scale against the value of CAS (210) on the inner scale (Fig 10b). The result is 476 kt.

7-14 Fig 10 Calculating TAS

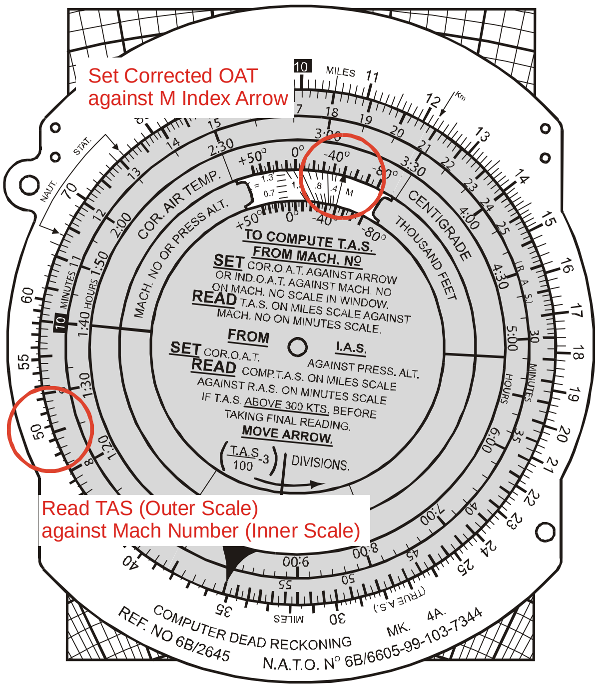
a Setting Altitude against OAT | **b Applying Compressibility Correction and Reading the Solution**



Mach Number/True Airspeed Conversion

20. The Mach number scale appears in the altitude window at the upper end of the altitude scale. The scale can be used for converting Mach number to TAS and vice versa (Fig 11).

7-14 Fig 11 Mach No/TAS Conversion



21. Inter-conversion of Mach Number and TAS. Mach number and TAS may be inter-converted in one of two ways:

a. Set corrected outside air temperature against the Mach index arrow (marked M).

b. Set indicated outside air temperature against the intersection of Mach number and 'K' factor. ('K' factor is empirically determined for each aircraft type).

In either case, TAS is read on the outer scale against Mach number on the inner scale.

22. Example. It is required to determine the TAS corresponding to M 0.85 in a corrected OAT of – 50° T.

Using the method in para 21a (see Fig 11):

a. Set –50° C against the 'M' index arrow.

b. Read TAS (495) kt on the outer scale against 0.85 on the inner scale.

CIRCULAR SLIDE RULE

Introduction

23. The reverse sides of the Mks 4A and 5A DR Computer carry a circular slide rule. Although the pocket electronic calculator has superseded the slide rule for carrying out arithmetic, the circular slide rule is nevertheless useful for the solution of the normal speed, distance and time, and fuel consumption problems which regularly occur in navigation. It should be remembered that, as with all slide rules, decimal points are ignored during calculation and only inserted at the end. It is therefore important to have an appreciation of the order of the result expected.

24. Reflecting the normal usage of the circular slide rule, the outer scale is marked 'MILES', and the scale on the rotating disc (the inner scale) is marked 'MINUTES'. The inner scale has a large black arrow indicating one hour.

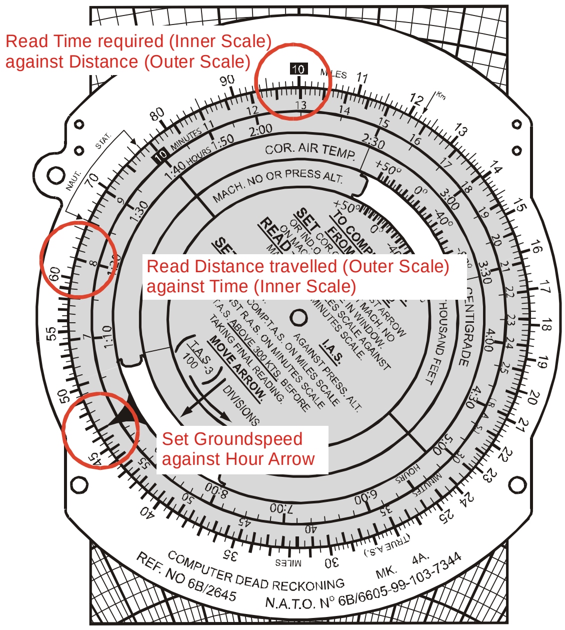
Calculating Distance and Time

25. The problem most often encountered, which is solved readily by the circular slide rule, is that of determining the time taken to cover a given distance, or conversely the distance covered in a given time. To solve these problems, the given groundspeed is set, in knots on the outer scale, against the black (hour) arrow of the inner scale. Distance is then read on the outer scale, against time in minutes on the inner scale.

26. Example (Fig 12). Given a groundspeed of 470 kt, how long will it take to fly 100 nm, and how far will the aircraft fly in 8 minutes? By setting 47 on the outer scale against the hour arrow it will be seen that a time of 12.8 minutes on the inner scale will be read against the 10 mark on the outer scale, ie 100

nm takes 12.8 minutes; against 8 on the inner (minutes) scale, a distance of 62.5 nm will be read on the outer scale.

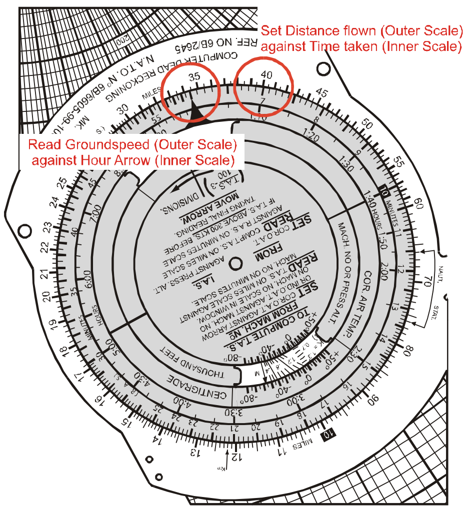
7-14 Fig 12 Distance/Time Calculation



Calculating Groundspeed

27. If the distance flown in a given time is known, the circular slide rule can be used to find the groundspeed. The procedure is to set the distance flown on the outer scale against the time taken on the inner scale. The groundspeed is then read on the outer scale against the black (hour) arrow of the inner scale, e.g. if 40 nm are flown in 7 minutes, a groundspeed of 343 kt is read against the black arrow (Fig 13).

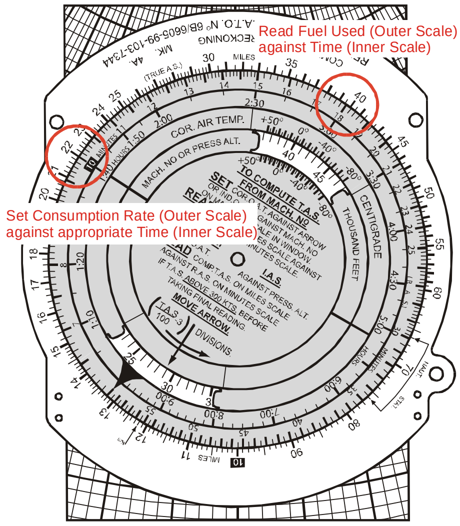
7-14 Fig 13 Calculating G/S



Fuel Consumption

28. Given the fuel consumption rate (e.g. in kg/min) and the leg time over which that consumption rate applies, the circular slide rule can conveniently be used to determine the total fuel used. The fuel consumption rate is set on the outer scale against the appropriate time on the inner scale. The total fuel used can then be read on the outer scale against the leg time on the inner scale. Thus, in the example, Fig 14, a fuel consumption rate of 22 kg/min is set against the 1 minute mark (remembering that there are no decimal points and 1 is identical to 10). Over a leg time of 18 minutes, it will be seen that 396 kg of fuel is used.

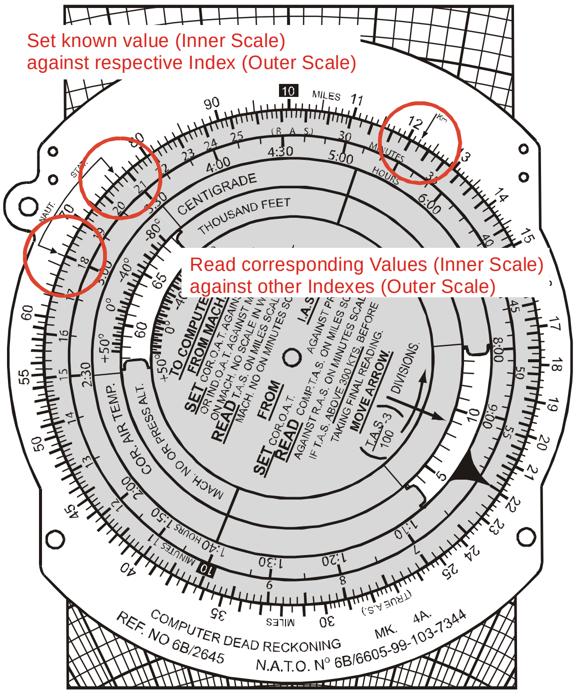
7-14 Fig 14 Fuel Consumption



Unit Conversions

29. Unit conversions only require the multiplication and division of numbers, so any such calculation could be carried out on a slide rule. However, this is not normally the quickest or most accurate method; electronic calculators or graphical methods are generally preferred. The circular slide rule can readily be used to convert between nautical miles, statute miles, and kilometres. The outer scale has indices marked for each unit and, by setting the known value on the inner scale against its respective index, the corresponding values in the other units can be read against the relevant index. Thus, for example, setting 18 against the 'Naut' index gives values of 20.7 statute miles and 33.3 kilometres (Fig 15).

7-14 Fig 15 Unit Conversion



CHAPTER 9 - SUNRISE, SUNSET AND TWILIGHT

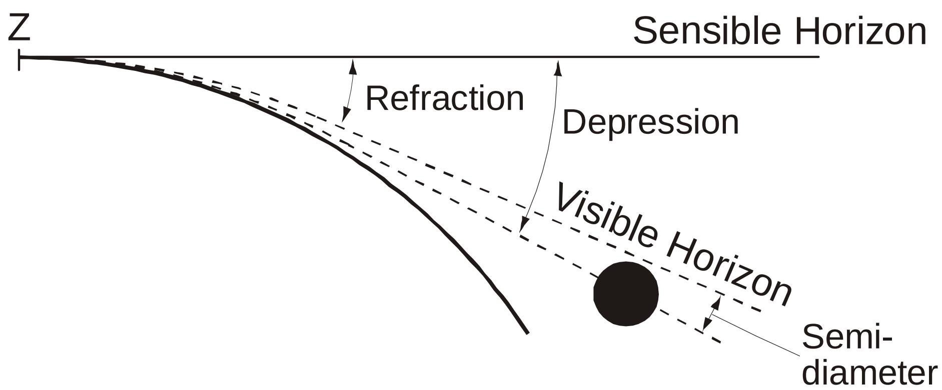
Introduction

1. The intensity of sunlight received at any point on Earth depends on the Sun's altitude[1], the maximum daily intensity being received at local noon when the Sun is at its zenith. Direct sunlight begins at sunrise and ceases at sunset when the Sun's upper rim is on the horizon. Due to the reflective properties of the atmosphere, a period of diffused light, known as twilight, precedes sunrise and follows sunset. This chapter should be read in conjunction with the UK Air Almanac which contains data regarding Sunrise and Sunset times, Moonrise and Moonset times and the duration of Twilight. The UK Air Almanac is available on the Aeronautical Information Documents Unit (AIDU) website (www.aidu.mod.uk/Milflip) and also as a free PDF download from HM Nautical Almanac Office at http://astro.ukho.gov.uk/ (www). The Almanac contains tables and graphs, along with instructions for use, to allow the user to determine the required data.

Theoretical Risings and Settings of the Sun

2. Theoretical rising and setting occurs when the Sun's centre is on the observer's celestial horizon.[2] Due to atmospheric refraction, an observer sees objects below his celestial horizon (Fig 1).

9-9 Fig 1 Sensible and Visible Horizons



SUNRISE AND SUNSET

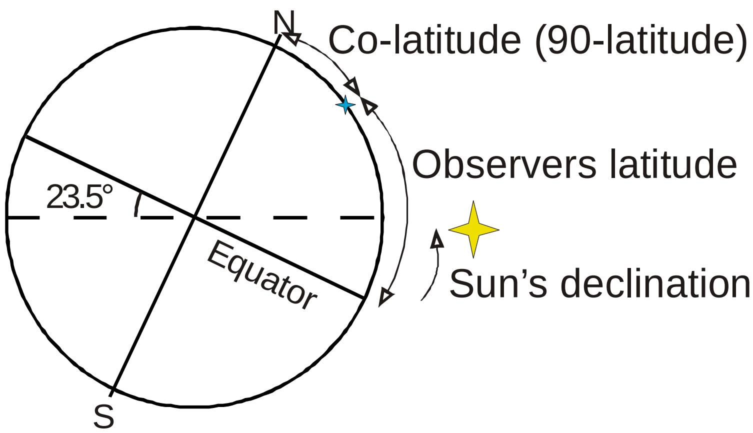
Depression

3. Sunrise and sunset are respectively defined as the point when the upper rim of the Sun just appears above (sunrise) or disappears below (sunset) the observer's visible horizon. At these times, the Sun's centre is 50' of arc below the celestial horizon. Atmospheric refraction accounts for 34' and the Sun's semi-diameter for the other 16'. The predicted times of sunrise and sunset tabulated in the Air Almanac[3] are calculated using this depression of 50' which approximates to 0.8°. The tabulated times of sunrise and sunset given in the Air Almanac are in local mean time (LMT).

Variation in Times of Sunrise and Sunset with Latitude

4. When the Sun's declination[4] (north or south of the celestial equator) is of the SAME name as the observer's latitude (north or south of the earth's equator), sunrise occurs earlier and sunset later as the observer's latitude increases. In high latitudes, when declination is greater than co-latitude (Fig 2), the Sun is continuously above the horizon. Conversely, when the Sun's declination and the observer's latitude are CONTRARY named, sunrise occurs later and sunset earlier as the observer's latitude increases.

9-9 Fig 2 Co-latitude

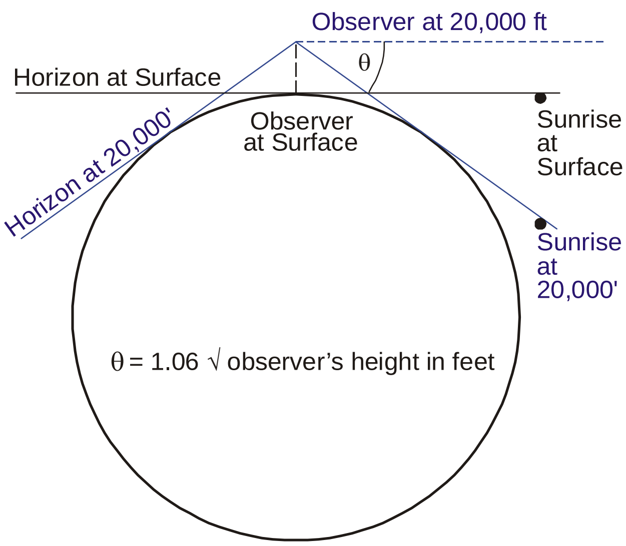


Variation in Times of Sunrise and Sunset with Height

5. The plane of the observer's visible horizon changes with change in height; sunrise becomes earlier and sunset later with an increase in height (Fig 3). θ is given by the formula:

$$\theta = 1.06\sqrt{\text{observer's height in feet}}$$

9-9 Fig 3 Effect of Height on Sunrise and Sunset



Tabulation of Sunrise and Sunset

6. Three ways of presenting the time of sunrise and sunset are given in the Air Almanac:

   a. Sunrise and Sunset Tables.
   b. Semi-duration of Sunlight Graphs.
   c. Rising, Setting and Depression Graphs.

Full descriptions of the Table and the Graphs are given in the Air Almanac; brief descriptions are included in paragraphs 7 to 9.

7. **Sunrise and Sunset Tables**. These tables give the times of sunrise and sunset for an observer at the surface on the Greenwich Meridian between latitudes 60° S and 72° N. The Coordinated Universal Time (UTC) of sunrise and sunset are tabulated at three-day intervals. UTC is referred to as UT in the Air Almanac. The tabulated UT of the occurrence may be taken as the local time of the occurrence at meridians other than Greenwich. The normal entering arguments are tabular date and observer's latitude. The following symbols indicate that the Sun is continuously above or below the horizon:

□ Sun continuously above horizon

■ Sun continuously below horizon.

8. **Semi-duration of Sunlight Graphs**. The times of sunrise and sunset at sea level for latitudes between 65° N and 90° N may be determined using the Semi-duration Graphs. The LMT of the Sun's transit and the semi-duration of sunlight are obtained from the graphs. The times of sunrise and sunset are found from the relationships:

LMT of sunrise = LMT of Transit – semi-duration
LMT of sunset = LMT of Transit + semi-duration.

9. **Rising, Setting and Depression Graphs**. Rising, Setting and Depression Graphs are provided for each 2° of latitude from 72° to 50° and every 5° from 50° to 0°. An associated table gives the following information:

   a. Daily LMT of Sun's meridian passage.
   b. Daily declination of Sun at 1200 UT.
   c. Sun's depression at rising or setting for heights between 0 feet and 60,000 feet.

The semi-duration of sunlight, expressed as an hour angle, is obtained by entering the graph for the appropriate latitude with Sun's declination and the depression value corresponding to aircraft height. The LMT of sunrise and sunset are calculated by applying the semi-duration to the LMT of meridian passage. In high latitudes, a small latitude change may correspond to a large change in hour angle, and a subsidiary graph is provided for interpolation. Without interpolation, the maximum error is 12 min up to 42°, increasing to 15 min by 52°.

TWILIGHT

Types of Twilight

10. The period of diffused light before sunrise and after sunset is known as twilight. The amount of illumination varies with the Sun's depression and also with atmospheric conditions. Three twilights, each occurring at a particular depression value, are recognized:

a. **Civil Twilight**. Civil twilight occurs when the Sun's centre is 6° below the sensible horizon. Light conditions are such that everyday tasks are just possible without artificial light.

b. **Nautical Twilight**. At nautical twilight, the Sun's centre is 12° below the sensible horizon. General outlines are still discernible, and all the brighter stars are visible.

c. **Astronomical Twilight**. At astronomical twilight, the Sun's centre is 18° below the sensible horizon. All the stars are visible. Astronomical twilight is regarded as synonymous with complete darkness.

Dimensions of the Twilight Zone

11. The difference between the depression angle of the Sun at sunrise and sunset (0.8°) and that for the beginning or end of civil twilight is 5.2°, which is the dimension of the twilight zone around the earth. This, in turn, can be converted into a distance of 312 nm because 1' of arc on the surface of the Earth is equal to 1 nm.

Factors Affecting Duration and Time of Twilight

12. The duration and time of twilight for a stationary observer depend upon the following:

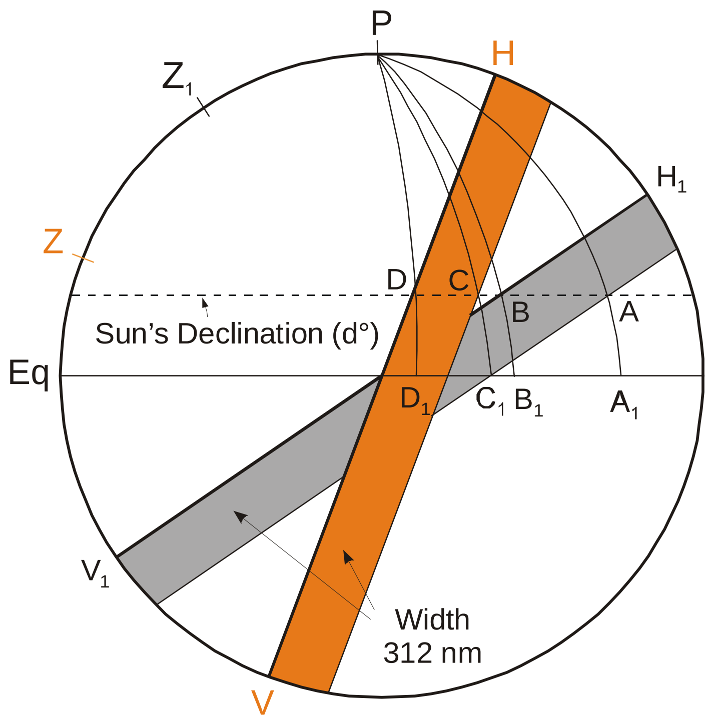
a. Observer's Latitude.
b. Sun's Declination.
c. Height of Observer above Sea Level.

Variation of Twilight with Latitude

13. Fig 4 shows two observers, Z and Z_1, their respective horizons, VH and V_1H_1, and associated twilight belts. The Sun, declination d°, crosses observer Z_1's twilight zone from A to B, the duration of twilight being A_1B_1, while for observer Z, the Sun crosses from C to D, giving duration C_1D_1. Duration A_1B_1 is greater than C_1D_1, and therefore the duration of twilight increases with increased latitude. In

high latitudes, ie when same-name declination is greater than co-latitude, the Sun is continuously above the horizon. Similarly, the Sun may remain less than 6° below the horizon giving twilight conditions throughout the night. This condition is indicated by the symbol //// in the Air Almanac.

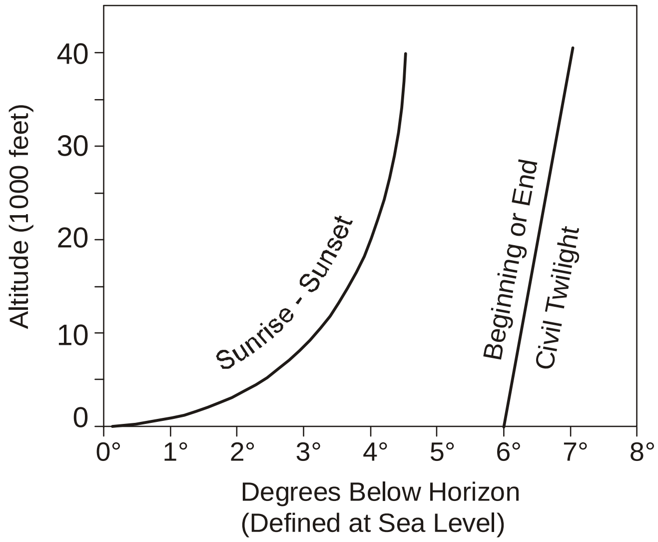
9-9 Fig 4 Variation in Duration of Twilight with Latitude



Variation of Twilight with Height

14. The Sun rises earlier and sets later with an increase in height. Morning twilight therefore occurs earlier and evening twilight later as height increases. The amount of pollution in the atmosphere decreases with height resulting in a decrease in the amount of light reflected and scattered by particles in the air. The degree of illumination associated with a depression of 6° at sea level occurs at a depression of less than 6° at height. Fig 5 shows the decrease in the duration of twilight with height.

9-9 Fig 5 Decrease in Duration of Twilight with Height



Tabulation of Duration of Twilight

15. The duration of twilight is presented in the Air Almanac, together with the times of sunrise and sunset. One table and two graphical solutions are provided. Full explanations are given in the Air Almanac, but brief descriptions are included below.

16. **Civil Twilight Tables**. The times of morning civil twilight and evening civil twilight are tabulated in the Air Almanac at three-day intervals for latitudes between 60° S and 72° N. The times given are the UT of the occurrences at sea level on the Greenwich Meridian, but the UT of the occurrences may be regarded as the LMT of the occurrences at other meridians.

17. **Duration of Twilight Graph**. The duration of Twilight graph gives the time interval between morning civil twilight and sunrise (or sunset to evening civil twilight). In the region "No Twilight nor Sunlight" the Sun is continuously more than 6° below the horizon. Adjacent to this "No Twilight nor Sunlight" region, is a region where the Sun's depression is less than 6° for part of the day, although the semi-duration of sunlight graphs show the Sun to be continuously below the horizon. In this region, the duration of twilight is the sum of the intervals between morning civil twilight and meridian passage, and meridian passage and evening civil twilight. The total duration of twilight is, therefore, double that given by the graph.

18. **Rising, Setting and Depression Graphs**. The numerical values of the depressions corresponding to specific brightness at various height are difficult to quantify. However, a particular brightness at a particular height is always associated with a specific depression value.

SUNLIGHT AND TWILIGHT IN HIGH LATITUDES

General

19. In high latitudes, the Sun may be above or below the horizon all day. Twilight conditions, where they exist, last longer than at low latitudes. In extreme cases, morning and evening twilights are continuous, the Sun remaining below the visible horizon all day.

20. The Sun's apparent path over the Earth is from East to West. An aircraft travelling westwards travels "with the Sun". If the westerly component of ground speed equals 15° of longitude per hour, the light conditions experienced remain constant. An aircraft travelling at less than 15° of westerly longitude per hour experiences a slower change of light conditions than a stationary observer on the Earth. On easterly tracks the Sun's westward velocity and the aircraft's easterly velocity combine, accelerating the normal daily change of light conditions. In the space of a few hours an aircraft might pass from daylight through evening twilight, night and morning twilight back into daylight.

21. In high latitudes, the times of sunrise, sunset, and twilight for various points along the route may be established from tables and graphs in the Air Almanac.

End note:

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[1] **Altitude** - The angular distance between the direction to an object and the horizon. Altitude ranges from 0 degrees for an object on the horizon to 90 degrees for an object directly overhead.

[2] **Celestial Horizon** - The celestial horizon is a great circle on the celestial sphere whose plane lies at 90° to the zenith/nadir axis of an observer and passes through the centre of both the Earth and the celestial sphere.

[3] **Air Almanac** - The UK Air Almanac is available as a free PDF download from HM Nautical Almanac Office at http://astro.ukho.gov.uk/ (www).

[4] **Declination** - The angular distance of a celestial body north or south of the celestial equator. Declination is analogous to latitude in the terrestrial coordinate system.

CHAPTER 10 - THE MOON

GENERAL

Introduction

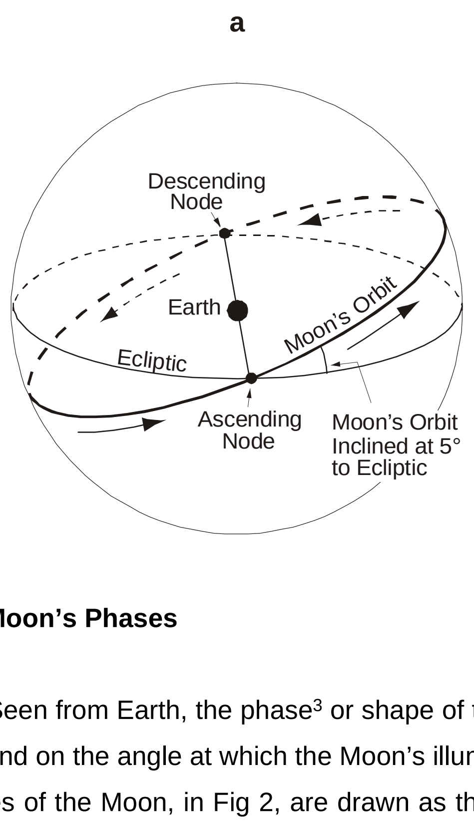
1. The Moon is the Earth's only natural satellite. Because of its short period of revolution about the Earth, the Moon's position on the celestial sphere[1] is constantly changing. Like the planets, the Moon is not self-luminous, but shines by reflecting sunlight. The intensity of moonlight varies with the Moon's phase.

THE MOON'S ORBIT

General

2. The Moon revolves around the Earth in an elliptical orbit in accordance with Kepler's first law[2], modified by perturbations caused by the sun. The orbit is inclined at 5° to the ecliptic, the points of intersection between the orbit and the ecliptic being known as the Ascending and Descending Nodes (Fig 1). The Moon's Nodes precess westwards along the ecliptic, completing one revolution in 18.6 years.

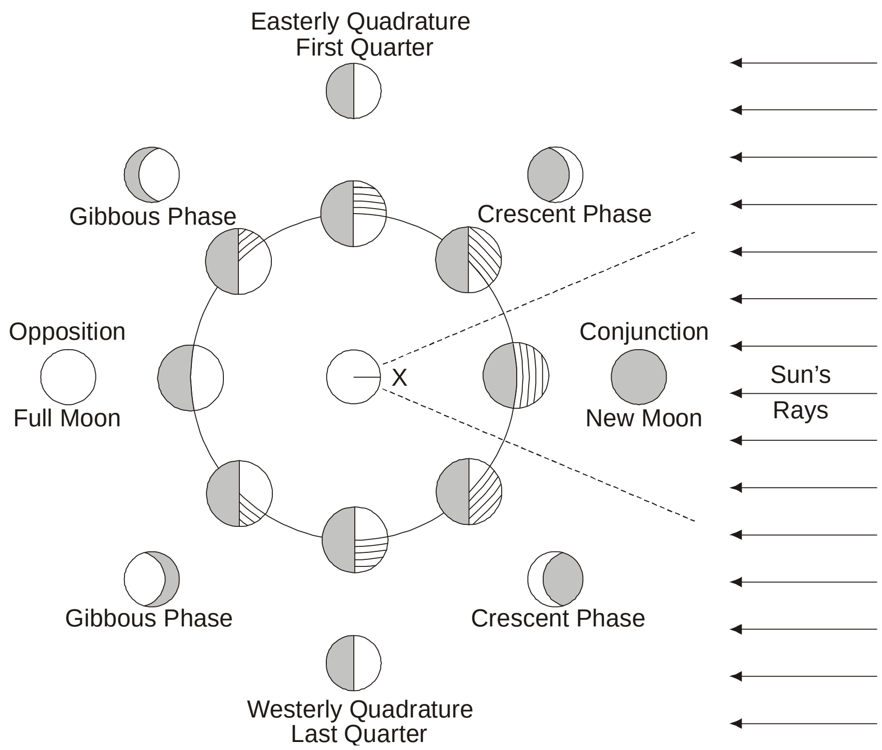
9-10 Fig 1 Motion of the Moon Relative to Ecliptic



The Moon's Phases

3. Seen from Earth, the phase[3] or shape of the Moon depends on the Moon's position relative to the Sun and on the angle at which the Moon's illuminated hemisphere is presented to the Earth. The eight phases of the Moon, in Fig 2, are drawn as they appear to an observer on Earth, ie looking outwards from the centre of the diagram.

9-10 Fig 2 Phases of the Moon



4. The interval between successive New Moons is approximately 29.5 days. The Moon's age is measured in days from the New Moon. At New Moon the Moon's age is 0 days and at First Quarter about 7 days. Full Moon occurs about 15 days and Last Quarter about 22 days. The Moon's age is given in the Air Almanac[4].

5. At New Moon, the Moon and the Sun are over the observer's meridian at the same time, ie local noon. When the Moon is above the horizon in the periods immediately preceding and following New Moon, the illuminated portion of the Moon presented to the observer is too small to be seen against the sunlight. The Moon crosses the observer's meridian at 1800 Local Mean Time (LMT) at the First Quarter, 2400 LMT at Full Moon, and 0600 LMT at Last Quarter.

MOONRISE AND MOONSET

Visible Rising and Setting

6. The Moon's visible risings and settings occur when the Moon's upper rim is just on the visible horizon. The Moon's average altitude at visible rising and setting is +7' of arc:

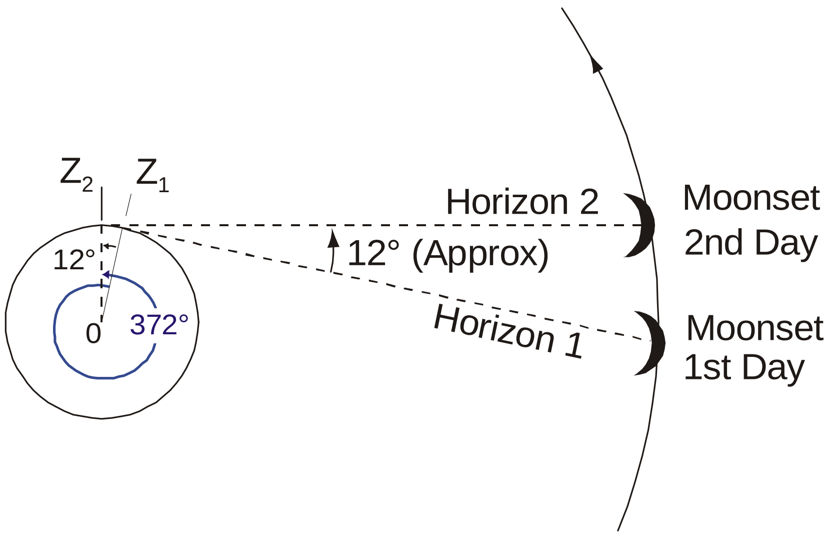
H_O upper rim	=	00º 00'
Atmospheric Refraction	=	– 34'
Semi Diameter	=	– 16'
Horizontal Parallax	=	+ 57' (average)
H_O Moon's Centre	=	+ 7'

Because of the varying distances between the Moon and the Earth the value of horizontal parallax varies between 54' and 61'. In practice, the times of visible rising and setting given in the Air Almanac are calculated using an altitude of (–50' + HP), where HP is the actual value of horizontal parallax at the time of the occurrence.

Retrograde Motion of the Moon

7. Calculation of the times of moonrise and moonset at longitudes other than Greenwich is complicated by the Moon's movement around its orbit. The Moon moves around its orbit in the same direction as the Earth's rotation, completing one orbit in approximately 29.5 days. The average daily movement along the orbit is approximately 12°, or 48 minutes of time. In Fig 3, Z_1 and Z_2 are the positions of successive moonsets, the Moon's declination being assumed constant. During the time it takes the Earth to rotate through 360°, the Moon moves 12° along its orbit. Moonset on the second day occurs at Z_2 and not Z_1. The observer moves 372° between moonsets, i.e. the elapsed time between moonsets is 24 hours 48 minutes.

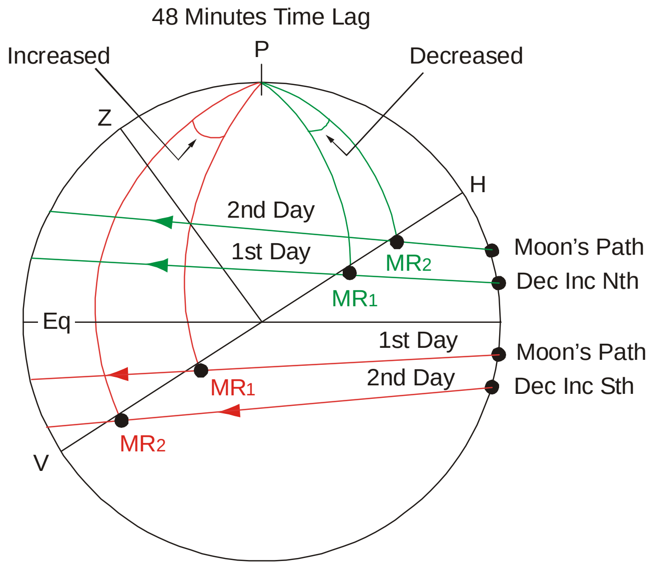
9-10 Fig 3 Retrograde Motion of the Moon



Effect of Declination Changes on Times of Moonrise and Moonset

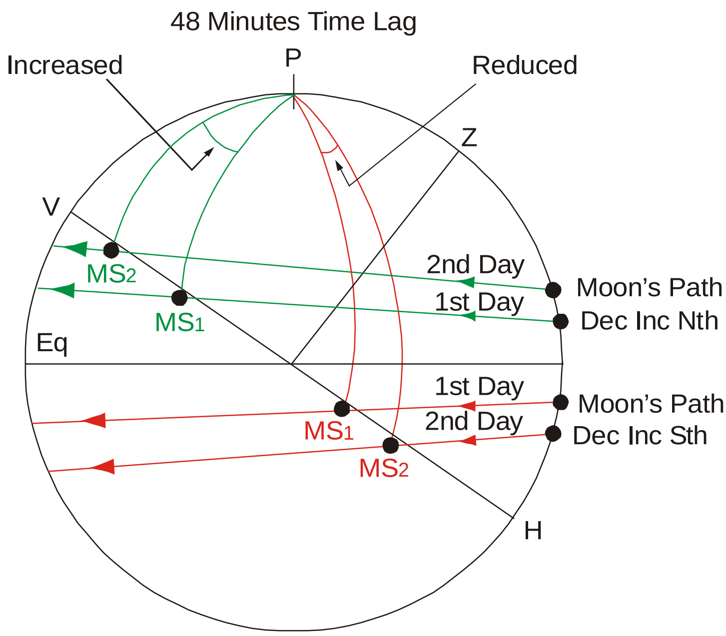
8. The daily change in declination[5] can be sufficiently great to have a considerable effect on the times of moonrise and moonset. When the Moon's declination is increasing, the daily time lag of 48 minutes in the time of moonrise reduces for SAME name declinations and increases for CONTRARY name declinations. Conversely, when the Moon's declination is decreasing, the daily time lag is increased for SAME name declinations and decreases for CONTRARY name declinations (Fig 4).

9-10 Fig 4 Effect of Declination Changes on Time of Moonrise



9. The effect of the declination changes on the time of moonset is reversed. When declination is increasing, the time lag, increases for SAME name declinations, and decreases for CONTRARY name declinations (Fig 5).

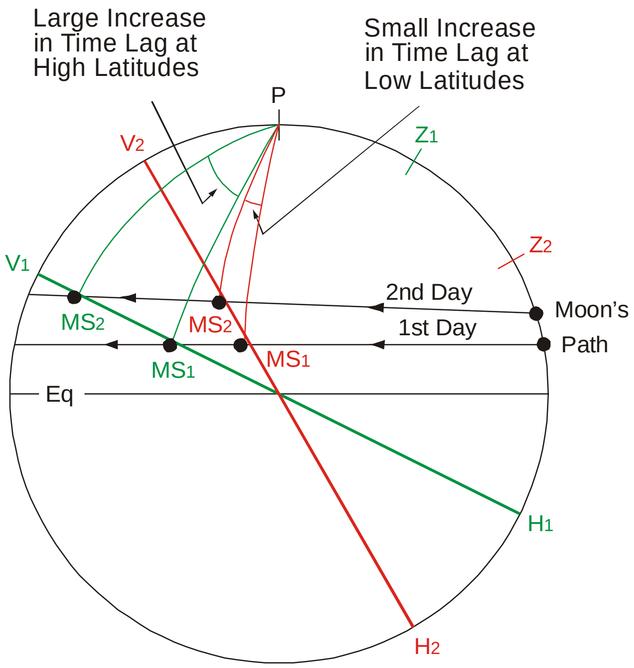
9-10 Fig 5 Effect of Declination Changes on Time of Moonset



Effect of Latitude on Times of Moonrise and Moonset

10. For any given daily change of declination, the effect on the times of moonrise and moonset increases with latitude. In Fig 6, the Moon's declination has the SAME name and is increasing. The time of moonset on both days is shown. The increase in time lag experienced by observer Z_1 is larger than the increase experienced by observer Z_2.

9-10 Fig 6 Effect of Latitude



Effect of Longitude on Times of Moonrise and Moonset

11. Due to the above effects, the LMT of moonrise and moonset at the Greenwich Meridian cannot be considered the LMT of the occurrences at other meridians. The difference between the times of the occurrences at Greenwich and the times of the occurrences at the 180° E/W meridian are calculated and tabulated in the Air Almanac. Since the rate of change of declination is almost constant, the difference between the time of an occurrence at Greenwich and the time at any other meridian may be found by simple proportion. A simple proportion table is provided to facilitate interpolation for intermediate longitudes. The corrected difference is applied to the LMT of the occurrence at Greenwich to give the LMT of the occurrence at the desired longitude.

Effect of Height on Times of Moonrise and Moonset

12. The effect of height on the times of moonrise and moonset is complicated by the Moon's rapid movement and is therefore ignored.

Variations in the Daily Time Lag and their Effect on Moonrise and Moonset

13. The 48 minute difference between the time of successive moonrise and moonset is modified by the effects of latitude and declination, but the overall interval between successive phenomena is usually greater than 24 hours. When the observer's latitude exceeds the complement of the obliquity of the Moon's orbit, the daily declination change may not only cancel out the 48-minute time lag, but reduce the time between successive risings or settings to less than 24 hours.

14. When the interval between successive phenomena is less than 24 hours, the Moon may rise and set twice in one day. Both times are given in the Air Almanac. Each month, around the last quarter, there is one day without a moonrise, and another, around the first quarter, without a moonset. On these occasions, the time of the following moonrise or moonset at Greenwich will be later than 2400, e.g. 2420. This time, e.g. 2420, is given to facilitate the calculation of the times of the phenomena at other longitudes.

Tabulation of Times of Moonrise and Moonset

15. **Daily Tables***.* The LMT of moonrise and moonset at latitudes between 60° S and 72° N on the Greenwich Meridian are tabulated in the Air Almanac. The LMT of the occurrences at longitudes other than Greenwich are established using the tabulated differences and the interpolation table discussed in para 11. When calculating the LMT of moonrise and moonset for a particular day, the time calculated may be in the previous or the following day; the time of the occurrence at Greenwich is for the required day, but the addition or subtraction of the difference correction may move the LMT of the occurrence into the previous or the following day. The LMT of the occurrence is then found by adding or subtracting 24 hours plus twice the tabulated difference. Twice the difference is applied because the difference correction to 360° of longitude is required, and the difference tabulated is for 180° of longitude.

16. **Semi-Duration of Moonlight Graphs**. The Semi-Duration of Moonlight Graphs give the LMT of the Moon's meridian passage and the semi-duration of moonlight for latitudes above 65° N. The times of meridian passage and the semi-durations change rapidly, and care must be taken to read the graphs accurately.

17. **Use of Moonlight Graphs***.* A rough idea of the times of moonrise and moonset may be obtained from a superficial examination of the graphs. The vertical from the appropriate date cuts the top scale at the LMT of meridian passage. The intersection of the vertical with the appropriate latitude line gives the semi-duration of moonlight. The semi-duration is added to and subtracted from the LMT of meridian passage to give the times of moonset and moonrise respectively. The times obtained are the LMT of the occurrences on the Greenwich Meridian. The times at meridians other than Greenwich may be obtained by either of the following methods:

a. The LMT of moonrise and moonset on the Greenwich Meridian is calculated for the required date and either the following date or the preceding date. The difference in the times represents the effect of a 360° change of longitude. The time of moonrise or moonset at the desired meridian is then established by proportioning the 360° difference.

b. The dates on the graph correspond to 00 hrs LMT at the Greenwich Meridian. The times of meridian passage, moonrise and moonset are estimated directly from the graphs. The times extracted are converted to the UT at the desired longitude. The graph is re-entered at the point on the daily scale corresponding to the UT of meridian passage at the desired longitude, and a new value of LMT meridian passage obtained. Similarly, the UT of moonrise and moonset are used to establish further semi-duration values. The LMT of moonrise and moonset are obtained by applying the new semi-duration values to the new time of meridian passage.

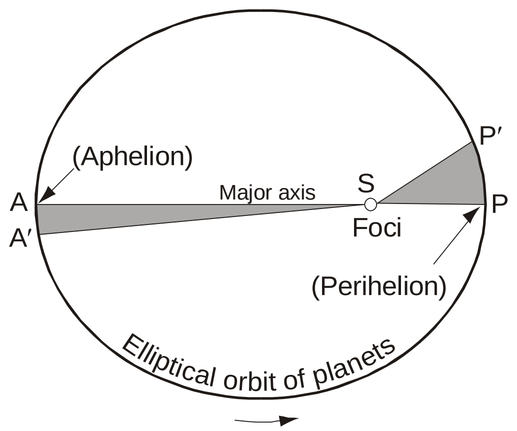
[1] **Celestial Sphere** - The celestial sphere is an imaginary sphere of infinite radius, concentric with the Earth, on which all celestial bodies are imagined to be projected.

[2] **Kepler's Laws** - Kepler defined the following laws of planetary motion:

a. The orbit of each planet is an ellipse, with the Sun at one of the foci.

b. The line joining the planet to the Sun sweeps across equal areas in equal times.

c. The square of the sidereal period of a planet is proportional to the cube of its mean distance from the Sun.



[3] **Moon – Phases**

Crescent Phase - The phase of the moon at which only a small, crescent-shaped portion of the near side of the Moon is illuminated by sunlight. Crescent phase occurs just before and after new moon.
Full Phase - The phase of the moon at which the bright side of the Moon is the face turned toward the Earth.
New Phase - The phase of the moon in which none or almost none of the near side of the Moon is illuminated by sunlight, so the near side appears dark.
Quarter phase - The phase of the moon in which half of the near side of the Moon is illuminated by the Sun.
Waning Crescent - The Moon's crescent phase that occurs just before new moon.
Waxing Crescent - The Moon's crescent phase that occurs just after new moon.

[4] **Air Almanac** - The UK Air Almanac is available as a free PDF download from HM Nautical Almanac Office

[5] **Declination** - The angular distance of a celestial body north or south of the celestial equator. Declination is analogous to latitude in the terrestrial coordinate system.

CHAPTER 11 - TIME

Introduction

1. From the earliest days, time has been measured by observing the recurrence of astronomical phenomena. The Earth's rotation on its axis produces the apparent rotation of the celestial sphere[1], allowing time to be measured from the relative positions of an astronomical reference point and a specific celestial meridian.

2. Nowadays, the fundamental properties of the atom are utilized to provide an independent basis for time measurement. The atomic timescale provides a precise measurement of time intervals, the summation of these time intervals providing an accurate measure of the passage of time. Atomic time is not related to "time of day", but the starting point of any period of atomic time may be specified in terms of an astronomical instant.

THE DAY AND THE YEAR

General

3. The Earth's rotation on its axis, and its revolution around the Sun, result in the natural time intervals of the day and the year.

The Day

4. The day is the duration of one rotation of the Earth on its axis and is the interval between two successive transits of a celestial reference point over a particular meridian.

Apparent Solar Day

5. The visible Sun is known as the apparent or true Sun, and the apparent solar day is the interval between two successive transits of the apparent Sun over a particular meridian. The Earth's variable speed along the ecliptic (Kepler's 2nd Law) causes variations in the length of the apparent solar day.

Mean Solar Day

6. A day of constantly changing length is inconvenient, and therefore the mean solar day of constant length is used, the length being based on the average of all apparent solar days over a period of years. Mean solar time is measured relative to the mean or astronomical mean Sun, a fictitious body assumed to travel around the equinoctial at a constant rate. The mean solar day is divided into 24 hours, each hour of 60 minutes, and each minute of 60 seconds of mean solar time or mean time.

7. The astronomical mean Sun must have a constant angular velocity in the plane of the equinoctial; a constant angular velocity in the plane of the ecliptic is unsatisfactory because the rate of change of hour angle fluctuates due to meridian convergence.

Equation of Time

8. Mean time increases at a constant rate while apparent time increases at a variable rate. The difference between mean and apparent time is known as the Equation of Time (E). E is not an equation in the normal sense, but merely a time difference. E is positive when apparent noon precedes mean noon and negative when apparent noon follows mean noon. By convention, E is the amount which is added algebraically to mean time to obtain apparent time.

THE YEAR

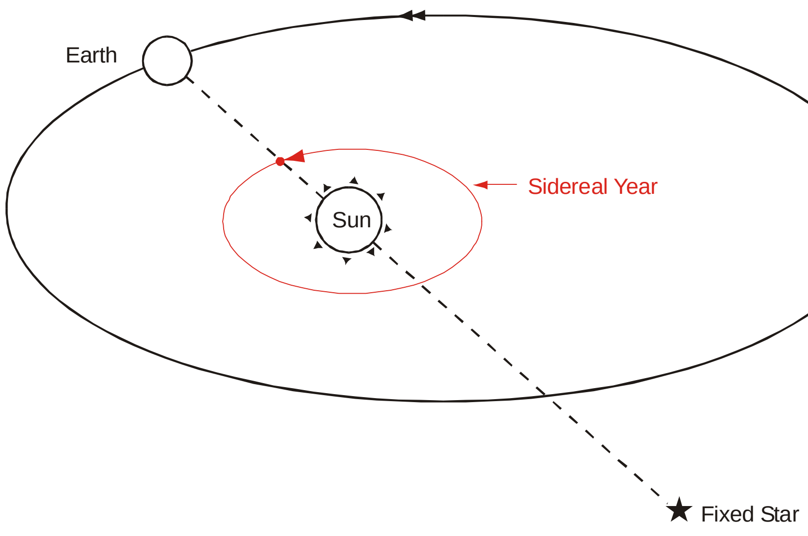
Introduction

9. One year is the period of one revolution of the Earth about the Sun relative to an astronomical reference. The type of year takes its name from the reference used.

Sidereal Year

10. The sidereal year is the period between two successive conjunctions of the Earth, Sun, and a fixed point in space (Fig 1).

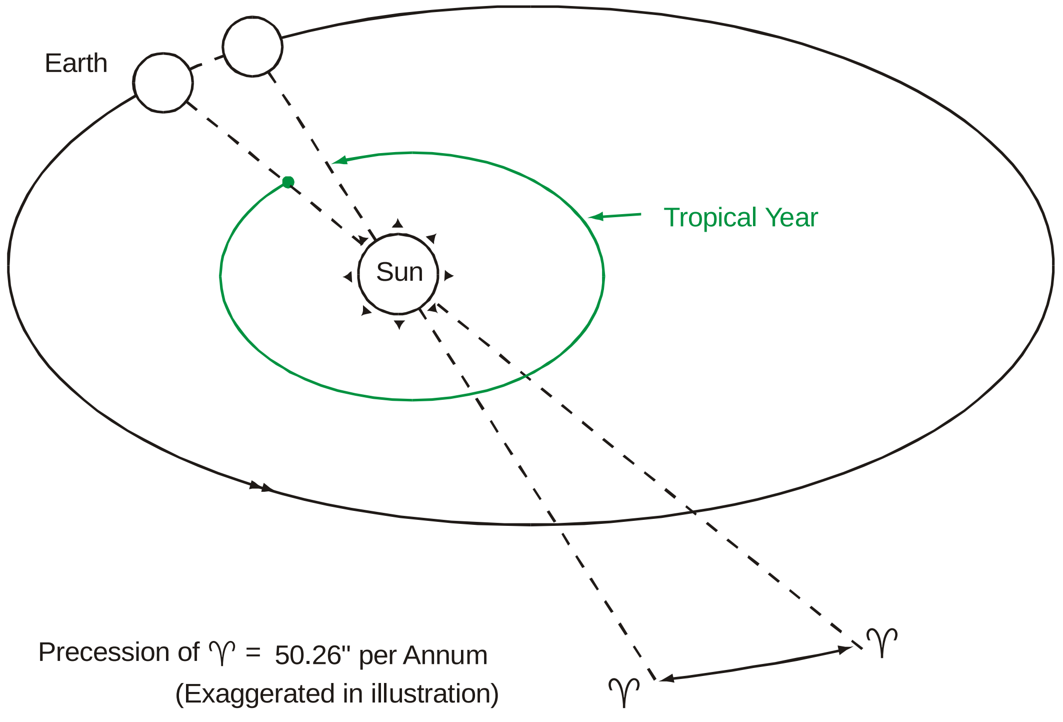
9-11 Fig 1 Sidereal Year



Tropical Year

11. The tropical year (Fig 2) is the period between two successive vernal equinoxes[2], i.e. the time taken for one orbit around the Sun relative to the First Point of Aries (♈)[3]. The tropical year contains one complete cycle of seasons. Its length is 365 days 5 hours 48 minutes 45.98 seconds, which is shorter than the sidereal year because of the westward precession of the equinoxes.

9-11 Fig 2 Tropical Year



Civil Year

12. The civil year is based on the tropical year, but the calendar is adjusted to give each year an exact number of days.

Gregorian Calendar

13. The Gregorian calendar assumes the length of a normal year to be 365 days, with every fourth year being a leap year containing 366 days. After four years, the civil year and the tropical year differ by 45 minutes, ie the calendar and the seasons are out of step by 45 minutes.

4 Civil Years	=	4 × 365 days + 1 day
	=	1,461 days
4 Tropical Years	=	1,460 days 23 hours 15 minutes.

After 400 years, the difference has increased to 3 days 3 hours. To correct for this, nearly every year whose number is a multiple of 100 (i.e. at the turn of each century) is treated as an ordinary year of 365 days, even though it can be divided by 4. Only when the century number (i.e. the first two figures of the year) is divisible by four, is it a leap year. This adjustment loses three days every 400 years and is known as the Gregorian Correction. At the end of 4,000 years the total error will be 1 day 4 hours 55 minutes.

Time and Hour Angle

14. The Earth rotates once in 24 hours relative to the mean Sun. 360° of hour angle is equivalent to 24 hours of mean solar time or mean time. Hour angle is therefore interchangeable with mean time:

360º	≡	24 hours
15º	≡	1 hour
15'	≡	1 minute
15''	≡	1 second.

Local Mean Time

15. Local Mean Time (LMT) is defined as the arc of the equinoctial intercepted between the observer's anti-meridian and the meridian of the mean Sun measured westwards, i.e. the elapsed time since the mean Sun's transit of the observer's celestial anti-meridian:

$$\text{LMT} = \text{local hour angle mean Sun (LHAMS)} \pm 12 \text{ hours.}$$

The anti-meridian is used so that the local date changes during the hours of darkness. The mean Sun crosses an observer's meridian at 1200 LMT, ie local noon.

16. Since LMT depends upon LHAMS, LMT varies with longitude; LMT at one longitude is converted to LMT at another longitude by applying the ch long converted to time. Ch long East, in hours and minutes, is added to LMT at the original longitude to obtain LMT at the desired longitude:

$$\text{LMT}_2 = \text{LMT}_1 \begin{array}{l} +\text{E ch long} \\ -\text{W ch long} \end{array}$$

a. **Example 1**. LMT and local date (LD) are 03.10.00 on 2 August at Longitude 12° W. Find LMT and LD at longitude 33° E.

LMT at 12° W	=	03.10.00 on 2 Aug
Ch long 45° E	≡	+03 (see para 20)
LMT at 33° E	=	06.10.00 on 2 Aug.

Note. The date must be included in all time problems. Where the sum of the original time and ch long exceeds 24 hours, the date is increased by one day. Conversely, where the sum is less, i.e. a negative value, the date is decreased by one day.

b. **Example 2**. LMT and LD are 09.40.00 at longitude 46° E on 2 August. Find LMT and LD in longitude 110° W.

LMT at 46° E	=	09.40.00 on 2 Aug
Ch long 156° W	≡	– 10.24.00
∴ LMT at 110° W	=	– 00.44.00 on 2 Aug
	=	23.16.00 on 1 Aug.

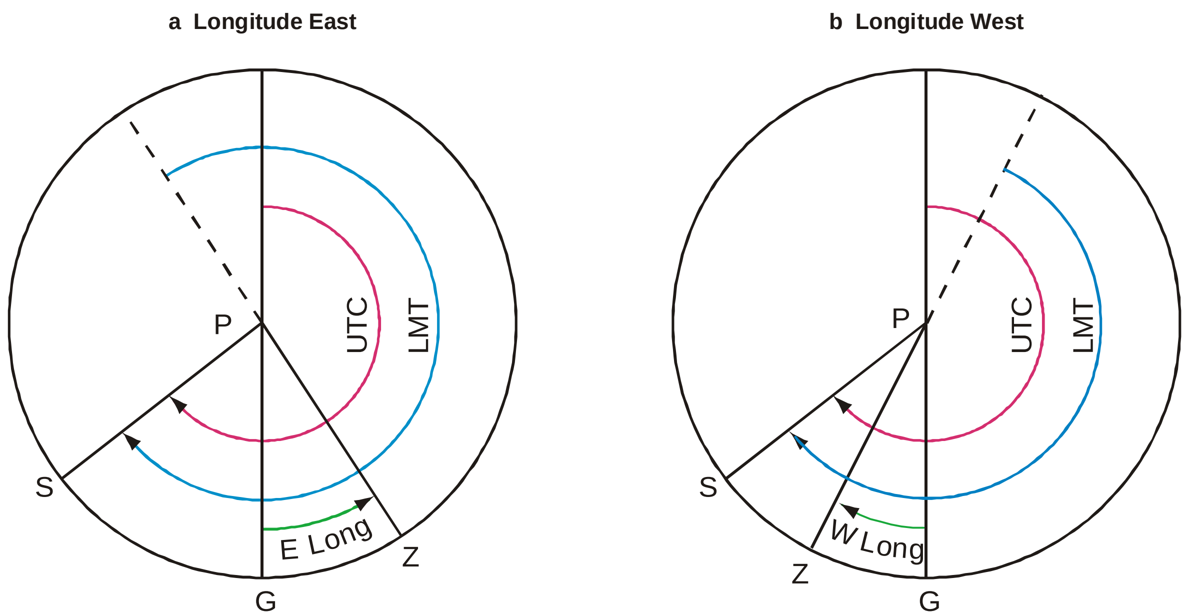
Coordinated Universal Time (UTC)

17. UTC is used as the world standard of reference time. For all practical purposes it can be regarded as LMT at the Greenwich Meridian. UTC can therefore be converted to LMT at any other meridian by applying longitude, converted to time:

$$\text{LMT} = \text{UTC} \begin{array}{l} + \text{ long E} \\ - \text{ long W} \end{array}$$

The relationship between UTC and LMT is illustrated in Figs 3a and 3b. G represents the Greenwich Meridian; Z the observer's meridian and S is the Sun's meridian.

9-11 Fig 3 Relationship Between UTC and LMT



a. **Example 3**. Find LMT at longitude 26° E when UTC is 10.30.00 on 2 August.

UTC	=	10.30.00 on 2 Aug
26° E	≡	+ 01.44.00
LMT	=	12.14.00 on 2 Aug

b. **Example 4**. Find the LMT at longitude 120° E, when UTC is 19.32.00 and Greenwich Date (GD) is 2 August.

UTC	=	19.32.00 on 2 Aug
120° E	≡	+ 08.00.00
LMT	=	27.32.00 on 2 Aug
	=	03.32.00 on 3 Aug

18. UTC and LMT are both unsuitable for regulating time in particular areas; UTC is in step with the phenomena of day and night only at the Greenwich Meridian, and all longitude changes, however small, result in changes in LMT. Zone time and standard time overcome the problems, being approximately in step with night and day, and having the additional advantage that time remains uniform in particular areas.

Zone Time

19. The Earth is divided, purely by longitude, into 25 zones, all of which are 15° of longitude (or 1 hour) wide, except for the two semi-zones adjacent to the International Date Line (approximately 180° E/W - see para 25). The central meridians of the zones are removed from the Greenwich meridian by multiples of 15° and the extremities of the zones are bounded by meridians 7.5° removed from the central meridian. The zones are each allocated an identifying letter as shown in Fig 4.

20. The zone time is the LMT of its central meridian, and therefore zone time differs from UTC by multiples of one hour. Furthermore, zone time is related to sun time ± 30 minutes.

21. The number of hours difference between zone time and UTC can be calculated by dividing the longitude by 15 and approximating the result to the nearest whole number, e.g.:

A ship at 48° W shows a zone time of 1800 hours on 2 August ie 1800 hours P. What is the UTC?

Dividing 48 by 15 gives 3.2, which is 3 to the nearest whole number. Therefore, UTC is 3 hours different from zone time. As the longitude is West the 3 hours must be added to zone time to find UTC. UTC is thus 2100 hours on August 2.

Standard Time

22. Each national authority throughout the world has decreed that a particular LMT shall be kept throughout its country; this time is known as standard time. In those countries with a significant east-west extent, such as the USA and Australia, further subdivision is necessary. Although the standard times, in general, approximate to zone time, the boundaries tend to follow natural features such as rivers or mountain ranges, or national or state borders, and are not tied to specific longitudinal changes.

23. Standard times mostly differ from UTC by whole numbers of hours and the Air Almanac contains three lists showing the differences between UTC and the standard times kept throughout the world. List I shows those places fast on UTC (mainly East of Greenwich), list II those places keeping UTC, and list III those places slow on UTC (West of Greenwich).

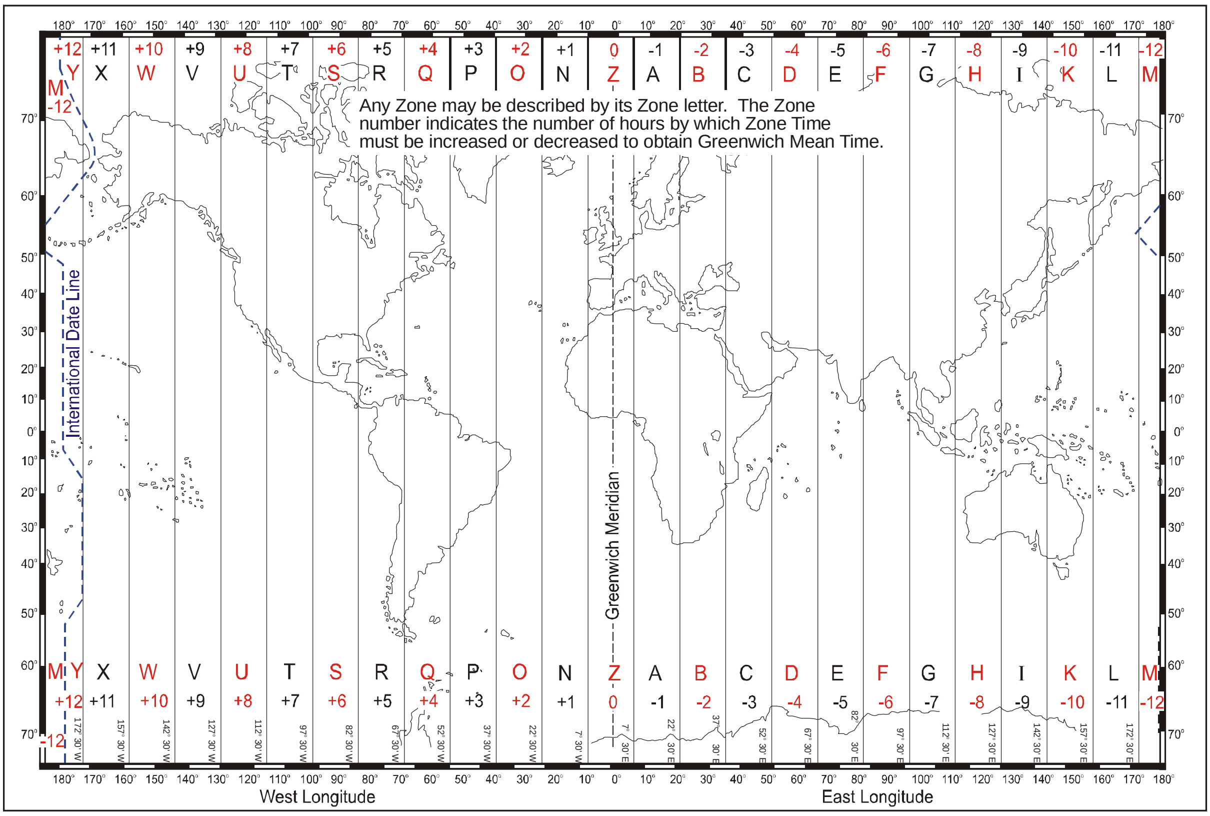
24. Many countries keep summer, or daylight-saving time, which is one hour fast on standard time, for all or part of the year. Such variations are noted in the Air Almanac.

International Date Line

25. The LMT of places east of Greenwich are ahead of UTC, and places west of Greenwich behind UTC, LMT on the Greenwich anti-meridian is therefore either 12 hours ahead or 12 hours behind UTC. There is a 24-hour time difference between neighbouring places separated by the Greenwich anti-meridian, ie local date changes on crossing the Greenwich anti-meridian.

26. The Greenwich anti-meridian is called the International Date Line. This date line deviates from the anti-meridian in places, to avoid date changes occurring in the middle of populated regions. The International Date Line is illustrated in Fig 4. On crossing the date line, one day is added on westerly tracks and subtracted on easterly tracks. Since zone time and standard time are based on Greenwich, there is also a change of one day in zone date and standard date when crossing the International Date Line.

9-11 Fig 4 Time Zones



TIME REFERENCES

Atomic Time

27. The atomic time standard is based on the fundamental properties of the caesium atom and forms the basis of the world standard of time, (UTC). Previously, the LMT at the Greenwich meridian was used as the standard and this is known as Greenwich Mean Time (GMT). Whereas UTC increases at a constant rate, GMT, which is a measure of the Earth's rotation on its axis, increases at a variable rate due to tidal friction and other periodic changes. The variations in GMT are small, varying between – 0.5 seconds and + 2.5 seconds a year, but UTC must be corrected for the variations before it equals GMT.

28. All primary time signals give UTC, and a coded correction is included to enable UTC to be converted to GMT to an accuracy of 0.1 second. By international agreement, UTC is allowed to depart from GMT by 0.7 seconds. When the correction reaches 0.7 seconds, a positive or negative leap second is applied to UTC. For all normal air navigation purposes UTC and GMT can be regarded as identical since the maximum error involved is 0.7 seconds.

Radio Time Signals

29. Numerous national and commercial broadcast stations throughout the world transmit frequent time signals whose accuracy is sufficient for all navigation purposes. Primary and secondary transmission sources are recognized and, whereas all stations transmit UTC, the primary transmissions include the coded correction that can be applied to UTC to obtain GMT accurate to 0.1 second. Some of the more important time signals are included in the Flight Information Handbook together with their transmission frequency and time.

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[1] **Celestial Sphere -** The celestial sphere is an imaginary sphere of infinite radius, concentric with the Earth, on which all celestial bodies are imagined to be projected.

[2] **Vernal Equinox** - The point in the sky where the Sun appears to cross the celestial equator moving from south to north. This happens approximately on March 21.

[3] **Aries - First Point of Aries (♈)** (**vernal** (**spring**) **equinox**) Over the course of a year the Sun, moving along its annual path, crosses the equator from south to north and again from north to south. These crossings occur on or near 21 March and 23 September and are known as the vernal (spring) and autumn equinoxes respectively. The vernal equinox is also known as the First Point of Aries (♈).

CHAPTER 12 – GLOSSARY OF ASTRONOMICAL TERMS

Air Almanac - The UK Air Almanac is available as a free PDF download from HM Nautical Almanac Office

Altitude - The angular distance between the direction to an object and the horizon. Altitude ranges from 0 degrees for an object on the horizon to 90 degrees for an object directly overhead.

Angular Momentum - The momentum of a body associated with its rotation or revolution. For a body in a circular orbit, angular momentum is the product of orbital distance, orbital speed, and mass. When two bodies collide or interact, angular momentum is conserved.

Aphelion - The point in the orbit of a solar system body where it is farthest from the Sun.

Apogee - The apogee is the point in the orbit of the Moon, planet or other artifical satellite farthest from the Earth.

Apparent Brightness - The observed brightness of a celestial body.

Apparent Magnitude - The observed magnitude of a celestial body.

Apparent Solar Day - The amount of time that passes between successive appearances of the Sun on the meridian. The apparent solar day varies in length throughout the year.

Apparent Solar Time - Time kept according to the actual position of the Sun in the sky. Apparent solar noon occurs when the Sun crosses an observer's meridian.

Aries - **First Point of Aries (♈)** (**vernal** (**spring**) **equinox**) Over the course of a year the Sun, moving along its annual path, crosses the equator from south to north and again from north to south. These crossings occur on or near 21 March and 23 September and are known as the vernal (spring) and autumn equinoxes respectively. The vernal equinox is also known as the First Point of Aries (♈).

Ascending Node - The point in the Moon's orbit where it crosses the ecliptic from south to north.

Autumnal Equinox - The point in the sky where the Sun appears to cross the celestial equator moving from north to south. This happens on approximately September 22.

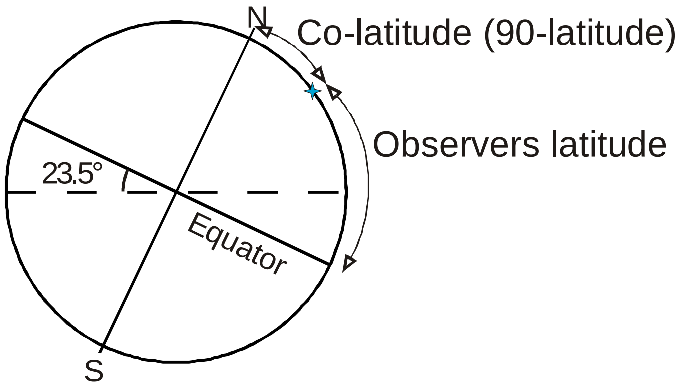
Azimuth - The angular distance between the north point on the horizon eastward around the horizon to the point on the horizon nearest to the direction to a celestial body.

Celestial Equator - The circle where the Earth's equator, if extended outward into space, would intersect the celestial sphere.

Celestial Horizon - The celestial horizon is a great circle on the celestial sphere whose plane lies at 90° to the zenith/nadir axis of an observer and passes through the centre of both the Earth and the celestial sphere.

Celestial Sphere - The celestial sphere is an imaginary sphere of infinite radius, concentric with the Earth, on which all celestial bodies are imagined to be projected.

Co-latitude – Co-latitude is 90º - latitude.



Coriolis Effect - The acceleration which a body experiences when it moves across the surface of a rotating body. The acceleration results in a westward deflection of projectiles and currents of air or water when they move toward the Earth's equator and an eastward deflection when they move away from the equator.

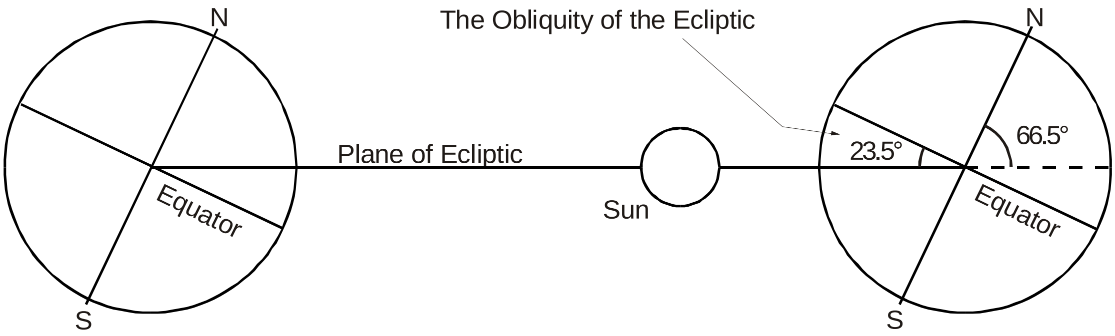
Declination - The angular distance of a celestial body north or south of the celestial equator. Declination is analogous to latitude in the terrestrial coordinate system.

Descending Node - The point in the Moon's orbit where it crosses the ecliptic from north to south.

Diurnal – Daily.

Diurnal Circle - The circular path that a celestial body traces out as it appears to move across the sky during an entire day. Diurnal circles are centered on the north and south celestial poles.

Earth Orbit - The Earth completes one orbit round the Sun in approximately 365.25 days. The orbital plane is called the **ecliptic**. The Earth's N-S axis is inclined at 66.5º to the ecliptic. The plane of the ecliptic makes an angle of 23.5º with the plane of the Earth's equator; this angle is known as the **obliquity of the ecliptic**.



Earth Rotation - The Earth rotates from west to east on its axis as it orbits the Sun. The Sun's apparent daily path over the Earth is along a parallel of latitude, the particular latitude depending on the position of the Sun along its apparent annual path. Since the Earth rotates from west to east, the apparent daily movement of the Sun and all other astronomical bodies is east to west.

Earth Seasons - The tilting of the Earth's axis causes the annual cycle of seasons. The projection of the Sun's apparent annual path on the Earth is a great circle inclined at 23.5º to the equator. About 23 December, the North Pole is inclined directly away from the Sun, which is overhead the 23.5º South parallel. Known as the winter solstice, this is winter in the northern hemisphere and summer in the southern hemisphere.

Eccentricity - A measure of the extent to which an orbit departs from circularity. Eccentricity ranges from 0.0 for a circle to 1.0 for a parabola.

Eclipse - The obscuration of the light from the Sun when the observer enters the Moon's shadow or the Moon when it enters the Earth's shadow. Also, the obscuration of a star when it passes behind its binary companion.

Eclipse Year - The interval of time (346.6 days) from one passage of the Sun through a node of the Moon's orbit to the next passage through the same node.

Ecliptic - The plane of the Earth's orbit about the Sun. As a result of the Earth's motion, the Sun appears to move among the stars, following a path that is also called the ecliptic.

Ellipse - A closed, elongated curve describing the shape of the orbit that one body follows about another.

Equator - The line around the surface of a rotating body that is midway between the rotational poles. The equator divides the body into northern and southern hemispheres.

Equatorial System - A coordinate system, using right ascension and declination as coordinates, used to describe the angular location of bodies in the sky.

Equinoctial - The equinoctial is the primary great circle of the celestial sphere, and is formed by the projection of the Earth's equator onto the celestial sphere.

Gravity - The force of attraction between two bodies generated by their masses.

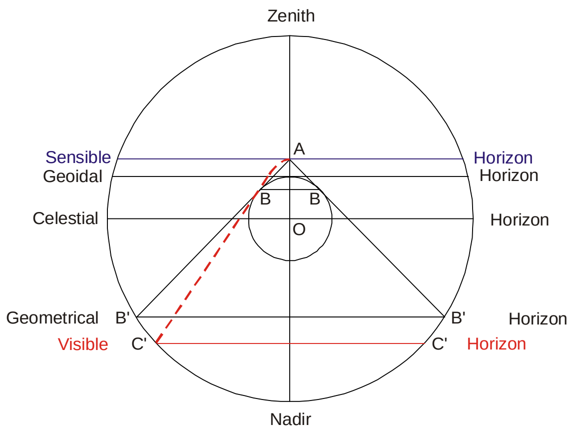
Great Circle - A circle that bisects a sphere. The celestial equator and ecliptic are examples of great circles.

Horizon –

Celestial Horizon - The celestial horizon is a great circle on the celestial sphere whose plane lies at 90° to the zenith/nadir axis of an observer and passes through the centre of both the Earth and the celestial sphere.

Visible or Apparent Horizon - The line at which the Earth and sky appear to meet is called the visible or apparent horizon. Although, on land, this is usually an irregular line, at sea, the visible horizon appears very regular. Its position relative to the celestial sphere depends primarily upon the refractive index of the air and the height of the observer's eye above the surface.

Geoidal/Sensible Horizon - If the plane of the horizon forms a tangent to the Earth it is called the geoidal horizon and if it passes through the eye of the observer (A) it is the sensible horizon.



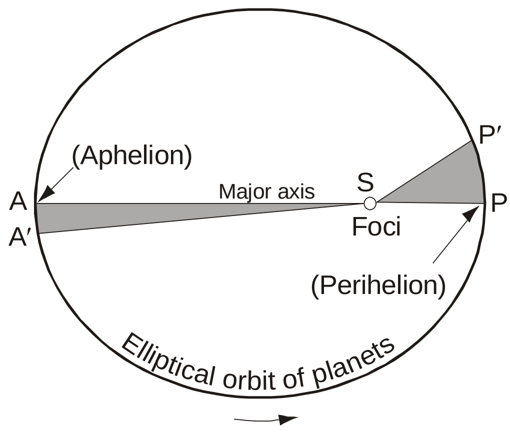
Inclination - The tilt of the rotation axis or orbital plane of a body.

Kepler's Laws - Kepler defined the following laws of planetary motion:

a. The orbit of each planet is an ellipse, with the Sun at one of the foci.

b. The line joining the planet to the Sun sweeps across equal areas in equal times.

c. The square of the sidereal period of a planet is proportional to the cube of its mean distance from the Sun.



Latitude - The angular distance of a point north or south of the equator of a body as measured by a hypothetical observer at the center of a body.

Local Hour Angle - The angle, measured westward around the celestial equator, between the meridian and the point on the equator nearest a particular celestial object.

Longitude - The angular distance around the equator of a body from a zero point to the place on the equator nearest a particular point as measured by a hypothetical observer at the center of a body.

Major Axis - The axis of an ellipse that passes through both foci. The major axis is the longest straight line that can be drawn inside an ellipse.

Mean Solar Time - Time kept according to the average length of the solar day.

Meridian - The great circle passing through an observer's zenith and the north and south celestial poles.

Moon – Phases

Crescent Phase - The phase of the moon at which only a small, crescent-shaped portion of the near side of the Moon is illuminated by sunlight. Crescent phase occurs just before and after new moon.

Full Phase - The phase of the moon at which the bright side of the Moon is the face turned toward the Earth.

New Phase - The phase of the moon in which none or almost none of the near side of the Moon is illuminated by sunlight, so the near side appears dark.

Quarter phase - The phase of the moon in which half of the near side of the Moon is illuminated by the Sun.

Waning Crescent - The Moon's crescent phase that occurs just before new moon.

Waxing Crescent - The Moon's crescent phase that occurs just after new moon.

Minute of Arc - A unit of angular measurement equal to 1/60 of a degree.

Nadir - The nadir is the point on the celestial sphere diametrically opposite the zenith.

Nodes - The points in the orbit of the Moon where the Moon crosses the ecliptic plane.

North Celestial Pole - The point above the Earth's north pole where the Earth's polar axis, if extended outward into space, would intersect the celestial sphere. The diurnal circles of stars in the northern hemisphere are centered on the north celestial pole.

Orbit - The elliptical or circular path followed by a body that is bound to another body by their mutual gravitational attraction.

Perigee - The point in the orbit of the Moon, planet or other artifical satellite nearest to the Earth.

Perihelion - The point in the orbit of a body when it is closest to the Sun.

Period - The time it takes for a regularly repeated process to repeat itself.

Perturbation - A deviation of the orbit of a solar system body from a perfect ellipse due to the gravitational attraction of one of the planets.

Precession - The slow, periodic conical motion of the rotation axis of the Earth or another rotating body.

Prime Meridian - The circle on the Earth's surface that runs from pole to pole through Greenwich, England. The zero point of longitude occurs where the prime meridian intersects the Earth's equator

Right Ascension - Angular distance of a body along the celestial equator from the vernal equinox eastward to the point on the equator nearest the body. Right ascension is analogous to longitude in the terrestrial coordinate system.

Sidereal Day - The length of time (23 hours, 56 minutes, 4.091 seconds) between successive appearances of a star on the meridian.

Sidereal Month - The length of time required for the Moon to return to the same apparent position among the stars.

Sidereal Period - The time it takes for a planet or satellite to complete one full orbit about the Sun or its parent planet.

South Celestial Pole - The point above the Earth’s South Pole where the Earth's polar axis, if extended outward into space, would intersect the celestial sphere. The diurnal circles of stars in the southern hemisphere are centered on the south celestial pole.

Summer Solstice - The point on the ecliptic where the Sun’s declination is most northerly. The time when the Sun is at the summer solstice, around June 21, marks the beginning of summer.

Synodic Month - The length of time (29.53 days) between successive occurrences of the same phase of the Moon.

Synodic Period - The length of time it takes a solar system body to return to the same configuration (opposition to opposition, for example) with respect to the Earth and the Sun.

Tropical Year - The interval of time, equal to 365.242 solar days, between successive appearances of the Sun at the vernal equinox.

Vernal Equinox - The point in the sky where the Sun appears to cross the celestial equator moving from south to north. This happens approximately on March 21.

Winter Solstice - The point on the ecliptic where the Sun has the most southerly declination. The time when the Sun is at the winter solstice, around December 22, marks the beginning of winter.

Year - The length of time required for the Earth to orbit the Sun.

Zenith - The point on the celestial sphere directly above an observer.

CHAPTER 13 - AERONAUTICAL DOCUMENTS

Introduction

1. The aim of this chapter is to summarize those aeronautical documents which have a direct application to the safe conduct of air navigation, and which are available and relevant to the Services as a whole. The chapter does not include any discussion of documents that are promulgated by Commands or lower authorities.

2. Aeronautical information is published in a series of documents and charts known under the generic title of Flight Information Publications (FLIPs). Revised editions of most FLIPs take effect on certain pre-determined dates which accord with those agreed internationally under the Aeronautical Information Regulation and Control (AIRAC) system (see para 10). The information published in FLIPs may be augmented or updated by Supplements to the UK Military Aeronautical Information Publication (UK Mil AIP) (see para 22) and Notices to Airmen (NOTAMs) (see para 12). Classified information is not published in either FLIPs or NOTAMs. FLIPs are available via the No 1 Aeronautical Information Documents Unit (No 1 AIDU) website.

MOD AERONAUTICAL CHARTS

The Ministry of Defence Catalogue of Geographic Products (GSGS 5893)

3. The MOD Catalogue of Geographic Products (GSGS 5893) provides details of the principal series of topographical maps, air charts and digital geographic products that are required by the Army, the Royal Air Force and the Royal Navy. The catalogue is available in electronic format only and is updated regularly.

4. For each series of maps or air charts, a coverage diagram depicts the geographical limits of both the series and of the individual sheets. A portion of a sheet is usually included as an example. Each map or chart series is further described under the following headings:

a. **Type.** This section gives the purpose of the series, e.g. "Topographical (Air), coloured, overprints".

b. **Format.** In addition to naming the map projection used, this section includes other details such as the standard parallels and the scale factor of the chart.

c. **Size**. This section states the physical size of individual charts.

d. **Characteristics.** This section gives details of the aeronautical information represented on the chart, and the base map used.

5. Moving Map Displays for aircraft are listed and detailed (including areas of coverage) within this catalogue.

Chart Amendment Document (CHAD)

6. **Chart Amendment Document**. The Chart Amendment Document (CHAD) is available on line via the AIDU website to inform all MOD flying units and other holders of the GSGS 5893 of:

a. Significant additions and corrections to be considered when using the current edition of published charts within the geographical areas defined in the CHAD.

b. Notices of special interest to MOD aeronautical chart users.

Chart Updating Manual (CHUM)

7. The Chart Updating Manual (CHUM) is available on line via the AIDU website and amends certain US and RAF charts (Low Flying Charts and the FLIP En Route Charts are excluded from the CHAD/CHUM coverage: see paras 8 and 31).

Chart Amendments - Low Flying (CALF)

8. The Chart Amendment–Low Flying (CALF) lists changes in aeronautical information affecting the airspace from ground level to FL195, depicted on Low Flying Overprint Charts. The CALF provides an amendment service for the Low Flying Charts (LFC), Transit Flying Chart (Low Level) (TFC (L)) and M5219-Air series. Incorporated in the CALF is the Low Flying Supplement, containing the operating hours of scheduled airspace within the coverage of the Low Flying Charts. This supplement does not include those areas which are permanently active or activated by NOTAM (see para 12).

THE UNITED KINGDOM AERONAUTICAL INFORMATION SERVICE

General

9. The United Kingdom Aeronautical Information Service (UK AIS) is part of National Air Traffic Services (NATS) Ltd and is located close to London Heathrow Airport. UK AIS is responsible for the collection and dissemination of information necessary for the safety, regularity and efficiency of air navigation throughout UK airspace. Details of UK AIS services and products can be obtained from the AIS website.

The AIRAC System

10. The Aeronautical Information Regulation and Control (AIRAC) system gives a framework for planned changes to aeronautical facilities, procedures and regulations. A series of pre-determined dates (known as AIRAC dates) is published in advance. Changes will normally be planned to take effect on these AIRAC dates. Thus, with reasonable notice (normally 28 days), all operators can be made aware of any forthcoming change and its effective date.

The UK Integrated Aeronautical Information Package

11. The UK AIS produces aeronautical information in several publication formats, under the generic title of 'The UK Integrated Aeronautical Information Package (UKIAIP)'. Details of the UKIAIP can be obtained from the AIS website. The UKIAIP consists of:

a. **The UK Aeronautical Information Publication (UK AIP).** The UK AIP contains information essential to air navigation and operations within UK airspace. The UK AIP can be accessed via the AIS website, www.ais.org.uk.

b. **UK AIP Supplements**. UK AIP Supplements detail temporary changes to the UK AIP, usually of long duration, and contain comprehensive text and/or graphics.

c. **Aeronautical Information Circulars (AICs).** AICs are notices relating to safety, navigation, technical, administrative or legal matters.

d. **NOTAMs.** NOTAMs are notices relating to the condition or change to any facility, service or procedure notified within the UK AIP. NOTAMs are discussed further in para 12.

e. **Pre-flight Information Bulletins (PIBs).** PIBs are summaries of the current status of aeronautical facilities and services and are available on the AIS website. They are produced for pre-selected areas, with almost world-wide coverage, and contain edited versions of selected NOTAMs. PIBs are issued as general bulletins containing route, aerodrome and general information, and also as navigation warning bulletins.

Notices to Airmen (NOTAMs)

12. A NOTAM is a notice, usually distributed by means of telecommunication, containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations. NOTAMs are also available from the AIS website.

13. The existence of a NOTAM advising of an activity within an area does not grant the sponsor sole use of the airspace concerned, but simply advises other airspace users of the activity.

14. A NOTAM will deal with one subject only and is originated by the unit where the change occurs. NOTAMs should be restricted to information of a temporary nature and of short duration but may also be used when operationally significant permanent changes, or temporary changes of long duration, are made at short notice. In the UK, there are two types of NOTAM, Civil and Military, and both are complemented by Aeronautical Information Supplements. NOTAMs are classified by their method of distribution which depends upon the time available for notification.

a. **NOTAM**. NOTAMs (sometimes referred to as NOTAM Class 1) are distributed by telecommunications signal. This method is used for addressees to whom the information is of direct operational significance and who would not have received at least seven days notice if information was sent by post.

b. **Aeronautical Information Supplement.** An Aeronautical Information Supplement (sometimes referred to as NOTAM Class 2) details temporary changes to the information in the AIP and is published by means of special pages sent by post. This is the preferred method of distribution and is used in all cases where a NOTAM Class 1 is not justified.

15. **The NOTAM Code**. Details of the NOTAM Code, its format and use are contained in the UK Mil AIP (see para 22), and in the Flight Information Handbook (FIH) (see para 29).

16. **The UK NOTAM Service**. The UK International NOTAM Office is a combined military and civil organisation within NATS and is part of the UK AIS. AIS Heathrow distributes NOTAMs to military units in accordance with distributions lists laid down by MOD. Low Flying Operations Squadron (Ops LF) based at RAF Wittering issue NOTAMs concerning the UK low flying system.

17. **NOTAM Display Boards**. NOTAMs are displayed in all RAF briefing rooms to facilitate easy reference to NOTAM information.

SNOWTAMs

18. A SNOWTAM is a specific type of NOTAM, used for notifying the presence or removal of hazardous conditions due to snow, slush, ice or standing water on the movement areas of aerodromes. The SNOWTAM proforma is explained in the UK Mil AIP (see para 22), and in the Flight Information Handbook (FIH) (see para 29).

MILITARY AERONAUTICAL INFORMATION SERVICES

No 1 Aeronautical Information Documents Unit (No 1 AIDU)

19. No 1 Aeronautical Information Documents Unit (No 1 AIDU) is responsible for the publication and distribution of all permanent unclassified information concerning any aeronautical facility, service, procedure or hazard, that might be required by UK military personnel directly involved with the operation and safety of aircraft. Most of this information is now provided in both hard copy and digital format. No 1 AIDU has a policy to migrate from the provision of paper-based products to an electronic format where customers will download and print products locally. The AIDU website should be accessed via the links below to obtain the latest information concerning No 1 AIDU products. The AIDU FLIP library is accessible through the link on the AIDU website homepage. A username and password can be obtained by logging on to the AIDU website and selecting MilFLIP, where a request for a new account can be processed. This will allow the user to apply for access and for AIDU to verify the request. Deployed or diverted crews can obtain emergency access via AIDU Customer Services on telephone +44 (0) 8833 8587 or Mil 95233 8587.

20. AIDU FLIP publications may be considered in three groups:

a. Planning Documents and Services.
b. En Route Publications.
c. Terminal Area Documents.

Although produced primarily for the Armed Forces, most of these publications are available for purchase by civilian operators.

Planning Documents and Services

21. **The Integrated Aeronautical Information Package**. Planning information is published in the Integrated Aeronautical Information Package, which comprises:

a. The UK Military Aeronautical Information Publication (UK Mil AIP).
b. The UK Military Low Flying Handbook, in hardcopy and on CD.
c. International Planning Information.

22. **The UK Military Aeronautical Information Publication (UK Mil AIP)*.*** The UK Mil AIP is made up of three parts. Part one contains general information, while part two contains information regarding en route operations. Part three contains aerodrome-specific information. The UK Mil AIP does not reflect the complete contents of the UK AIP. The contents of both publications can be viewed via the AIDU website, and logging into the MilFLIP area in accordance with the instructions in para 19. The UK AIP can also be accessed via the AIS website.

23. **Amendments to the UK Mil AIP**. Amendments to the UK Mil AIP are issued once every four weeks, in the form of replacement sheets, to coincide with the AIRAC dates. The amendment is used to introduce permanent, operationally significant changes into the AIP on the indicated AIRAC date. These are issued in advance but do not become effective until the relevant AIRAC date.

24. **UK Mil AIP Supplements**. UK Mil AIP Supplements contain operational items of a temporary nature only. They are printed on yellow paper and normally issued every 28 days. The period of validity of the information will usually be given in the Supplement itself.

25. **United Kingdom Low Flying Handbook**. This document is published in hardcopy and on CD. It provides a guide to the UK low flying regulations and the Low Flying System.

a. **Section 1 The UK Low Flying System**. Section 1 contains a description of the UK Low Flying System with associated regulations and restrictions and details of the notification and booking requirements. The High Intensity Radio Transmission Area (HIRTA) scheme is explained in this section.

b. **Section 2 The Low Flying Areas (LFAs).** Section 2 describes in detail each LFA, its geographical co-ordinates, protected locations, details of other aerial activity, obstructions, HIRTAs and special procedures.

c. **Section 3 The UK Night Low Flying System**. Section 3 contains the structure, regulations and procedures for night low flying.

d. **Section 4 Helicopter Training Areas**. (Currently unused.)

e. **Section 5 Terrain Following Radar (TFR) Training**. Section 5 contains the regulations and procedures for operations within the Highlands Restricted Area (EGR 610 A-D), for both TFR and non-TFR traffic.

f. **Section 6 Thames Valley Avoidance Area (TVAA).** Section 6 specifies the geographical co-ordinates of the TVAA and contains information relevant to operations within it, including obstructions and HIRTAs.

g. **Section 7 Pipeline Inspection Notification System (PINS).** Section 7 contains height deconfliction, warnings and general information concerning pipeline inspections by civil helicopters.

h. **Section 8 Miscellaneous**. Section 8 contains details of bird concentrations, helicopter routes and permanent prohibited and restricted areas.

26. **International Planning Information**. The International Planning Document that contained information on foreign airspace structure and national air traffic procedures is no longer available in print. This document has been replaced by a Library/Enquiry Service operated by the Aeronautical Information Bureau of No 1 AIDU. Enquiries can be made via telephone on DFTS 95233 8713 or civil 020 8833 8713. Some foreign AIPs are available via the AIDU website.

En Route Publications

27. No 1 AIDU produces aeronautical information for use by aircrew in flight, in a series of conveniently sized publications. The coverage of RAF en route FLIPs is from the Eastern seaboard of the USA, through Europe, Africa, the Middle East and Southern Asia. British military users operating outside this area of coverage should use the appropriate FLIPs produced by the US Department of Defense, Canadian Forces or Royal Australian Air Force.

28. **The En Route Supplement (ERS).** The ERS is produced in four volumes, based on specified geographical areas (British Isles and North Atlantic (BINA), Northern Europe (NOREU), Southern Europe and Mediterranean (EUMED), South Atlantic, Africa, Asia and Far East (SAAAFE)). Each ERS contains comprehensive details of aeronautical information and facilities within its specific area, including:

a. All active British military aerodromes, regardless of size.

b. Selected civil and other military aerodromes with a hard surface runway length of at least 5,000 ft, and some communications facilities.

c. Other aerodromes at the discretion of No 1 AIDU.

d. Relevant communications and navigational facilities.

29. **The Flight Information Handbook (FIH).** The FIH is designed to provide a digest of information useful to aircrew during flight planning, and when airborne. It includes en route procedures, general planning information, emergency and safety procedures, codes and conversion tables.

30. **The Radio Communication Failure Booklet**. This document was withdrawn with effect from March 2009. Procedures to be followed are now contained within ERSs.

31. **En Route Charts (ERCs).** ERCs provide details of ATS routes, designated airspace, airspace reservations, radio navigation facilities and en route communications. Due to chart congestion, sufficient information is given for transit flight only. ERCs should, therefore, always be used in conjunction with ERS, Planning Documents and Terminal Publications. ERCs are drawn to plotting chart standards, based on the Oblique Mercator projection or the Lamberts Conformal projection. The latitude and longitude graticule on ERCs is based on WGS 84. Topographical data, other than major water features, is not shown. However, the Maximum Elevation Figure (MEF) is printed for each one-degree quadrangle, where scale permits, for en route safety. The chart coverage diagrams in UK Mil AIP gives existing coverage. The following types of ERC are published:

a. **Low Altitude**. These charts portray aeronautical information within the vertical limits of each Flight Information Region (FIR), as stated on the chart panel.

b. **High Altitude**. Aeronautical information is shown only for the Upper Airspace. Where no Upper Flight Information Region (UIR) is defined, the lower limit of aeronautical information shown on the chart is FL 245. The true vertical limit of each FIR and UIR is shown on the chart panel.

c. **High/Low Altitude (H/L).** These charts show aeronautical information for combined upper and lower airspace.

d. **Area Navigation (Rnav).** Area navigation information is shown on charts which cover routes in the European area.

32. **En Route Chart Legend.** The ERC Legend is an A4 size card, that provides a decode for the symbols and abbreviations used on the ERCs.

Terminal Area Documents

33. **Terminal Charts**. The term 'Terminal Chart' (TC) covers the range of Standard Instrument Arrival and Departure Charts, Terminal Approach Procedure Charts, and Aerodrome Charts. TCs are provided in two different specifications (see para 34), and are available in the following formats:

a. **Loose-leaf Format**. All TCs are available in loose-leaf format. The full list of current TCs is published in the Terminal Charts Specification and Legend.

b. **Fast-jet Terminal Chart Booklets**. Two volumes of selected TCs are designed principally for use by fast-jet aircrew. They contain ILS and TACAN approaches for each instrument runway, plus an Aerodrome Chart. Special Procedures, Arrival and Departure charts are included where relevant.

c. **Aerodrome Booklets**. These booklets contain TCs for individual aerodromes, or a clutch of aerodromes within a geographical area, and are based on operational requirements.

d. **Terminal Charts UK North & South**. These booklets are updated eight-weekly and contain full TCs for UK military airfields and extensive coverage of civil airfields.

34. **Terminal Chart Specifications**. The majority of TCs made available through No 1 AIDU are produced by them, but some are purchased from the European Aeronautical Group (EAG) to cover gaps in the AIDU catalogue.

a. No 1 AIDU produce TCs known as No1 AIDU (RAF) New Specification charts. These charts use International Civil Aviation Organisation (ICAO) and UK AIP symbols and abbreviations. Exceptionally, abbreviations unique to AIDU are used. The symbols and abbreviations used on No1 AIDU (RAF) New Specification TCs can be found in the No1 AIDU Terminal Charts, Specification and Legend book. Some of the TCs listed in the Terminal Charts Catalogue (TCC) (see para 37b) are the editorial responsibility of the EAG. AIDU is responsible for all military airfields and EAG, in general, for major international airfields.

b. The EAG produce TCs known as NAVTECH EAG charts. Symbols and abbreviations used on NAVTECH EAG TCs can be found in the NAVTECH Aerodromes Charts Specification and Legend book.

35. **Minor Aerodromes UK.** The Minor Aerodromes UK booklet contains information for selected aerodromes (Military, government and civil) in the UK that either do not have a published instrument let-down procedure, or do not meet the minimum criteria for inclusion in other FLIPs.

36. **Helicopter Landing Sites (HLS).** Three HLS booklets are published, each containing detailed graphics and associated information for selected sites. These booklets are titled:

a. Helicopter Landing Sites UK.
b. Helicopter Landing Sites Hospitals UK.
c. Helicopter Landing Sites and Visual Approach/Departure Charts - Europe.

No 1 AIDU Amendment Services

37. FLIPs are amended by routine reprinting, and by an assortment of amendment bulletins, which form an integral part of all FLIPs. These amendments are produced and distributed in hard copy, and are

also available via the AIDU website. The aeronautical information in FLIPs is also augmented and updated by NOTAM. The following amendment documents are issued:

a. **FLIP En route Bulletin**. The En route Bulletin is issued monthly on AIRAC dates and updates all FLIPs (except TCs) to the date of that bulletin. It also provides advance information of impending changes. Each issue replaces the previous edition.

b. **Terminal Charts Catalogue (TCC).** The TCC is published monthly on AIRAC dates, and lists charts covering UK military, selected UK civil, European and other operational airfields. Charts other than those listed are available electronically.

c. **Terminal Charts Amendment Bulletin (TCAB).** The TCAB is published monthly on AIRAC dates. It updates those charts produced by No1 AIDU. Unlisted charts are deemed to be withdrawn. Each issue of the TCAB replaces the previous edition.

d. **Terminal Documents Amendment Supplement (TDAS).** The TDAS is published monthly on AIRAC dates. It supplements the Emergency and Unplanned Diversion Books (Vols 1-2), TC UK N & S and Fast-jet N & S. Only significant changes are published.

38. **Accuracy of FLIP Information**. All users of documents produced by No 1 AIDU, on finding an error or omission, have a responsibility for notifying No 1 AIDU without delay via AIDU Customer Services on telephone +44 (0) 8833 8587 or Mil 95233 8587.

39. **Accuracy of Aeronautical Charts**. Where errors are identified in aeronautical information on topographical charts (eg boundaries of controlled airspace) then, again, No 1 AIDU is to be informed. However, in the event that the error concerns the geographical base map (e.g. mapping details, including obstructions), then the point of contact is the Geo Support department at the Defence Geographic Centre, Feltham via +44 208 818 2726 or Mil (9)4641 4726.

CHAPTER 14 - NAVIGATION PLANNING

Introduction

1. The navigation planning requirements for any flight will depend largely on the nature of the task, the area of operation and any procedures or orders relevant to a particular aircraft type or role. Many tasks will be of a 'standard' nature, e.g. regular air transport routes, and, in such cases, maximum use can be made of Standard Operating Procedures (SOPs), computerized planning facilities and statistical meteorological data. Alternatively, the mission may be of an operational or emergency nature and the normal flight planning procedures may have to be amended or circumvented in the interests of expediency; much reliance will be placed on the use of SOPs and on the experience of the crew. It would be inappropriate to attempt to cover all of the specialist procedures in use; rather this chapter will review the basic navigation planning requirements for a straightforward flight at medium or high level. Fuel planning, which is an integral part of flight planning, will be covered in Volume 9, Chapter 15.

2. In order to highlight the principle ingredients of navigation planning, by way of example, this chapter will investigate the planning requirements and procedures for a straightforward flight from St Mawgan to Valley.

Pre-planning Considerations

3. Before any actual planning can take place a number of factors must be considered which will help to determine the route and techniques to be used. Among these factors are:

a. The task.
b. The fuel requirements or limitations.
c. Aircraft performance.
d. The geography of the area to be overflown.
e. The meteorological forecast for the route or area.
f. The availability and serviceability of navigation aids.
g. Air traffic control restrictions, danger areas and prohibited airspace.
h. Any special procedures that must be obeyed.
i. Availability of diversion airfields.

4. **The Task**. In this example, the task is straightforward; to navigate the aircraft safely between St Mawgan and Valley, in accordance with normal operating and air traffic procedures. It should be borne in mind, however, that frequently the task is more complex, eg there may be intermediate stops, specific times to make good at reporting points, air-to-air refuelling to be accomplished. The only restriction in this example is that the flight is to take place at cruising levels around FL 200.

5. **Fuel**. In this case, the flight is well within the capability of the aircraft with regards to fuel consumption. The detail of fuel planning is covered in Volume 9, Chapter 15.

6. **Aircraft Performance**. In this case, the aircraft has no performance limitations with respect to the cruising level, or with the runway lengths at either airfield. It should be noted that this is not always the case,

for example, at some All-up Weights (AUWs) it may not be possible to climb to the desired level, and there may be prohibitive restrictions on runway length. On a short route, such as in this example, a major consideration is that, if the aircraft is fully fuelled at take-off, it may arrive at the destination, at an AUW which is too heavy for landing.

7. **Geography**. There are no particular geographical factors pertaining to this flight, except that it should be noted that the northern end of the route is over mountainous terrain and particular care must be taken when calculating safety altitude and when monitoring the descent.

8. **Meteorology**. The following meteorological data will be assumed:

a. **Cloud**. A general cloud base of 2,500 ft over the whole area, multi-layered up to tops at 15,000 ft.

b. **Wind**. The following wind structure applies to the whole route including departure and arrival airfields:

Surface	310°/15 kt
2,000 ft	315°/22 kt
5,000 ft	325°/30 kt
10,000 ft	330°/35 kt
20,000 ft	340°/45 kt
25,000 ft	350°/55 kt

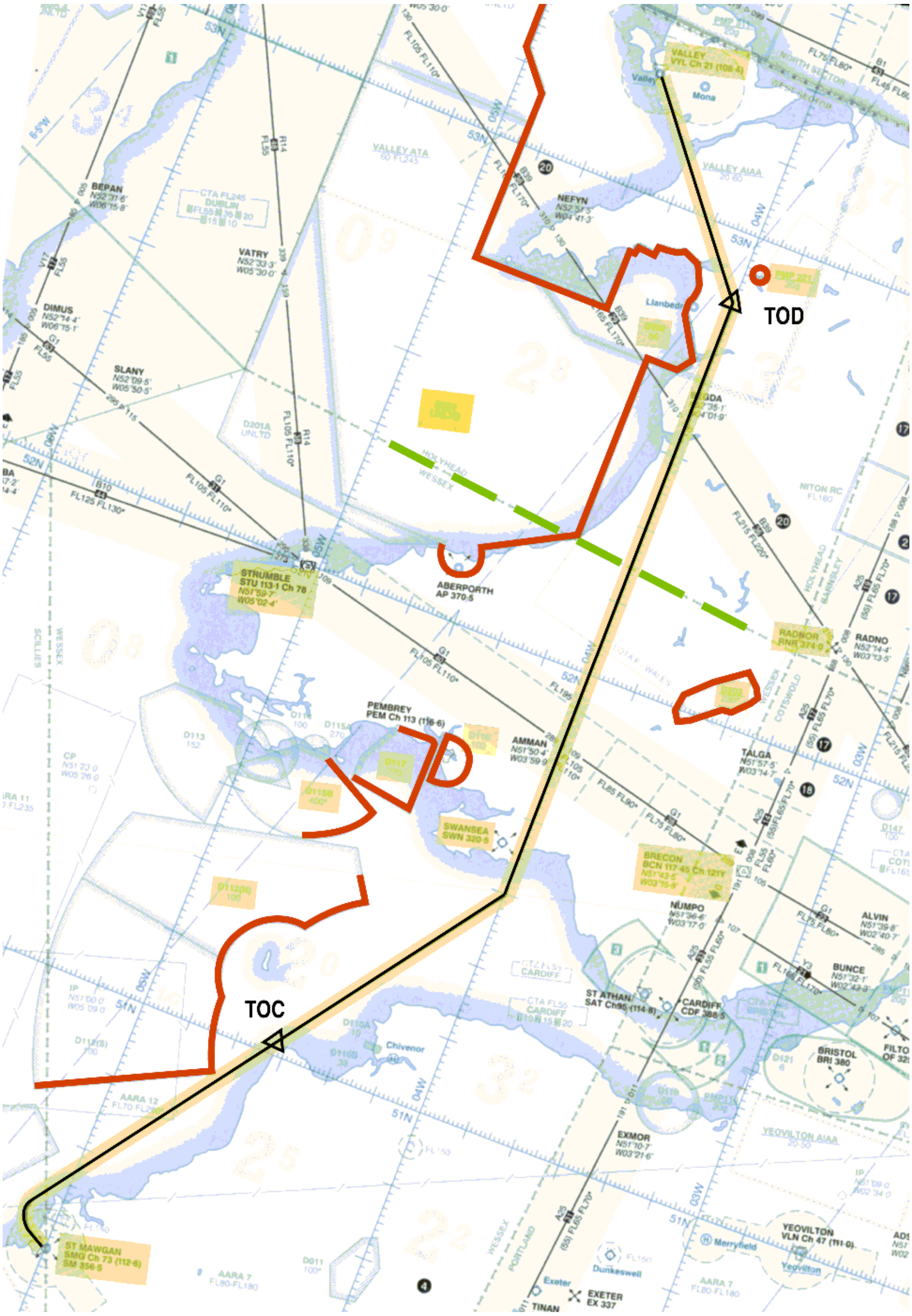
c. **Temperature**. The temperature is ISA +4.

d. **Weather**. There is no significant weather either en route or at either airfield.

9. **Navigation Aids**. It will be assumed that the aircraft is fitted with serviceable TACAN, VOR, ADF. All of the appropriate ground beacons are also serviceable.

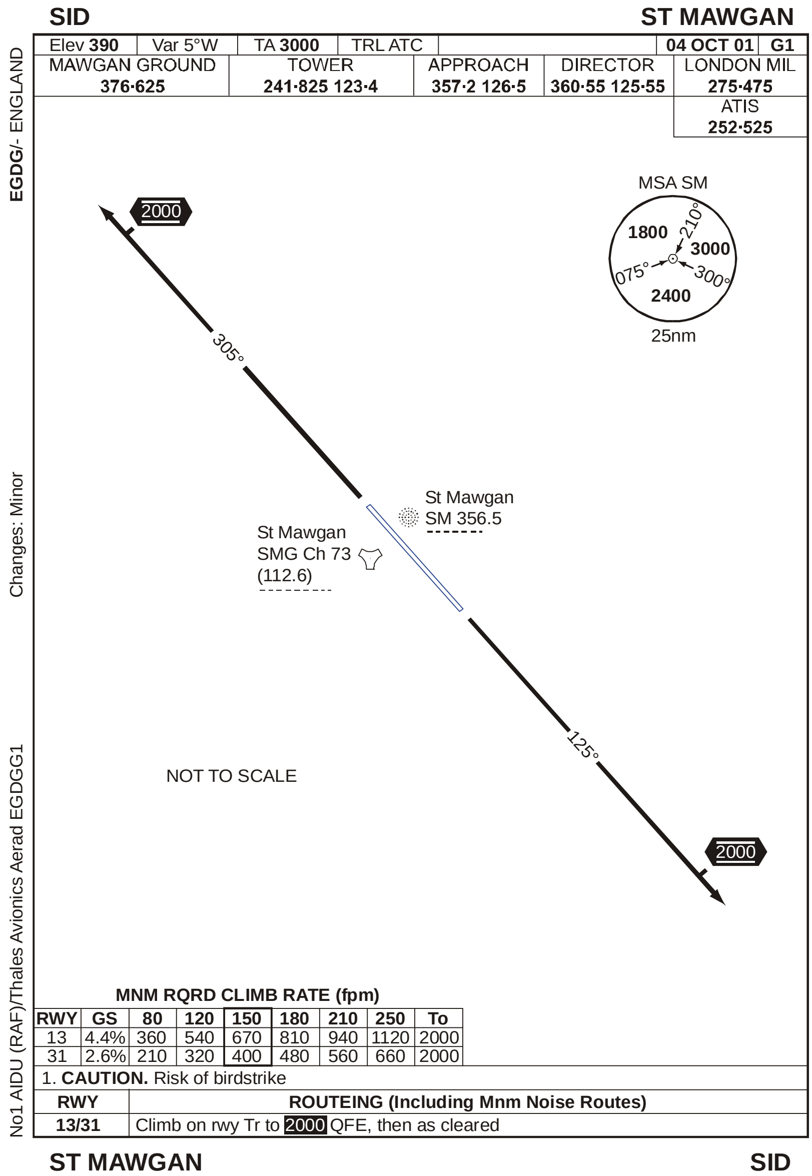
10. **Restricted Airspace**. A study of the en route chart (Fig 1) reveals that there are a number of Danger Areas to be avoided, and some Airways to cross (for which clearance or control will be necessary).

9-14 Fig 1 En Route Chart for Route - St Mawgan to Valley (example only)



11. **Special Procedures***.* Fig 2 shows the SID for St Mawgan, and it will be apparent that it involves no more than a climb on runway heading to 2,000 ft (QFE) before setting heading as required. The intention at Valley is to descend to the overhead at 1,000 ft, to join the visual circuit. These are simple procedures; however, particularly at major civilian airfields, the procedures are likely to be far more complex and will often influence the selection of the route to include specific reporting points. SIDs, STARs, the ERS, and the Planning Document will need to be consulted at the planning stage.

9-14 Fig 2 St Mawgan Standard Instrument Departure (example only)



12. **Diversion Airfields**. There are no significant problems with availability of diversion airfields in this example. Cardiff and Shawbury are not far from the route should it be necessary to divert en route; Mona, Ronaldsway, Liverpool, Woodvale and Warton would make suitable diversion airfields should it be impossible to land at Valley. When selecting diversion airfields, it is important to consider their suitability with regards to runway length, navigation and landing aids, weather (including any cross-wind limitations) and necessary services, e.g. availability of appropriate fuels and oils. The fuel planning implications of diversion will be reviewed in Volume 9, Chapter 15.

Route Determination and Chart Preparation

13. For the example exercise, the En Route Low Altitude and Area Navigation (R-NAV) charts are appropriate. It would be prudent to carry High Altitude charts in case it is necessary for weather or air traffic reasons to fly in the upper airspace or cross R-NAV(H) routes. Also a topographical chart should be carried, and in any case will need to be consulted in order to ascertain safety altitudes.

14. **Route**. For convenience, the runway heading at St Mawgan will be maintained until the edge of the MATZ before turning onto the desired track. The principle constraint on the choice of the route is the need to avoid the numerous Danger Areas in the Bristol Channel and Cardigan Bay. With this in mind, turning points have been selected at 5130N 00400W and at 5250N 00400W, before making for the Valley overhead (Fig 1). If required, the turning points may be lettered or numbered to aid identification.

15. **Chart Preparation**. Having drawn the route on the chart, other points of interest can be added or highlighted, e.g. isogonals, ASR boundaries, suitable navigation beacons and Danger Area boundaries. NOTAMs should be checked to ensure that no activity is likely to affect the flight and, if necessary, the route may have to be amended. It may be convenient to draw range arcs, centred on Valley, to make navigation in the terminal phase easier. Once the top of descent point has been determined, further range arcs back along track from this point, and from intermediate turning points, may be constructed if desired. Care must be taken to ensure that working areas of the chart do not become over-cluttered.

Completing the Navigation Flight Plan

16. Fig 3 shows a typical flight plan form. Different operators will use variations of this form to cater for their particular requirements. The top part of the form is self-explanatory and needs no further comment here. The bottom part acts as a reminder of various fuel requirements. This chapter will be concerned with the main body of the form and its completion.

9-14 Fig 3 Flight Plan Form

A/C	C/S	DATE	PILOT	NAV	SCREEN

DIVERSION	1	TR ( )	DIST NM	FL

TR (T)	W/V	HDG (T)	VAR	HDG (M)	DR	WP	ROUTE TO	SALT	RAS MACH	*FL* *ALT*	OAT	TAS	G/S	LEG DIST	LEG TIME	ET	ETA	START	FUEL FLOW	FUEL USED	FUEL 8000	FUEL MIN
035	*330/35*	*028*	*6W*	*034*	*7S*		*TOC*	*3000*		*210*		*267*	*250*	*46*	*11*	*11*						
														80								
035	*340/45*	*028*	*6W*	*034*	*7S*		*5130N 0400W*	*4000*	*210*	*210*	*-23*	*290*	*262*	*34*	*8*	*19*						
359	*340/45*	*356*	*6W*	*002*	*3S*		*5250N 0400W/TOD*	*5600*	*210*	*210*	*-23*	*290*	*249*	*80*	*19*	*38*						
319	*330/35*	*320*	*6W*	*326*	*1P*		*VALLEY*	*5600*		*1000*		*282*	*250*	*32*	*8*	*46*						

MIN THRESHOLD	800
INST APP AT DIVERSION	400
OVERSHOOT AND CLIMB AT DESTN	100
TRANSIT FUEL (W/C + ICING)	
FUEL ON THE GROUND	

FUEL FOR APPROACHES	
VISUAL APPROACH	100
INSTRUMENT APPROACH	200
FULL INSTRUMENT PATTERN AND APPROACH	400

Notes: 1. Max x-wind component - 25 kt. 2. Max surface W/V limit - 40 kt

RW.....................................ROLL.......................................
MIN FUEL..........................COMBAT..................................

RW.....................................ROLL.......................................
MIN FUEL..........................COMBAT..................................

17. The first stage is to enter the names or positions of the waypoints in the column marked "Route To". The first point will be 'Top of Climb' (TOC), and the penultimate point 'Top of Descent' (TOD), although these

points have not yet been determined. Tracks and distances are measured and entered in the appropriate columns. The first and last leg distance will be divided once the climb and descent planning has been completed. In this example, the initial part of the climb from take-off to five miles has been ignored for the purpose of calculating headings, although it will of course be included in the total distance and in the time and fuel calculations.

18. **Climb Planning**. Fig 4 shows the appropriate page from the Operating Data Manual (ODM) for the climb portion of the flight. Care must be taken to ensure that the page is correct with respect to the climb profile (if the aircraft can undertake a variety of climb profiles), and to the temperature profile (ISA +4 in this case). The layout of the ODM will vary between aircraft, but the example is fairly typical. The first task is to decide the level to which it is intended to climb. The route brief has specified Flight Levels around FL200 and in this situation FL210 is selected. By finding this level in the left-hand column and reading across to the appropriate take-off weight (21,000 lb in this example) it will be seen that the mean TAS for the climb is 267 kt and the time for the climb is 11 minutes. This data can be inserted in the appropriate columns on the first line of the flight plan. In practice, the fuel used in the climb can also be extracted at this stage and recorded in the flight plan, but fuel planning is covered in Volume 9, Chapter 15.

9-14 Fig 4 ODM Climb Table

NORMAL CLIMB

(ISA + 3°C to ISA + 7°C)

PRESS HEIGHT ft X 1000	ISA TEMP °C	MEAN T A S kt	TAKE-OFF WEIGHT (lb X 1000) 21		20		19		18		17		16		15		14		ISA TEMP °C	PRESS HEIGHT ft X 1000
			FUEL LB	TIME MIN	FUEL LB	TIME MIN	FUEL LB	TIME MIN	FUEL LB	TIME MIN	FUEL LB	TIME MIN	FUEL LB	TIME MIN	FUEL LB	TIME MIN	FUEL LB	TIME MIN		
42	-57	318							1745	36	1525	30	1375	26	1245	23	1130	20	-57	42
41	-57	314							1585	30	1420	26	1295	23	1180	21	1080	19	-57	41
25	-35	281	1060	13	1005	13	945	12	890	11	835	10	785	10	740	9	690	9	-35	25
24	-33	278	1020	13	955	12	905	11	850	10	805	10	755	9	710	9	665	8	-33	24
23	-31	274	980	12	920	11	870	10	820	10	775	9	725	9	685	8	640	8	-31	23
22	-29	271	940	11	880	11	835	10	785	9	745	9	695	8	660	8	615	7	-29	22
21	-27	267	900	11	845	10	800	9	755	9	715	8	670	8	635	7	595	7	-27	21
20	-25	264	860	10	805	9	770	9	720	8	685	8	645	7	610	7	570	7	-25	20
19	-23	260	820	9	775	9	740	8	695	8	660	7	620	7	590	7	550	6	-23	19
18	-21	257	785	9	740	8	705	8	670	8	630	7	595	7	565	6	530	6	-21	18
17	-19	254	745	8	705	8	675	7	640	7	605	7	575	6	540	6	510	6	-19	17
16	-17	251	710	8	670	7	640	7	610	7	580	6	545	6	520	6	485	5	-17	16
15	-15	247	670	7	635	7	610	7	575	6	550	6	520	6	495	5	465	5	-15	15
14	-13	244	635	7	605	7	580	6	550	6	525	6	495	5	470	5	445	5	-13	14
13	-11	240	600	6	570	6	550	6	520	6	500	5	470	5	450	5	425	5	-11	13
12	-9	237	565	6	540	6	520	5	490	5	470	5	450	5	425	4	405	4	-9	12
11	-7	233	530	6	510	5	490	5	465	5	445	5	425	4	405	4	385	4	-7	11
10	-5	229	495	5	480	5	460	5	440	5	420	4	400	4	380	4	365	4	-5	10
9	-3	224	465	5	445	5	430	4	410	4	395	4	380	4	360	4	345	4	-3	9
8	-1	219	430	4	415	4	400	4	380	4	370	4	355	4	335	3	325	3	-1	8
7	+1	213	400	4	385	4	370	4	355	4	345	3	330	3	315	3	300	3	+1	7
6	+3	207	365	4	350	4	340	3	330	3	320	3	305	3	295	3	285	3	+3	6
5	+5	200	335	3	352	3	310	3	305	3	295	3	285	3	275	3	265	3	+5	5
4	+7	187	290	3	280	3	270	3	265	3	255	3	250	2	245	2	235	2	+7	4
3	+9	175	245	2	240	2	235	2	230	2	220	2	215	2	210	2	205	2	+9	3
2	+11	163	200	2	195	2	195	2	190	2	190	2	185	2	185	2	180	2	+11	2
1	+13	151	150	2	150	2	150	2	150	2	150	2	150	2	150	2	150	2	+13	1

Time to height at intermediate rating (min.)	*Increase in time to height at max. cont. power (min.)*	*Increase in fuel to height at max. cont. power (lb.)*
4	1	35
6	2	60
8	3	95
10	4	135
12	5	180
14	6	230
16	7	295

19. The next stage is to determine the wind velocity for the climb, and then to use the DR Computer to calculate the heading, groundspeed and distance to the TOC and enter the results on the form. It will be assumed that the aircraft climbs at a steady rate to FL 210, and as the meteorological forecast shows that the wind varies uniformly with height, the mid-height wind can be used; in this case the 10,000 ft wind, 330°/35 kt, will be satisfactory. The TOC position can now be plotted on the chart.

20. **Descent Planning**. The descent is planned in a similar manner to the climb using the appropriate page from the ODM (Fig 5) and the correct descent profile (Normal Descent in this example). Mean TAS, fuel used, and time taken are extracted from the table, allowing the heading, groundspeed, and distance to be calculated, again using mid-height wind (330°/35 kt at 10,000 ft). The TOD can now be plotted on the chart. In this example, the calculated TOD point is within a mile of the last planned turning point and therefore it is reasonable to make them coincident.

9-14 Fig 5 ODM Descent Tables

	Normal Descent (0.66M_{IND}/234kt I A S) (85%N_{MAX} to 30000 FT. Then Flight Idling)		
Pressure Height ft X 1000	*Fuel lb*	*Time Min*	*Mean T A S kt*
42	390	20	341
41	375	19	338
40	360	18	335
39	340	18	331
38	325	17	328
37	310	16	325
36	290	15	322
35	270	15	319
34	250	14	315
33	235	13	312
32	215	13	309
31	200	12	306
30	185	11	303
29	180	11	300
28	175	10	297
27	170	10	295
26	165	10	293
25	160	9	290
24	155	9	288
23	150	9	286
22	145	8	284
21	140	8	282
20	135	8	280
19	130	7	278
18	125	7	276
17	120	6	274
16	110	6	272
15	105	6	270
14	100	5	268
13	95	5	266
12	90	5	264
11	80	4	262
10	75	4	260
9	70	3	258
8	65	3	256
7	55	3	254
6	50	2	252
5	40	2	250
4	30	1	248
3	20	1	246
2	10	0	244
1	0	0	242

	Fast Descent (0.715M_{IND}/279kt I A S) (Air Brakes Open, Flight Idling Throughout)		
Pressure Height ft X 1000	*Fuel lb*	*Time Min*	*Mean T A S kt*
42	80	5	377
41	80	5	375
40	75	5	375
39	75	5	371
38	75	5	369
37	70	4	367
36	70	4	365
35	70	4	363
34	65	4	360
33	65	4	358
32	65	4	356
31	60	4	354
30	60	4	351
29	60	4	349
28	60	4	347
27	55	3	345
26	55	3	342
25	55	3	340
24	50	3	338
23	50	3	335
22	50	3	333
21	45	3	331
20	45	3	329
19	45	3	326
18	40	3	324
17	40	2	322
16	40	2	320
15	35	2	317
14	35	2	315
13	35	2	313
12	30	2	311
11	30	2	309
10	25	2	306
9	25	1	304
8	20	1	302
7	20	1	300
6	15	1	298
5	15	1	296
4	10	1	294
3	5	0	291
2	5	0	289
1	0	0	287

FOR DESCENT BETWEEN TWO INTERMEDIATE HEIGHTS THE MEAN TAS IS OBTAINED BY ADDING THE MEAN TAS AT EACH HEIGHT AND SUBTRACTING THE FOLLOWING:

NORMAL DESCENT 240 KNOTS

FAST DESCENT 290 KNOTS

21. **Cruise Planning**. Having determined the TOC and TOD positions, the leg distances for the cruise portion can be measured and inserted in the flight plan. The cruise section of the ODM can now be consulted, once again ensuring that the correct cruise type or speed, and the correct temperature profile are selected (Fig 6). In this case, the data obtained from the ODM is TAS and fuel flow rate. The TAS

may, alternatively, be calculated on the DR Computer using the forecast meteorological information. The DR Computer can now be used to determine headings, groundspeeds and times for each of the cruise legs, and this data entered on the flight plan form. Elapsed times and ETAs can be entered in the appropriate columns of the flight plan.

9-14 Fig 6 ODM Long Range Cruise Table

Long Range Cruise

(ISA + 3°C to ISA + 7°C)

Pressure Height ft X 1000	ISA Temp °C	Speed (below line) knots T A S	Fuel Flow (above line) lb/hr	Speed (knots T A S) above line / Fuel Flow (lb/hr). below line / Weight (lb/1000) 19	18	17	16	15	14	13	Fuel Flow (above line) lb/hr	Speed (below line) knots T A S	ISA Temp °C	Pressure Height ft X 1000
42	-57		1675				360	1655	1590	1540		375	-57	42
41	-57		1760			357	1735	1670	1615	1565		375	-57	41
40	-57		1845		356	375	1750	1695	1645	1595		375	-57	40
39	-57		1935	356	375	1830	1775	1720	1670	1625		375	-57	39
38	-57	375		1975	1910	1850	1800	1750	1700	1660		375	-57	38
37	-57	367		1940	1885	1830	1780	1730	1795	1645		367	-57	37
36	-57	359		1915	1860	1810	1760	1710	1670	1635		359	-57	36
35	-55	352		1910	1855	1805	1760	1715	1675	1640		352	-55	35
34	-53	346		1900	1850	1805	1760	1720	1680	1640		346	-53	34
33	-51	340		1900	1850	1805	1760	1720	1680	1645		340	-51	33
32	-49	334		1900	1855	1810	1765	1720	1680	1645		334	-49	32
31	-47	328		1905	1855	1810	1765	1725	1690	1655		328	-47	31
30	-45	323		1910	1860	1815	1770	1730	1695	1660		323	-45	30
29	-43	317		1910	1865	1820	1780	1740	1700	1665		317	-43	29
28	-41	312		1915	1870	1825	1785	1745	1705	1670		312	-41	28
27	-39	307		1920	1875	1830	1785	1745	1710	1675		307	-39	27
26	-37	301		1925	1880	1835	1790	1750	1715	1680		301	-37	26
25	-35	296		1930	1880	1835	1795	1755	1720	1685		296	-35	25
24	-33	306		2040	1995	1955	1915	1880	1845	1815		306	-33	24
23	-31	301		2040	2000	1960	1920	1885	1850	1820		301	-31	23
22	-29	296		2045	2005	1965	1925	1890	1860	1830		296	-29	22
21	-27	291		2055	2015	1975	1935	1900	1865	1835		291	-27	21
20	-25	287		2070	2030	1990	1950	1915	1885	1855		287	-25	20
19	-23	282		2075	2035	1995	1960	1925	1895	1865		282	-23	19
18	-21	277		2085	2045	2010	1975	1940	1910	1885		277	-21	18
17	-19	273		2095	2060	2025	1990	1960	1930	1905		273	-19	17
16	-17	268		2115	2075	2040	2010	1980	1950	1925		268	-17	16
15	-15	265		2140	2105	2070	2040	2010	1985	1960		265	-15	15
14	-13	261		2165	2130	2100	2070	2040	2010	1985		264	-13	14
13	-11	256		2195	2160	2125	2095	2065	2040	2015		256	-11	13
12	-9	252		2225	2190	2155	2125	2095	2070	2045		252	-9	12
11	-7	248		2255	2220	2190	2160	2130	2105	2085		248	-7	11
10	-5	245		2295	2260	2230	2205	2180	2155	2135		245	-5	10
9	-3	241		2330	2300	2275	2250	2225	2200	2180		241	-3	9
8	-1	238		2375	2345	2320	2295	2270	2250	2230		238	-1	8
7	+1	234		2425	2395	2370	2345	2325	2300	2280		234	+1	7
6	+3	230		2475	2445	2420	2395	2375	2350	2330		230	+3	6
5	+5	227		2535	2505	2480	2455	2430	2405	2380		227	+5	5
4	+7	224		2590	2560	2535	2505	2475	2450	2425		224	+7	4
3	+9	221		2645	2610	2580	2550	2525	2495	2470		221	+9	3
2	+11	217		2695	2660	2630	2600	2570	2545	2520		217	+11	2
1	+13	214		2750	2715	2680	2650	2620	2590	2565		214	+13	1

<u>Recommended Speeds</u>

Altitude (ft/1000)	Speed
1 - 24	205 kt I A S
25 - 38	195 kt I A S
39 - 42	.64 M_{IND}

NOTE: For operation above line throttles are set to give Maximum Continuous Power.

For operation below line engines are throttled back to give Recommended Speed.

For fuel flows above line reduce fuel flow by 10 lb / hr / 1000 lb for weights greater than 15000 lb, and increase fuel by 10 lb / hr / 1000 lb for weights less than 15000 lb.

22. **Safety Altitude***.* The safety altitude (SALT) for each leg or section must be determined from a topographical chart using whatever criteria are laid down by the Command, Group, or other operating authority. In this example, the basic criterion has been to find the highest obstacle within 30 nm of each planned section of track, and then add 1,000 ft (2,000 ft in the case where the obstacle is 3,000 ft or

higher). That sum has then been rounded up to the nearest 100 ft. The SALT figure for each track is then annotated on the flight plan form (Fig 3).

Note: SALT calculation is explained in detail in Volume 9, Chapter 23.

23. **F2919/CA48**. If necessary, an F2919/CA48 - Flight Plan can now be completed and submitted. The occasions when this form should be completed, and instructions for its completion, are contained in the UK Military Aeronautical Planning Document and in FLIPs.

CHAPTER 15 - FUEL PLANNING

Introduction

1. Fuel planning is an integral part of flight planning, and accurate calculation of the fuel requirement for a particular flight is important for safety, economical operation, and the maximum utilization of payload.

2. The methods of calculating the fuel plan, and of monitoring the fuel consumption in flight, will vary between aircraft type and role, and on the requirements of the flight. The requirements, and terms used, for fast-jet operations are described in Volume 9, Chapter 18. The principles outlined in this chapter are applicable mostly to larger aircraft.

Fuel Planning Data

3. Fuel consumption is a function of altitude, air temperature, speed, all-up weight (AUW) and engine RPM. Data on fuel consumption, expressed in either pounds (lb) or kilograms (kg) per minute or hour, is presented in the Operating Data Manual (ODM) for the aircraft type, usually in tabular form with entering arguments of altitude and AUW. The other parameters are assumed constant, with their values stated on the table, and with a selection of tables for variations in these parameters. Fig 1 shows a typical ODM table. The title 'Long Range Cruise' specifies the flight profile and a secondary table shows the assumed speeds. The heading 'ISA –2 to ISA +2' specifies the air temperature range for which the table is valid. There will be additional tables for different flight profiles (e.g. climb, descent, endurance cruise), and for different air temperature regimes

9-15 Fig 1 ODM Long Range Cruise Table

Long Range Cruise

(ISA -2°C to ISA +2°C)

Pressure Height ft X 1000	*ISA Temp °C*	*Speed (Below Line) knots T A S*	*Fuel Flow (Above Line) lb/hr*	*Speed (knots T A S) Above Line / Fuel Flow (lb/hr). Below line / Weight (lb/1000)* 19	18	17	16	15	14	13	*Fuel Flow (Above Line) lb/hr*	*Speed (Below Line) knots T A S*	*ISA Temp °C*	*Pressure Height ft X 1000*
42	-57		1730			352	1685	1625	1565	1510		371	-57	42
41	-57		1815		349	1760	1705	1645	1590	1540		371	-57	41
40	-57		1905	348	1840	1785	1720	1665	1615	1565		371	-57	40
39	-57	371		1915	1860	1800	1745	1690	1640	1595		371	-57	39
38	-57	371		1940	1875	1820	1770	1720	1675	1630		371	-57	38
37	-57	362		1905	1850	1795	1750	1700	1655	1615		362	-57	37
36	-57	355		1885	1830	1775	1730	1685	1645	1605		355	-57	36
35	-55	348		1875	1825	1775	1730	1685	1645	1610		348	-55	35
34	-53	342		1870	1820	1775	1730	1690	1650	1615		342	-53	34
33	-51	336		1865	1820	1775	1730	1690	1650	1615		336	-51	33
32	-49	330		1870	1825	1780	1735	1695	1655	1620		330	-49	32
31	-47	325		1875	1830	1785	1740	1700	1660	1625		325	-47	31
30	-45	319		1880	1830	1785	1745	1705	1670	1635		319	-45	30
29	-43	314		1885	1840	1795	1750	1710	1675	1640		314	-43	29
28	-41	309		1885	1840	1800	1755	1715	1680	1645		309	-41	28
27	-39	303		1890	1845	1805	1760	1720	1685	1650		303	-39	27
26	-37	298		1895	1850	1805	1765	1725	1690	1655		298	-37	26
25	-35	293		1900	1855	1810	1770	1730	1695	1660		293	-35	25
24	-33	303		2015	1970	1930	1890	1855	1820	1790		303	-33	24
23	-31	298		2015	1975	1935	1895	1860	1825	1795		298	-31	23
22	-29	293		2020	1980	1940	1900	1865	1835	1805		293	-29	22
21	-27	288		2025	1985	1945	1910	1875	1840	1810		288	-27	21
20	-25	284		2045	2005	1965	1925	1890	1860	1830		284	-25	20
19	-23	279		2050	2010	1970	1935	1900	1870	1845		279	-23	19
18	-21	275		2060	2020	1980	1945	1915	1885	1860		275	-21	18
17	-19	270		2070	2035	2000	1965	1930	1905	1880		270	-19	17
16	-17	266		2085	2050	2015	1985	1955	1925	1900		266	-17	16
15	-15	262		2115	2080	2045	2015	1985	1960	1935		262	-15	15
14	-13	258		2140	2105	2070	2040	2010	1985	1960		258	-13	14
13	-11	254		2165	2130	2100	2070	2040	2010	1985		254	-11	13
12	-9	250		2195	2160	2130	2100	2070	2045	2020		250	-9	12
11	-7	246		2230	2195	2160	2130	2105	2080	2060		246	-7	11
10	-5	243		2265	2235	2205	2180	2155	2130	2110		243	-5	10
9	-3	239		2300	2270	2245	2220	2195	2175	2155		239	-3	9
8	-1	235		2345	2315	2290	2265	2245	2225	2205		235	-1	8
7	+1	232		2395	2365	2340	2315	2295	2275	2255		232	+1	7
6	+3	228		2445	2415	2390	2365	2395	2320	2300		228	+3	6
5	+5	225		2500	2475	2450	2425	2400	2375	2350		225	+5	5
4	+7	222		2560	2530	2500	2470	2445	2420	2400		222	+7	4
3	+9	219		2615	2575	2550	2520	2495	2470	2445		219	+9	3
2	+11	216		2665	2630	2600	2570	2545	2515	2490		216	+11	2
1	+13	212		2715	2680	2650	2620	2590	2560	2535		212	+13	1

Recommended Speeds

Altitude (ft/1000)	Speed
1 - 24	205 kt I A S
25 - 38	195 kt I A S
39 - 42	.64 M_{IND}

NOTE: For operation above line throttles are set to give Maximum Continuous Power.

For operation below line engines are throttled back to give Recommended Speed.

For fuel flows above line reduce fuel flow by 10 lb / hr / 1000 lb for weights greater than 15000 lb, and increases fuel by 10 lb / hr / 1000 lb for weights less than 15000 lb.

4. The ODM will normally present a rapid planning section where the fuel requirement for a given sector distance is tabulated against a variety of head or tail wind components (Fig 2). These tables are valuable in the initial planning stages, to see whether a proposed flight is possible and to give an idea of the payload that might be carried. Additional tables give diversion fuel requirements (Fig 3) and holding fuel (Fig 4). In all of these cases it is important to note the assumptions on which the tables are calculated.

9-15 Fig 2 ODM Sector Fuel and Time Table

Sector Distance Nautical Miles	Headwind - Knots																					Sector Distance Nautical Miles
	100		90		80		70		60		50		40		30		20		10		0	
	Fuel lb	Time hr min	Fuel lb	Time hr min	Fuel lb	Time hr min	Fuel lb	Time hr min	Fuel lb	Time hr min	Fuel lb	Time hr min	Fuel lb	Time hr min	Fuel lb	Time hr min	Fuel lb	Time hr min	Fuel lb	Time hr min	Fuel lb	Time hr min	
100	2500	0:41	2500	0:40	2450	0:39	2450	0:39	2400	0:38	2400	0:38	2350	0:37	2350	0:37	2300	0:36	2300	0:36	2250	0:35	100
150	2950	0:52	2900	0:51	2850	0:50	2800	0:49	2750	0:48	2750	0:47	2700	0:46	2650	0:45	2600	0:45	2600	0:44	2600	0:43	150
200	3350	1:03	3300	1:02	3200	1:00	3150	0:59	3100	0:57	3050	0:56	3050	0:55	3000	0:54	3000	0:53	2950	0:53	2900	0:51	200
250	3750	1:14	3700	1:12	3600	1:10	3550	1:09	3500	1:07	3450	1:06	3400	1:05	3350	1:03	3300	1:02	3250	1:01	3200	0:59	250
300	4100	1:25	4000	1:23	3950	1:21	3850	1:19	3800	1:17	3750	1:15	3700	1:14	3650	1:12	3600	1:11	3550	1:09	3500	1:07	300
350	4500	1:36	4400	1:33	4300	1:31	4200	1:28	4150	1:26	4050	1:24	4000	1:23	3950	1:21	3900	1:19	3850	1:17	3800	1:16	350
400	4850	1:47	4750	1:44	4650	1:41	4550	1:38	4450	1:36	4400	1:34	4300	1:32	4250	1:30	4150	1:28	4100	1:26	4050	1:24	400
450	5250	1:57	5100	1:54	5000	1:51	4900	1:48	4800	1:45	4700	1:43	4650	1:41	4550	1:38	4500	1:36	4400	1:34	4350	1:32	450
500	5600	2:08	5450	2:04	5300	2:01	5200	1:58	5100	1:54	5050	1:52	4950	1:49	4850	1:47	4800	1:44	4700	1:42	4650	1:40	500
550	5900	2:19	5750	2:15	5650	2:11	5550	2:07	5450	2:04	5350	2:01	5250	1:58	5150	1:55	5050	1:52	4950	1:50	4900	1:47	550
600	6250	2:30	6100	2:25	5950	2:21	5850	2:17	5700	2:14	5600	2:10	5500	2:07	5400	2:04	5300	2:01	5250	1:58	5150	1:56	600
650	6550	2:41	6450	2:36	6250	2:31	6150	2:27	6000	2:23	5900	2:19	5750	2:16	5650	2:12	5600	2:09	5500	2:07	5400	2:04	650
700	6900	2:51	6750	2:46	6550	2:42	6400	2:37	6300	2:33	6150	2:28	6050	2:24	5950	2:21	5850	2:18	5750	2:15	5650	2:11	700
750	7250	3:03	7050	2:57	6850	2:52	6700	2:46	6550	2:42	6450	2:37	6350	2:33	6200	2:30	6100	2:26	6000	2:23	5850	2:19	750
800	7550	3:14	7350	3:08	7200	3:02	7000	2:56	6850	2:51	6700	2:46	6600	2:42	6450	2:38	6350	2:34	6250	2:30	6150	2:27	800
850					7500	3:13	7300	3:07	7150	3:01	7000	2:56	6850	2:52	6700	2:47	6600	2:43	6500	2:38	6400	2:35	850
900									7450	3:11	7300	3:06	7150	3:01	7000	2:56	6850	2:51	6750	2:47	6600	2:43	900
950											7550	3:15	7400	3:10	7250	3:05	7100	3:00	7000	2:55	6850	2:51	950
1000															7500	3:14	7350	3:09	7250	3:04	7100	2:59	1000
1050																			7450	3:13	7350	3:07	1050
1100																					7550	3:16	1100
1150																							1150
1200																							1200
1250																							1250
1300																							1300
1350																							1350
1400																							1400

Notes
1. Take-off and climb to 1,000 ft (2 min) and landing (10 min) time allowances added.
2. Take-off and climb to 1,000 ft (150 lb) and landing and baulked landing (1,150 lb) fuel allowances added.
3. Procedure-normal climb to 38,000 ft, long range cruise at 38,000 normal descent to 1,000 ft.

9-15 Fig 3 ODM Diversion Table

Diversion Distance Nautical Miles	Headwind - Knots											Tailwind - Knots										Diversion Distance Nautical Miles
	100	90	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80	90	100	
20	400	350	350	300	300	300	300	300	250	250	250	200	200	200	200	200	150	150	150	150	150	20
40	650	650	600	600	550	550	500	500	450	450	450	400	400	400	350	350	350	350	300	300	300	40
60	850	850	800	800	750	750	700	700	650	650	600	600	550	550	550	500	500	500	500	450	450	60
80	1050	1000	950	950	900	900	850	850	800	800	750	750	700	700	700	650	650	650	600	600	600	80
100	1200	1150	1100	1100	1050	1050	1000	1000	950	950	900	900	850	850	800	800	800	750	750	750	700	100
120	1300	1300	1250	1200	1200	1150	1150	1100	1100	1050	1050	1000	1000	950	950	900	900	900	850	850	800	120
140	1450	1400	1350	1350	1300	1250	1250	1200	1200	1150	1150	1100	1100	1050	1050	1050	1000	1000	950	950	900	140
160	1550	1550	1500	1450	1400	1400	1350	1300	1300	1250	1250	1200	1200	1150	1150	1100	1100	1100	1050	1050	1000	160
180	1700	1650	1600	1550	1550	1500	1450	1400	1400	1350	1350	1300	1300	1250	1250	1200	1200	1150	1150	1150	1100	180
200	1800	1750	1700	1650	1650	1600	1550	1500	1500	1450	1450	1400	1400	1350	1350	1300	1300	1250	1250	1200	1200	200
220	1950	1900	1850	1800	1750	1700	1650	1600	1600	1550	1500	1500	1450	1450	1400	1400	1350	1350	1300	1300	1250	220
240	2050	2000	1950	1900	1850	1800	1750	1700	1700	1650	1600	1600	1550	1500	1500	1450	1450	1400	1400	1350	1350	240
260	2150	2100	2050	2000	1950	1900	1850	1800	1750	1750	1700	1650	1650	1600	1550	1550	1500	1500	1450	1450	1400	260
280	2300	2200	2150	2100	2050	2000	1950	1900	1850	1800	1800	1750	1700	1700	1650	1600	1600	1550	1550	1500	1500	280
300	2400	2300	2250	2200	2150	2100	2050	2000	1950	1900	1850	1850	1800	1750	1750	1700	1650	1650	1600	1600	1550	300

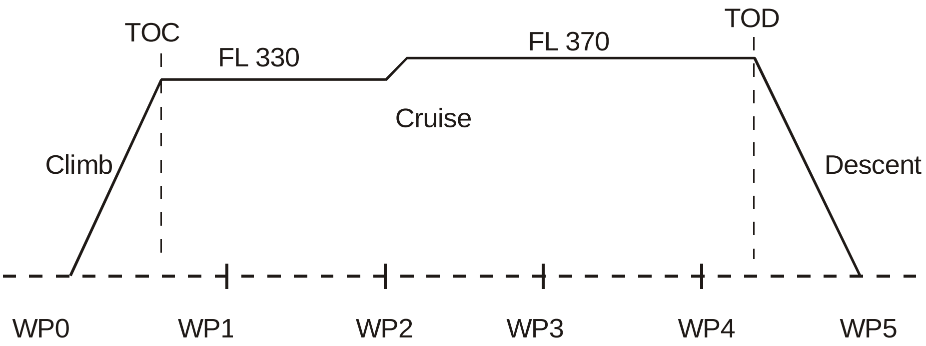
9-15 Fig 4 ODM Holding Fuel Table

Pressure Height ft/1000	*Fuel Flow (lb/hr) Weight - lb*				*Pressure Height ft/1000*
	18000	*16000*	*14000*	*12000*	
42	1850	1700	1450	1340	42
41	1810	1660	1440	1330	41
40	1770	1620	1420	1320	40
39	1750	1590	1410	1310	39
38	1710	1580	1400	1300	38
37	1690	1570	1390	1300	37
36	1680	1570	1380	1290	36
35	1680	1570	1380	1290	35
34	1670	1560	1390	1290	34
33	1670	1560	1390	1300	33
32	1670	1560	1390	1300	32
31	1670	1560	1390	1310	31
30	1670	1570	1400	1310	30
29	1670	1570	1360	1270	29
28	1670	1570	1370	1280	28
27	1670	1580	1380	1290	27
26	1680	1580	1380	1300	26
25	1680	1590	1390	1320	25
24	1690	1600	1410	1330	24
23	1700	1610	1420	1350	23
22	1710	1620	1440	1370	22
21	1720	1640	1460	1390	21
20	1730	1650	1480	1410	20
19	1750	1670	1510	1440	19
18	1770	1690	1530	1470	18
17	1790	1720	1560	1500	17
16	1810	1740	1590	1530	16
15	1840	1770	1620	1560	15
14	1870	1810	1660	1590	14
13	1910	1840	1690	1620	13
12	1950	1880	1720	1650	12
11	1990	1920	1760	1680	11
10	2030	1960	1790	1720	10
9	2080	2000	1820	1750	9
8	2120	2040	1860	1780	8
7	2160	2080	1890	1810	7
6	2200	2120	1930	1850	6
5	2250	2160	1960	1880	5
4	2290	2200	2000	1910	4
3	2330	2240	2030	1940	3
2	2370	2280	2070	1980	2
1	2410	2320	2100	2010	1

The Fuel Plan

5. Preparing the basic fuel plan is straightforward, using the data from the appropriate tables of the ODM. The following example will illustrate the procedure. A simple route is shown in profile in Fig 5; it consists of a climb, a cruise portion at two flight levels, and a descent. The cruise portion is divided by a number of waypoints. Even if this were not necessary for navigation purposes, the cruise would need to be divided for fuel planning as the fuel consumption rate depends on AUW, which will, of course, reduce during flight. The length of each section for fuel planning considerations will depend on the aircraft type. The flight plan entries for this route are shown in Fig 6.

9-15 Fig 5 Simple Route (Elevation)



9-15 Fig 6 Simplified Flight Plan

Route to	SA MSFL	RAS MACH	FL ALT	OAT DEV	TAS	G/S	LEG DIST	LEG TIME	ET	ETA	START WEIGHT	FUEL 8000 FLOW	USED	REM	DTG
TOC		230 .56	240	– 4	293	328	115 315	21	21		21000	—	1410	6590	840
WP 1		200	330	– 1	336	428	200	28	49		19590	1865	870	5720	640
WP 2		✓	330	✓		437	175	24	73		18720	✓	750	4970	465
WP 3		✓	370	✓	362	287	110	23	96		18070	1850	710	4260	355
WP 4		✓	370	✓	✓	284	180	38	134		17360	1795	1140	3120	175
TOD		✓	370	✓	✓	286	95 175	20	154		16220	1750	590	2530	80
WP 5 (Dest)		240 .67	180	✓	325	300	80	16	170		15600	—	310	2220	0
						Totals	955	170		Total Fuel used			5780		

Tick (✓) indicates 'same as above'

6. **Climb**. The fuel for the climb section is extracted from the climb table of the ODM, ensuring that the correct climb and temperature profile is selected. In practice, this will be done at the same time that the mean TAS and time to climb are found for navigation planning (see example in Volume 9, Chapter 14). The top of climb (TOC) position is plotted allowing the first cruise leg to be defined. The fuel used is entered in the appropriate column of the flight plan and, by subtraction, the fuel remaining and AUW at the top of climb are calculated and entered.

7. **Descent**. The descent fuel is similarly found using the ODM descent tables, as per the example in Volume 9, Chapter 14. The top of descent (TOD) point can be plotted, thus allowing the last cruising leg to be defined. It should be noted that the descent table will normally assume a descent to 1,000 ft. If it is planned to stop the descent at an intermediate level, then an adjustment must be made. For example, if it is intended to descend from FL 310 to FL 40 then the figures for fuel and time for a descent from FL 40 are subtracted from those for a descent from FL 310. The fuel calculated for use in the descent is then entered in the flight plan.

8. **Cruise**. The start weight at the beginning of the first leg is used as an entering argument with altitude to determine the fuel flow rate. The table for the correct cruise conditions (speed, temperature) in this example yields a rate of 1,865 lb/hr (Fig 7). The time for the 200 nm leg is 28 minutes and therefore the fuel used is 870 lb. This can be entered in the flight plan and subtracted from the fuel remaining to give the new fuel remaining, and from the previous AUW to give the AUW for the next leg. The process is repeated for the remaining cruise legs.

9-15 Fig 7 Extraction of Cruise Fuel Rate

(Extract from Fig 1)

Long Range Cruise

Pressure Height ft X 1000	ISA Temp °C	Speed (Below Line) knots T A S	Fuel Flow (Above Line) lb/hr	Speed (knots T A S) Above Line / Fuel Flow (lb/hr). Below line / Weight (lb/1000) 19	18	17	16	15	14	13
42	-57		1730			352	1685	1625	1565	1510
41	-57		1815		349	1760	1705	1645	1590	1540
40	-57		1905	348	1840	1785	1720	1665	1615	1565
39	-57	371		1915	1860	1800	1745	1690	1640	1595
38	-57	371		1940	1875	1820	1770	1720	1675	1630
37	-57	362		1905	1850	1795	1750	1700	1655	1615
36	-57	355		1885	1830	1775	1730	1685	1645	1605
35	-55	348		1875	1825	1775	1730	1685	1645	1610
34	-53	342		1870	1820	1775	1730	1690	1650	1615
33	-51	336		1865	1820	1775	1730	1690	1650	1615
32	-49	330		1870	1825	1780	1735	1695	1655	1620
31	-47	325		1875	1830	1785	1740	1700	1660	1625

(Extract from Fig 6)

TAS	G/S	LEG DIST	LEG TIME	ET	ETA	START WEIGHT	FUEL 8000 FLOW	USED	REM	DTG
293	328	115 315	21	21		21000	—	1410	6590	840
336	428	200	28	49		19590	1865	870	5720	640
	437	175	24	73		18720	✓	750	4970	465
362	287	110	23	96		18070	1850	710	4260	355
✓	284	180	38	134		17360	1795	1140	3120	175
✓	286	95 175	20	154		16220	1750	590	2530	80
325	300	80	16	170		15600	—	310	2220	0
	Totals	955	170			Total Fuel used		5780		

Tick (✓) indicates 'same as above'

Minimum Fuel Requirements

9. **Minimum Fuel Overhead the Destination**. The planning procedure discussed above has determined the amount of fuel needed to carry out the flight but has taken no account of the quantity of fuel with which it is necessary to arrive at the destination. The ODM-based calculations give the amount of fuel remaining when the aircraft arrives overhead the destination at 1,000 ft (2,220 lb in Fig 6). The minimum fuel required overhead the destination should be calculated, and is normally the sum of the following factors:

a. **Minimum Landing Fuel**. There will be a minimum landing fuel permitted for the aircraft type. This usually allows sufficient for taxiing to dispersal, plus an allowance for gauging errors.

b. **Missed Approach and Transit to Alternate Airfield**. It is normal to carry a fuel allowance for a 'Missed Approach' at the destination airfield, and subsequent transit to the alternate (diversion) airfield. Extra fuel may be required within this allowance, for factors such as forecast icing and its associated fuel penalty, or air traffic restrictions.

c. **Approach Fuel**. A fuel allowance will be required to provide for the approach (either visual or instrument) from 1,000 ft overhead the destination, to touchdown. Similarly, an allowance must be made for the approach at the alternate airfield.

10. **'Standard' Diversion Figures**. For most aircraft there will be 'standard' amounts for these various fuel requirements (perhaps printed on the flight plan form for convenience - see Fig 3 to Volume 9, Chapter 14). In addition, there is usually a locally produced table giving the transit fuel required to the commonly-used diversion airfields. For other airfields, the transit fuel will have to be calculated, normally by the use of a table such as that shown in Fig 3.

11. **En Route Minimum Fuel**. The 'en route minimum fuel' is the amount of fuel required at a specific point to enable the aircraft to complete the route as planned, arriving at the destination with the specified overhead fuel. Once the fuel overhead the destination has been calculated, it is possible to work back through the fuel plan and calculate the en route minimum fuel for any point on the flight plan.

In-flight Fuel Monitoring

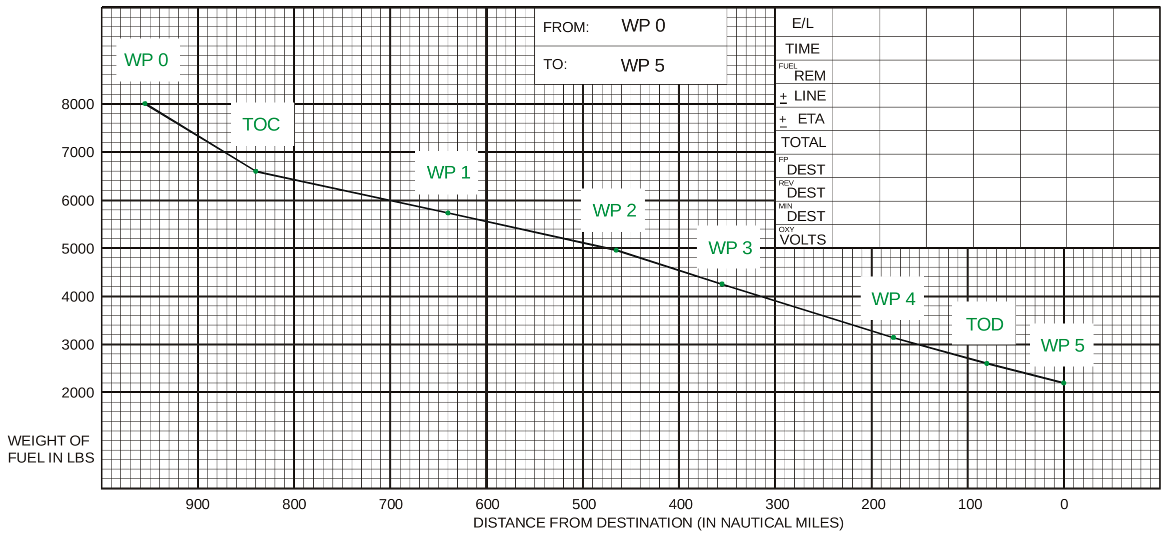
12. The fuel plan, as calculated, gives an indication of the expected fuel consumption, leg by leg. However, if the fuel consumption varies from that expected, it can be difficult to make an accurate assessment of any trend from the flight plan form. To overcome this shortcoming, the fuel graph has been developed. The fuel graph presents a visual solution: the fuel expected is plotted on the vertical axis against either time or distance on the horizontal axis. The former is known as the fuel/time Howgozit and the latter as the fuel/distance Howgozit. Each type is suited to certain roles; in general, the maritime and AAR roles use fuel/time graphs while transport operations tend to use the fuel/distance graph. The fuel/distance Howgozit has the advantage of being ideally suited to the solution of critical point and other tactical problems (Volume 9, Chapter 16).

13. **COMBAT, BINGO and JOKER Fuels**. The terms 'COMBAT', 'BINGO' and 'JOKER' can be used to assist with in-flight fuel management. These terms are described fully in Volume 9, Chapter 18.

Fuel/Distance Howgozit

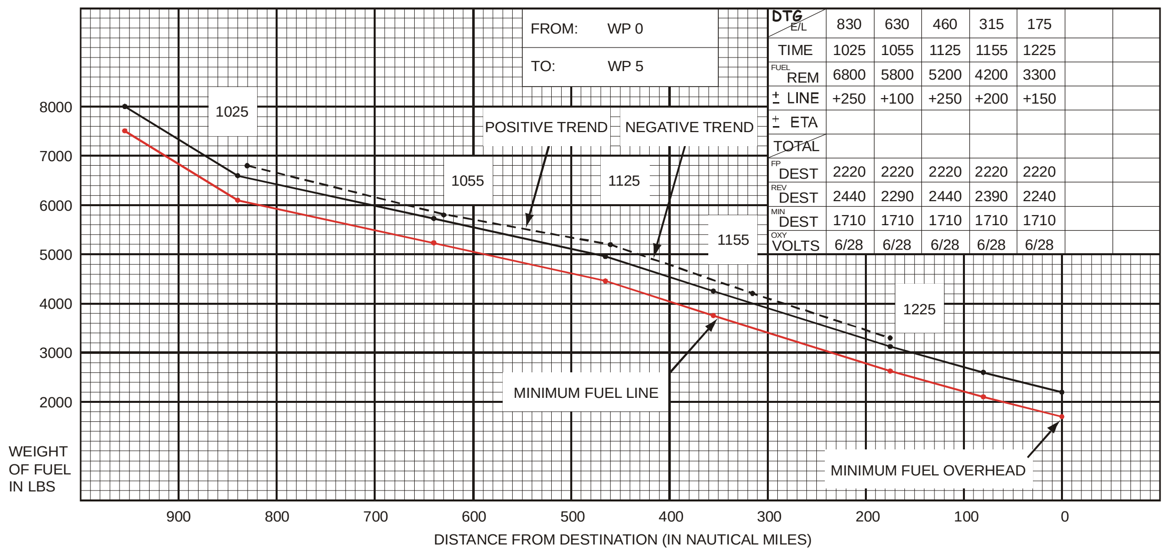
14. **Construction**. Fig 8 shows an example fuel/distance Howgozit, based on the flight plan at Fig 6. The vertical axis represents fuel remaining while the horizontal axis represents the distance to go to the destination. The departure airfield is represented by the intersection of the total route distance and the take-off fuel, in this example 955 nm and 8,000 lb. The destination is similarly represented by the intersection of the flight plan fuel remaining overhead the destination (2,220 lb) and zero distance to go. The predicted fuel consumption between these points is plotted using the flight plan values of fuel remaining at each waypoint and the corresponding distance to go. As fuel consumption is a function of time rather than distance, the gradient of the line will vary with changes in groundspeed (higher groundspeeds giving shallower gradients). This fact can be used as a cross-check of the plotting as the gradient changes can be correlated with the flight plan groundspeed changes.

9-15 Fig 8 Fuel/Distance Howgozit



15. **Minimum Fuel Line**. The graph plotted in Fig 8 represents the expected fuel consumption for the flight and, in particular, terminates at the expected fuel remaining overhead the destination. For the reasons outlined in paras 9 to 11, there will be a minimum fuel requirement overhead the destination; this value is plotted at the zero distance-to-go point. In the example (Fig 9), the minimum fuel overhead is assumed to be 1,710 lb. A minimum fuel line may now be constructed through this minimum fuel point and parallel to the planned fuel line. As a flight safety item, the minimum fuel line is normally plotted in red. Any in-flight fuel check that falls below this line means that the destination cannot be reached with the stipulated reserves and some action must be taken to remedy the situation.

9-15 Fig 9 Fuel/Distance Howgozit with Minimum Fuel Line and Plotted Fuel Checks



16. **In-flight Fuel Checks**. One advantage of graphical monitoring of fuel consumption is that fuel checks can be carried out at any convenient time and are not restricted to pre-planned times or positions. The fuel remaining at any time is simply plotted against the distance to go at that time. If

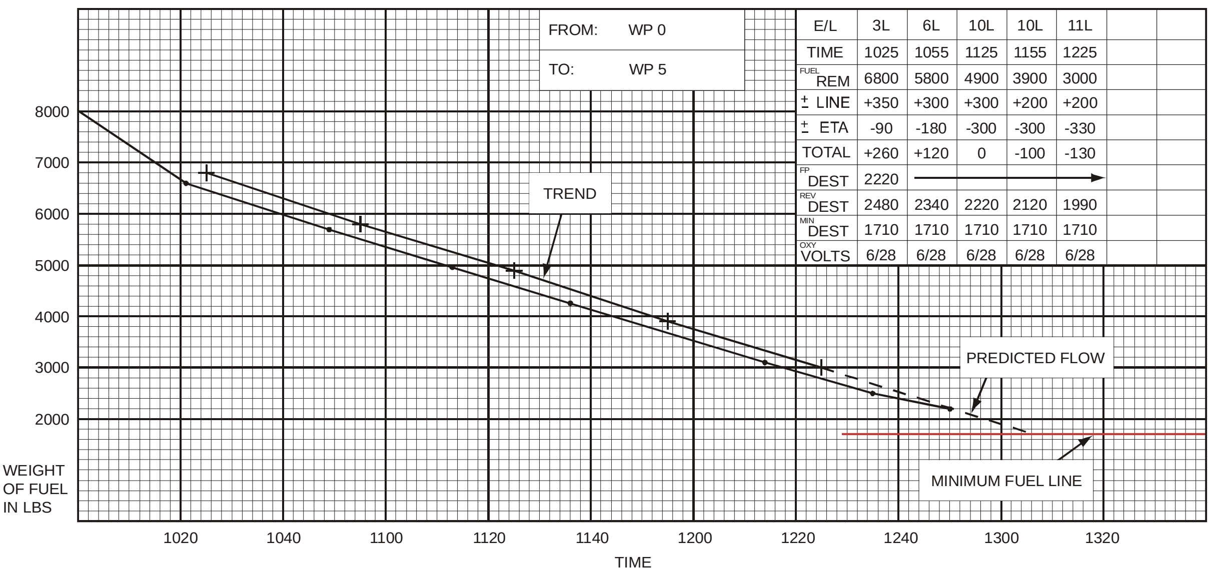
the fuel check plots above the line, then there is more fuel than planned and vice versa. A series of such checks is shown in Fig 9. From the first fuel check it will be seen that the fuel consumption is 'above the line'. There may be several reasons for this; a greater than expected start fuel, colder temperatures, better than average engine efficiency. At this stage, the only assumption that can be made is that the fuel for the remainder of the flight will be as planned and therefore the fuel remaining overhead the destination will be above the line by a similar amount. The frequency of fuel checks will normally be stipulated by the operating authority, but, in general, a check will be made at TOC, just prior to TOD and at approximately 30-minute intervals during the cruise.

17. **Fuel Consumption Trend**. After a number of fuel checks, it will be possible to join them to establish an impression of the actual, rather than the predicted, consumption. This trend line may be extrapolated to estimate the effect on the expected destination fuel. Clearly, such estimates must be treated with caution and, the longer the period over which the trend can be established, the more reliable it is likely to be. It is important to give some consideration as to the reason for a trend varying from the prediction. For example, it may be due to winds differing from forecast, in which case this difference may not necessarily persist for the rest of the flight. In the case of a circular route back to base, it is quite likely that such a trend established on the outbound section will be reversed on the inbound section. This effect is shown in Fig 9 where the positive trend between 1055 hrs and 1125 hrs is reversed between 1125 hrs and 1155 hrs.

Fuel/Time Howgozit

18. **Construction**. The fuel/time Howgozit is constructed in a similar manner to the fuel/distance variety except that the horizontal axis represents flight plan elapsed time from take-off. Fig 10 shows an example graph on which a horizontal minimum fuel line has been plotted. The gradient of the fuel/time line is more constant than the fuel/distance line as the fuel flow with respect to time is relatively constant. The minor difference as AUW reduces is not readily apparent at the scale of the graph.

9-15 Fig 10 Fuel/Time Howgozit with Minimum Fuel Line and Plotted Fuel Checks



19. **In-flight Fuel Checks**. Once airborne, the elapsed times on the horizontal axis can be replaced with real times, if required. Fuel checks are plotted on the graph as values of fuel remaining against time, or elapsed time from take-off. Revision of fuel expected at destination requires an extra stage when using this graph. Suppose that a fuel check plots above the line by 200 lb. It is not sufficient to assume that the destination fuel will be better by 200 lb; it is first necessary to check how airborne ETAs correspond with the flight plan ETAs. At the time of the fuel check, the ETA for the next waypoint is calculated and compared with the flight plan ETA. If the flight is running, say, 3 minutes behind flight plan then 3 minutes extra fuel will be used (assuming that the 3-minute discrepancy is maintained). Using an average fuel flow rate of 30 lb/min in this example, an extra 90 lb of fuel will be used. Thus, the revision to the overhead fuel is 200 – 90 = +110 lb. An extra facility can be offered, on the fuel/time Howgozit, by joining 2 representative fuel checks, and extending that line downwards. Where this line intercepts the minimum fuel line, the time can be estimated for achieving that fuel state. In the example in Fig 10, by joining the 1155 hrs and 1225 hrs fuel checks and projecting that line, it can be forecast that the minimum fuel of 1,710 lb will be reached at approximately 1306 hrs.

Fuel Saving

20. If, during the flight, a fuel check falls below the minimum fuel line, or if a reliable trend shows that the fuel will be below minimum at the destination, then some fuel saving action must be initiated.

21. The action to be taken will depend on a number of factors such as the aircraft type and performance, the nature of the task, and airspace restrictions. Although no precise guidance can be given, the following options might be considered:

a. **Reduce Time on Task**. Reducing time on task is a simple method of saving fuel but may not be operationally acceptable.

b. **Shorten the Route**. This is normally the most effective method but is dependent upon the route geometry. It should be relatively simple in a route with large turns but will be impossible in a straight route. In addition, there may be air traffic control or airspace restrictions preventing re-routeing.

c. **Alter the Cruise Profile**. There are various techniques which may be considered within the cruise profile. When on task, it may be possible to change to a more economical speed (endurance cruise), or perhaps fly higher. On route to the destination, best speed for range should be utilized. A higher cruising flight level may also save fuel over a long distance (but the effect of a different fuel flow rate and of a different wind structure must be considered). Approaching the destination, it may be beneficial to remain at height for longer and then execute a rapid, rather than normal, rate of descent. Finally, the planned approach may be changed, eg straight-in visual rather than full instrument recovery, weather permitting.

d. **Re-negotiate the Minimum Overhead Fuel**. It may be possible to change the planned diversion airfield to one that is closer or has better weather (allowing a visual approach instead of an instrument approach) thereby permitting a reduced minimum fuel overhead the destination.

CHAPTER 16 - CRITICAL POINT AND POINT OF NO RETURN

Introduction

1. An important aspect of flight planning is the calculation of the action to be taken in the event of a diversion or an emergency. The decision to be made is whether, with the available fuel and knowledge of the wind velocity, it will be preferable to return to base, divert, or continue to the destination, and indeed which of these options is feasible. This chapter will describe the various decision points which can be determined at the flight planning stage and the methods by which they can be calculated.

CRITICAL POINT

Definition

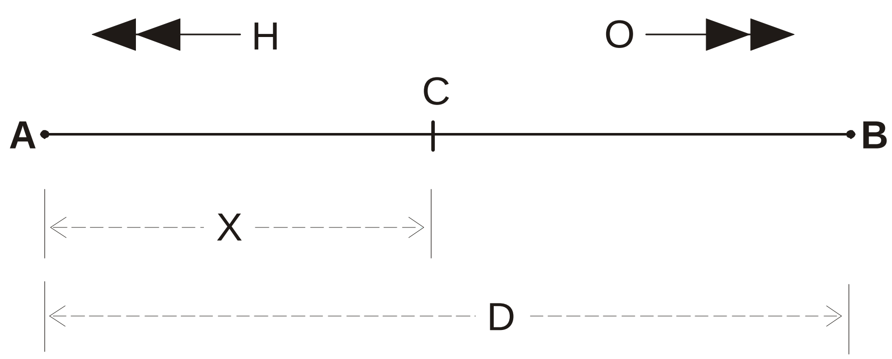
2. **Route Critical Point (CP)**. The CP is the point between two airfields from which it would take the same time to fly to either airfield. The calculation of critical point is based on the ratio of groundspeed to destination and groundspeed back to base. These speeds are computed from a mean wind velocity for the flight for simplicity. The TAS selected for the calculation depends on the type of emergency envisaged. For example in the case of an engine failure a reduced TAS will be used, whereas in the case of a sudden deterioration in the condition of a patient on a medical evacuation flight a higher than normal TAS might be appropriate.

3. There are three methods of determining the critical point between two airfields; formula (DR Computer), Howgozit and critical line graphics.

Formula (DR Computer) Method

4. Fig 1 illustrates the problem to be solved. A and B are the two airfields and C is the critical point whose position along AB is to be found. The distance from A to B is D, and the distance from A to C is X. The groundspeed on to the destination is O and the ground-speed back to base is H. In most cases, these ground-speeds will be calculated on the basis of a reduced TAS.

9-16 Fig 1 Critical Point Problem



By the definition of Critical Point, the time from C to A is the same as the time from C to B.

Therefore:

$$\frac{D - X}{O} = \frac{X}{H}$$

$$XO = H(D - X)$$

$$XO = HD - HX$$

$$XO + XH = HD$$

$$\text{ie } X = \frac{HD}{O + H}$$

$$\text{or } \frac{X}{D} = \frac{H}{O + H}$$

5. In this latter form, the equation can be solved for X on the DR Computer by setting H on the outer scale against (O + H) on the inner scale and then reading X on the outer scale against D on the inner scale.

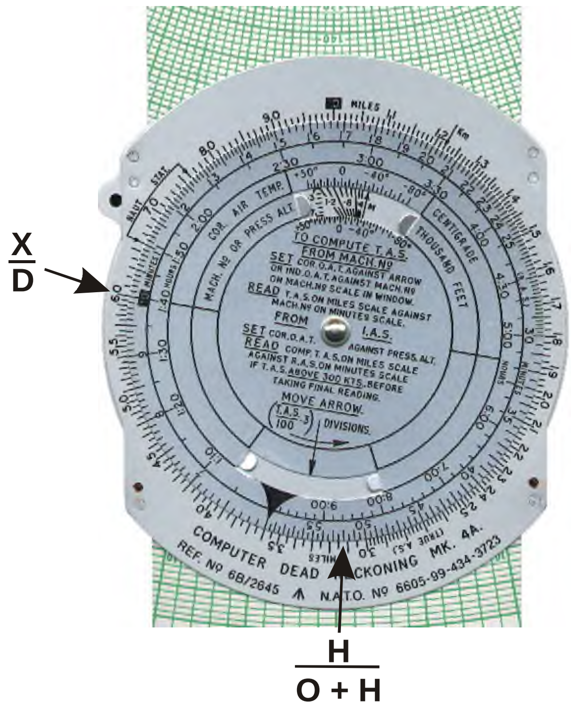
6. Example.

D	=	1,000 nm
Reduced TAS	=	260 kt
W/V	=	060°/60
Track	=	090°T
O	=	208 kt
H	=	312 kt
O+H	=	520 kt

From the DR Computer (Fig 2)

X = 600 nm

9-16 Fig 2 DR Computer Solution to Critical Point

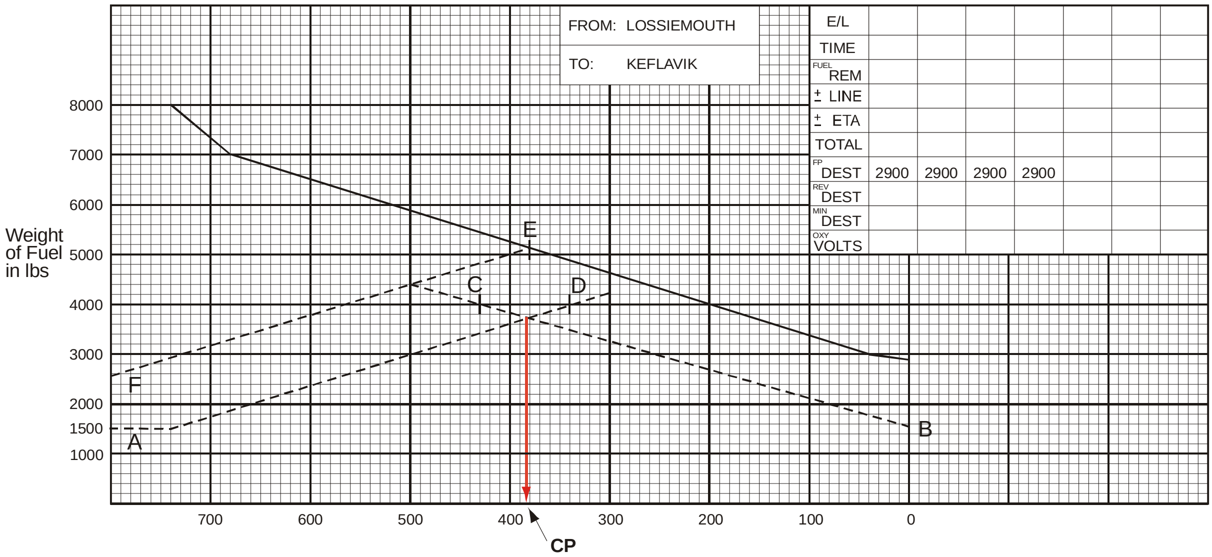


Howgozit Method

7. The CP can be determined using the fuel/distance Howgozit graph. The principle is to back plot, from the point at the departure and destination airfield representing the minimum fuel, two fuel gradient lines equivalent to the expected fuel consumption rate from the CP. The intersection of these gradients will then be at the CP.

8. Fig 3 shows a fuel/distance Howgozit for a flight of 741 nm. The minimum fuel required at either the destination or on return to base is 1,500 lbs. Points A and B represent this fuel value at the departure and destination airfields.

9-16 Fig 3 Howgozit Solution of Critical Point



9. The requirement now is to determine the fuel gradients in terms of fuel against distance, taking into account the optimum single-engine cruising level and speed, a representative AUW, and the expected wind velocity. The ODM table (Fig 4) shows an example of the distance flown whilst using 2,500 lbs of fuel (from 4,000 lbs to 1,500 lbs) for a selection of head and tail wind components. Other aircraft will have different figures, but the principle remains the same. The gradients can now be constructed by stepping these distances from the departure and destination airfields on the graph and plotting the 4,000 lbs of fuel point.

9-16 Fig 4 ODM Table - Distance Flown for 2500 lbs of Fuel

Headwind Knots	*Distance Naut. Miles*	*Tailwind Knots*	*Distance Naut. Miles*
0	415	0	415
5	405	5	425
10	400	10	430
15	390	15	440
20	380	20	450
25	375	25	455
30	365	30	465
35	355	35	475
40	350	40	480
45	340	45	490
50	330	50	500
55	325	55	505
60	315	60	515
65	305	65	525
70	300	70	530
75	290	75	540
80	280	80	550
85	275	85	555
90	265	90	565
95	255	95	575
100	250	100	580

10. On the example graph, the 'home' wind component is 9 kt head and the 'out' component is 8 kt tail. These values are computed using forecast wind velocity and a reduced TAS in the single engine case. Fig 4 gives distances of 401 nm and 428 nm respectively for these wind components. Point C is plotted at 4,000 lbs and 428 nm from destination; point D is plotted at 4,000 lbs and 401 nm from departure (741 – 401 = 340 DTG). CB and AD are then the required fuel gradients and their intersection gives the CP position, 383 nm DTG.

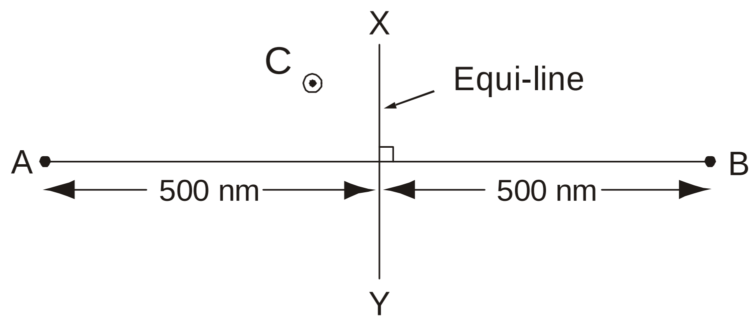
11. It should be remembered that the CP represents the equal time point between two bases and the fact that the solution has been determined on a fuel Howgozit graph does not in itself guarantee that the aircraft will arrive at base or destination with the minimum required fuel. The expected fuel can be determined by drawing a line through the flight plan fuel point at the CP parallel to the appropriate gradient determined above. Thus, on the example graph, if it was decided to return to base from the CP under the single-engine conditions, the fuel line would be plotted as EF, parallel to AD, giving an expected fuel at base of 2,900 lbs. However an adverse combination of distance and wind velocity could bring the overhead fuel level to less than minimum.

Critical Line

12. The critical point represents that point on track from which it will take equal time to proceed to destination or return to base. If the aircraft is off track however, the critical point loses its significance and must be replaced by a critical line. For a straight line track, as in Fig 5, in still air the perpendicular

bisector of track represents the equal time line back to A or on to B. Thus, for an aircraft well off track (at C), it would be quicker to return to A than proceed to B in still air.

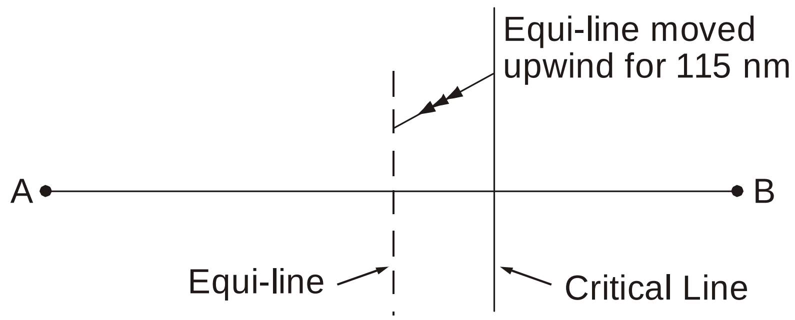
9-16 Fig 5 Critical Line in Still Air



13. To be valid, this line must be modified for the effect of wind. The time for the aircraft to fly from the still air critical line to either A or B in still air at the reduced TAS is calculated. The critical line is then moved upwind by a distance equal to the still air time multiplied by the wind speed.

14. In the example, the still air critical line is at 500 nm, the reduced TAS is 260 kt and the wind velocity is 060°/60. The still air time to fly from the critical line to either A or B is 115 minutes (1.923 hrs). Thus the critical line must be moved upwind (i.e. in the direction 060° T) by 1.923 × 60 nm = 115 nm (Fig 6).

9-16 Fig 6 Wind - Modified Critical Line



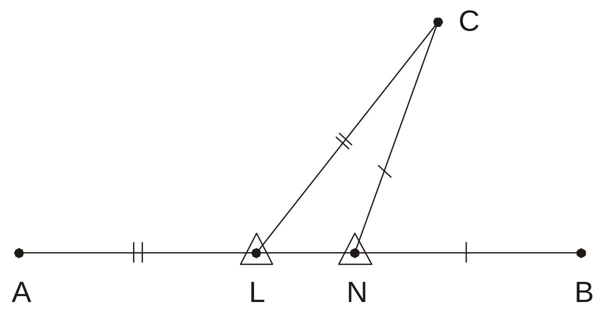
15. The assumption in this solution is that the distance, from any point on the still air critical line to A or B, is the same (i.e. 500 nm in this example). This assumption becomes less valid as distance off track increases but the errors induced are unlikely to be significant unless the track error is large and the route relatively short.

Critical Point/Line Between Three Airfields

16. The discussion in the foregoing paragraphs has considered only the case where the options available are proceeding to the destination or returning to base. More commonly, there will be a third option of diverting to an off-track airfield. Fig 7 shows the still air situation, where, between A and L, it will be quicker to return to base, from L to N it will be quicker to divert to C, and beyond N it will be quicker to

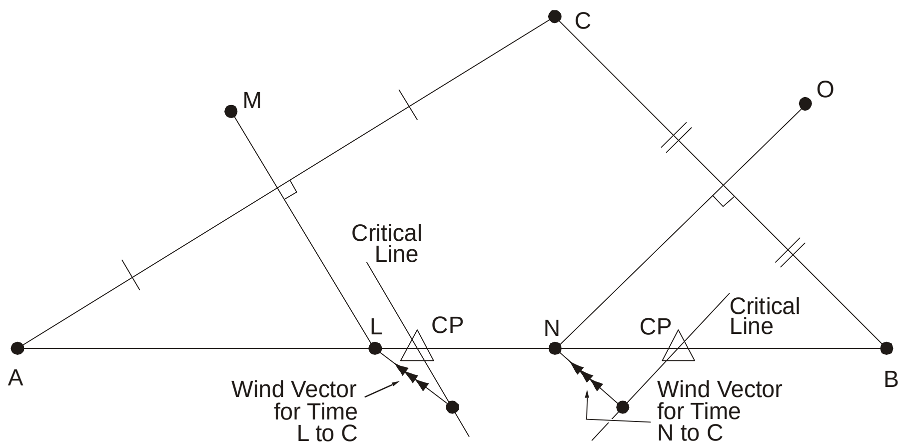
proceed to B. Thus, L and N represent two critical points. The best method of finding the positions of L and N is graphical and is based on the critical line solution.

9-16 Fig 7 Critical Point Between Three Airfields



17. The method is illustrated in Fig 8. AC and BC, joining the departure and destination airfields to the diversion, are drawn, and the perpendicular bisectors of these lines (LM and NO) are constructed to cut the track, AB, at L and N. As L is equidistant from A and C, and N is equidistant from B and C, L and N are the still air critical points.

9-16 Fig 8 Graphical Solution for Critical Points/Lines Between Three Airfields



18. To account for the wind effect the points L and N are moved upwind, in the same manner as constructing a critical line, by an amount equal to the wind speed multiplied by the time to fly from L and N respectively to C at the reduced TAS. Critical lines are drawn through the ends of the wind vectors, parallel to LM and NO, and where these cut the track represent the critical points.

POINT OF NO RETURN

Definition

19. The point of no return (PNR) is that point furthest removed from base to which an aircraft can fly and still return to base within its safe endurance. PNR is normally calculated on long flights where the

aircraft is unable to land between the departure and destination airfields. As with the CP, there are three methods of solution, but only the formula (DR Computer) and Howgozit methods are practical.

Formula (DR Computer) Method

20. By definition, the distance to the PNR equals the distance from the PNR back to base. If T is the time to the PNR, O the outbound groundspeed (using full TAS), H the homebound groundspeed (full TAS), and P the aircraft endurance, then:

$$\begin{aligned} T \times O &= (P - T)H \\ TO &= PH - TH \\ T(O + H) &= PH \end{aligned}$$

$$\text{ie} \quad T = \frac{PH}{O + H}$$

Distance to the PNR is then found from T × O.

21. The problem can be solved on the DR Computer by transposing the formula into the form:

$$\frac{T}{P} = \frac{H}{O + H}$$

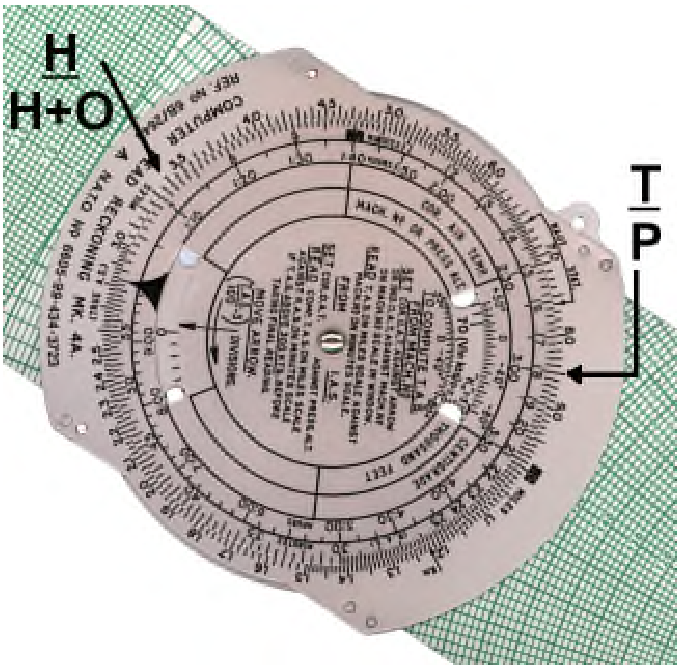
H is set on the outer scale against O + H on the inner scale and then T can be read on the outer scale against P on the inner scale.

22. Example.

$$\begin{aligned} O &= 380 \text{ kt} \\ H &= 340 \text{ kt} \\ P &= 3 \text{ hrs} \\ \therefore \frac{T}{180} &= \frac{340}{380 + 340} = \frac{340}{720} \end{aligned}$$

From Fig 9, T can be seen to equal 85 minutes. Distance to PNR is then equal to 85 minutes at 380 kt = 538 nm.

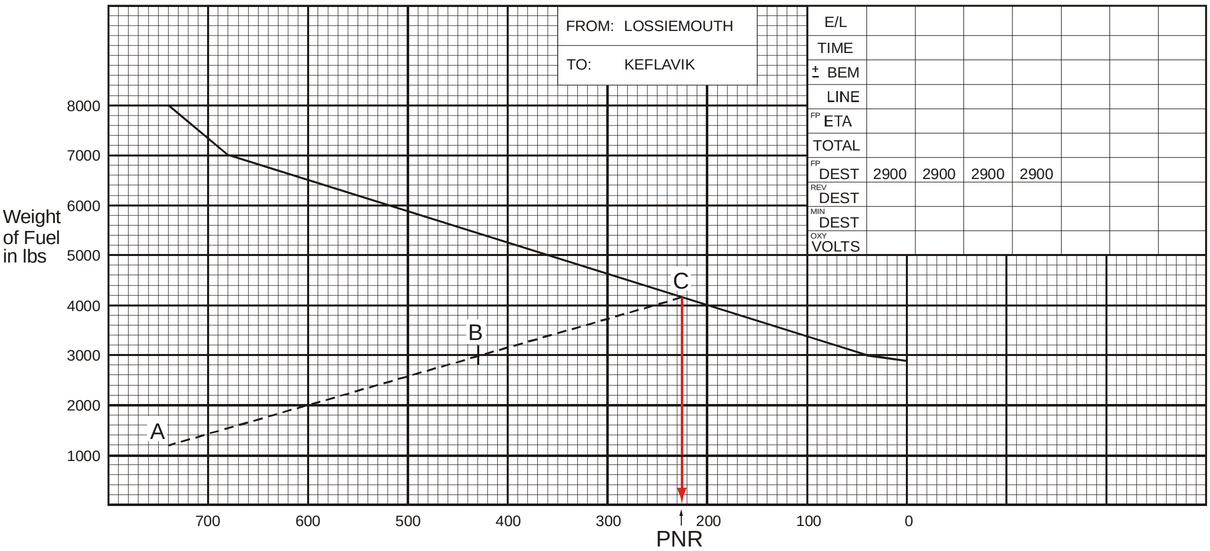
9-16 Fig 9 DR Computer Solution to PNR



Howgozit Method

23. Fig 10 shows a fuel/distance Howgozit for a flight of 741 nm. Point A represents the minimum fuel requirement on arrival back at base (1,200 lbs) and it is necessary to construct a fuel gradient back to this point.

9-16 Fig 10 Howgozit Solution for Point of No Return



24. From the ODM cruise table, the TAS and fuel flow rate for the appropriate return flight level is extracted. An assumption will have to be made for the AUW pertinent to the return leg, a mid-AUW will probably suffice.

25. The groundspeed is now calculated for the homebound leg, using the ODM TAS and the forecast wind velocity. There is now sufficient information to plot the gradient as the fuel used per hour and the distance flown per hour are known and therefore the fuel used per distance is known. In the example, the fuel rate is 1760 lbs/hr and the groundspeed is 312 kt and a point on the graph at 1760 + 1200 = 2960 lbs and 312 nm from base can be plotted (B in Fig 10).

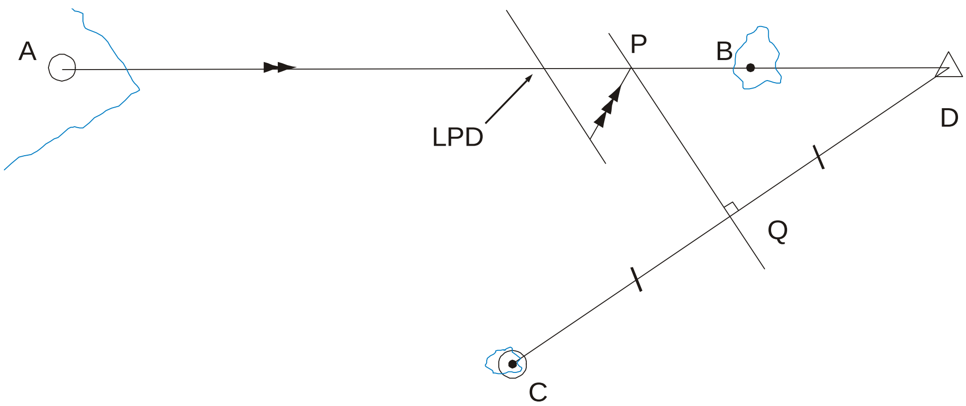
26. The fuel gradient is drawn in by joining AB and is extended to intersect the planned consumption line (C in Fig 10). The distance corresponding to this point represents the PNR.

Last Point of Diversion

27. The last point of diversion (LPD) is a special case of the point of no return. Under normal circumstances, an aircraft will arrive at its destination with sufficient fuel reserves to divert to and reach its diversion with a specified minimum fuel. However, occasionally, routes may be flown where the nearest diversion is at such a distance from the destination that the aircraft cannot carry enough fuel to reach the destination and then divert safely. Under these circumstances it is possible to determine that point along track beyond which it is impossible to reach the diversion airfield safely. This point is known as the 'Last Point of Diversion'.

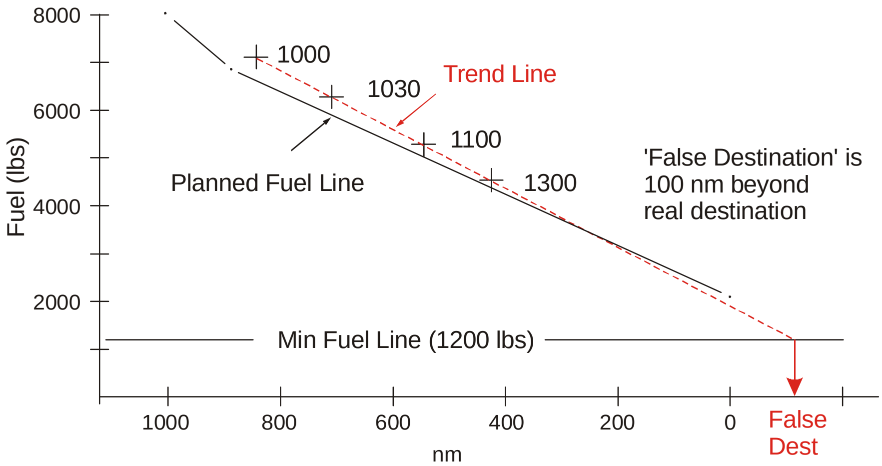
28. The LPD is found graphically and the procedure is illustrated in Fig 11, where B is the intended destination. AB is the final track, and C is the diversion airfield. The track AB is extended to D (the false destination) such that AD represents the limit of safe endurance at the groundspeed along that track. CD is joined and a perpendicular bisector is constructed, QP, cutting AD at P. The still air time from P to C is calculated and a wind vector is drawn upwind from P for this time. A critical line can now be drawn parallel to PQ cutting the track AB at the last point of diversion for C.

9-16 Fig 11 Last Point of Diversion (LPD) Solution



29. In flight it may be necessary to amend the position of the false destination in accordance with a Howgozit fuel trend. Fig 12 shows a Howgozit graph with a fuel trend drawn in. This is extended to intersect the minimum fuel line and the distance equating to this point defines the false destination, in this example 100 nm beyond the destination. The LPD is then constructed graphically as above.

9-16 Fig 12 Howgozit Solution of False Destination (FD)



CHAPTER 17 - TIMING TECHNIQUES

Introduction

1. Many air operations require that aircraft reach a given point at a precise time. As it is usually easier to lose time than to gain it, such operations are often planned with a margin of time in hand. Whether or not this is done, some adjustment to the speed or to the distance flown will invariably be necessary to achieve the planned arrival time.

TIMING BY SPEED ADJUSTMENT

General

2. The obvious way to alter an aircraft's time of arrival at its target is to increase or decrease the airspeed, thus changing the groundspeed. If the aircraft is equipped with a navigation system giving a direct readout of groundspeed, it is more convenient to base adjustments directly on groundspeed.

3. Only a small increase above the standard operating speed of an aircraft at a given height is normally possible without an appreciable penalty in fuel consumption. Small speed changes result in only small increases or decreases in flight time. For example, at a groundspeed of 200 kt an adjustment in groundspeed of 10 kt will gain or lose only three minutes in an hour; the same adjustment at 400 kts gives a difference of only one and a half minutes per hour. If, therefore, accurate timing at the target is to be achieved by speed adjustments, action must be initiated as early as possible. The ideal is to be on time at the beginning of a flight, and stay on time by adjusting the speed at each fix.

4. Two factors usually tell against attainment of the ideal. If operating in an area not served by a reliable wind forecasting service (a situation more common operationally than in training), to stay on time during the early part of the flight might lead to impracticable speed changes being required when near the target, to compensate for major changes from the forecast head or tail wind component. Furthermore, frequent speed changes when operating high performance aircraft are expensive in fuel. It is therefore good practice to make only one or two adjustments to speed in the early stages of theflight, and changes at turning points are usually adequate. The aim is to stay nearly on time but with a progressively decreasing amount of time in hand, arriving on time at a suitable way point near enough to the target to allow any reasonable wind changes to be taken care of by speed adjustment. From that waypoint, to the target, timing is checked and speed adjusted at each fix.

Calculation of Speed Adjustments

5. The required groundspeed changes can be calculated as follows:

a. On the Dead Reckoning computer, by calculating the groundspeed required between a fix and the next turning point, by using time and distance to go.

b. By the use of tables, prepared for the usual operating speeds, giving the amount of time gained or lost if various speed changes are applied for a given period.

c. By using annotations, made on the flight plan, of the airspeed adjustments required to gain or lose one minute, computed for each leg.

d. By estimation in flight using mental DR (MDR).

6. An MDR change of G/S can be converted to an MDR change in CAS by multiplying it by the approximate ratio of CAS to TAS. Thus, if the required G/S is an increase of 44 kt with a current CAS of 209 kt and a TAS of 282 kt, then the CAS should be increased by 44 × 0.75, i.e. 33 kt.

Change of Mach Number

7. When an aircraft is being flown by reference to a Mach meter, rather than an airspeed indicator, an adjustment to indicated Mach number to gain or lose time can be calculated as follows:

a. **Computer Method**.

(1) Determine the present groundspeed.

(2) Determine the groundspeed required to make good the required ETA.

(3) Calculate, on the computer, a new Mach number to fly, using the following formula:

$$\frac{\text{Current Mach No}}{\text{Current G / S}} = \frac{\text{New Mach No}}{\text{Required G / S}}$$

This method is adequate under most circumstances, but becomes increasingly inaccurate with head or tail wind components in excess of 50 kt.

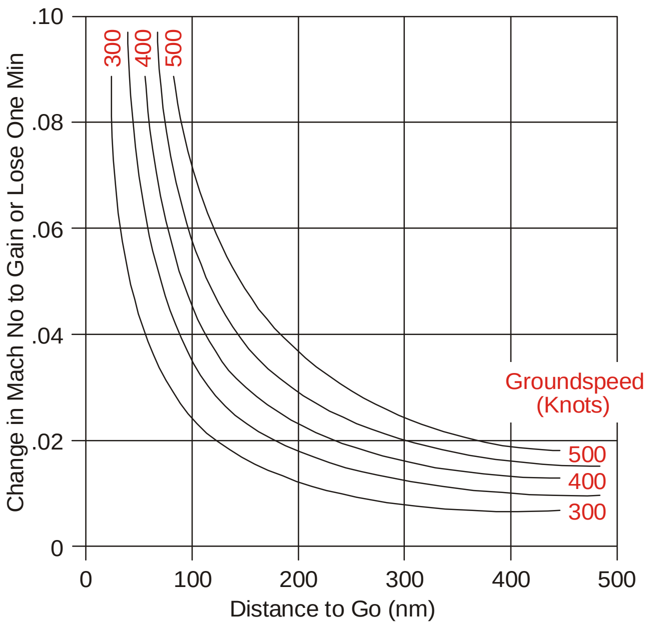
b. **Use of Timing Graph**. The change in Mach number required can be determined directly from a graph (such as that illustrated at Fig 1); the method is as follows:

(1) Calculate the ETA, using the current groundspeed and the distance to go.

(2) From this ETA and the required ETA, determine the amount early or late.

(3) Enter the graph with distance to go and current groundspeed, extract the Mach number change required to gain or lose one minute, and by proportion determine the Mach change needed.

9-17 Fig 1 Change of Mach Number to Gain or Lose Time



TIMING BY ADJUSTMENT OF DISTANCE TO BE FLOWN

General

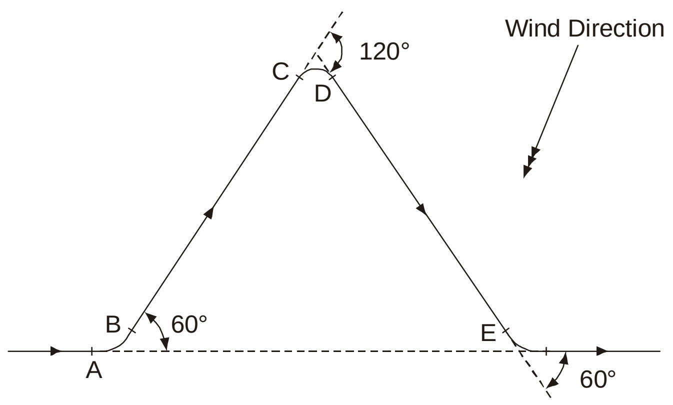
8. It may sometimes be desirable to adjust timing by altering the distance to go rather than by changing airspeed. The various methods of doing this, some of them requiring pre-planning and some not, are described in the following paragraphs.

Losing Time by 60° Dog-leg

9. Heading is altered 60° in either direction for the length of time that is to be lost, then altered 120° in the opposite direction for the same length of time to regain track. Heading to the next turning point, or target, is then resumed. The aircraft will, thus, have flown two sides of an equilateral triangle, and the time lost will be equal to the time taken to fly one side.

10. Small inaccuracies in tracking and time lost will be introduced by the wind effect during the procedure, but they will usually be negligible if the amount of time to be lost is small. If the same constant rate of turn is maintained throughout the three turns, and if legs are timed accurately from levelling out after a turn to the start of the next turn (see Fig 2), the effect on time lost of the time taken to turn can be ignored.

9-17 Fig 2 60° Dog-leg Procedure



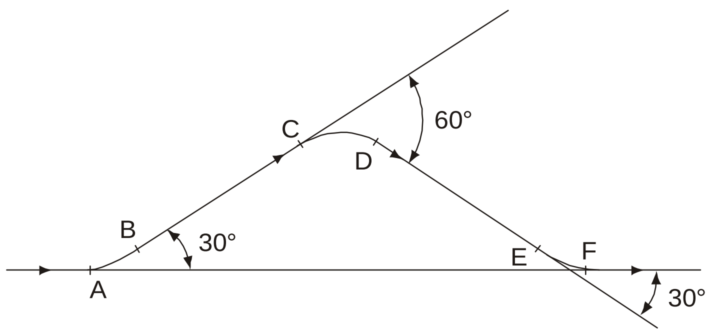
Notes.
1. Legs are Timed Between B-C and D-E.
2. Time Lost ≏ Time Flown B-C.

11. The 60° dog-leg procedure, as described above, can normally be used for small time losses. If more than two minutes is to be lost, or if the wind is strong, it will be necessary to adjust the time on the second leg to ensure that the final turn will bring the aircraft back on track. If this is not done, the resulting track error will leave a further timing problem, particularly if near the next turning point. Where such an adjustment will be necessary, it is usual to make the first turn towards the 'into wind' direction. This will ensure that track can be rejoined with time in hand, and that it will not be necessary to extend the second leg to regain track, thus putting the aircraft in the more difficult position of having to make up time.

Losing Time by 30° Dog-leg

12. A similar procedure, altering heading first 30° in one direction, then 60° in the other, before resuming heading, may be used for small adjustments in ETA (see Fig 3).

9-17 Fig 3 30° Dog-leg Procedure



Notes.
1. Legs are Timed B-C and D-E.
2. Time A-F ≏ $\frac{7}{8}$ of time A-C-F and time loss ≏ 1 min in 8 mins.

13. For each minute to be lost, each leg is flown for four minutes. This procedure is useful for small time losses (up two minutes) when it is desired to stay near track and avoid big alterations of heading.

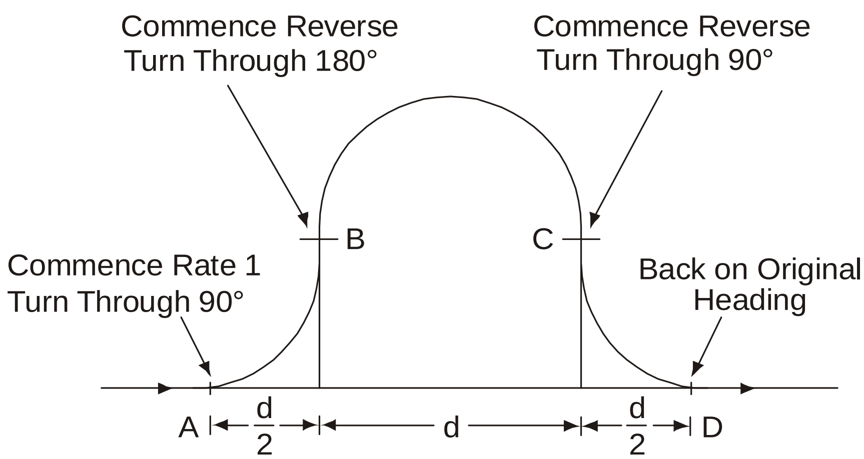
14. Even when timing is not a consideration, adoption of a formal dog-leg procedure to avoid obstacles or weather will enable the track to be regained and ETA amended with minimum calculation.

Losing Time by Rate 1 Turns (90° Method)

15. The procedure illustrated at Fig 4 could occasionally be useful in high performance aircraft. The time lost by using the procedure is arrived at as follows:

Distance A-B-C-D	=	π d (where 'd' is the diameter of turn)
Time A-B-C-D	=	2 mins (360°at Rate 1)
Direct Distance A-D	=	2d
Time A-D	=	$2d \times \frac{2}{\pi d}$ mins
	=	1¼ mins approx
∴ Time lost	=	¾ min

9-17 Fig 4 Losing Time by 90° Method



16. To lose more than ¾ min, subtract ¾ min from the time to be lost, and straighten up between each reverse for half the resultant time.

Summary of Dog-leg and 90° Methods

17. The above methods suffer from the disadvantages that:

a. They are imprecise in regaining track.

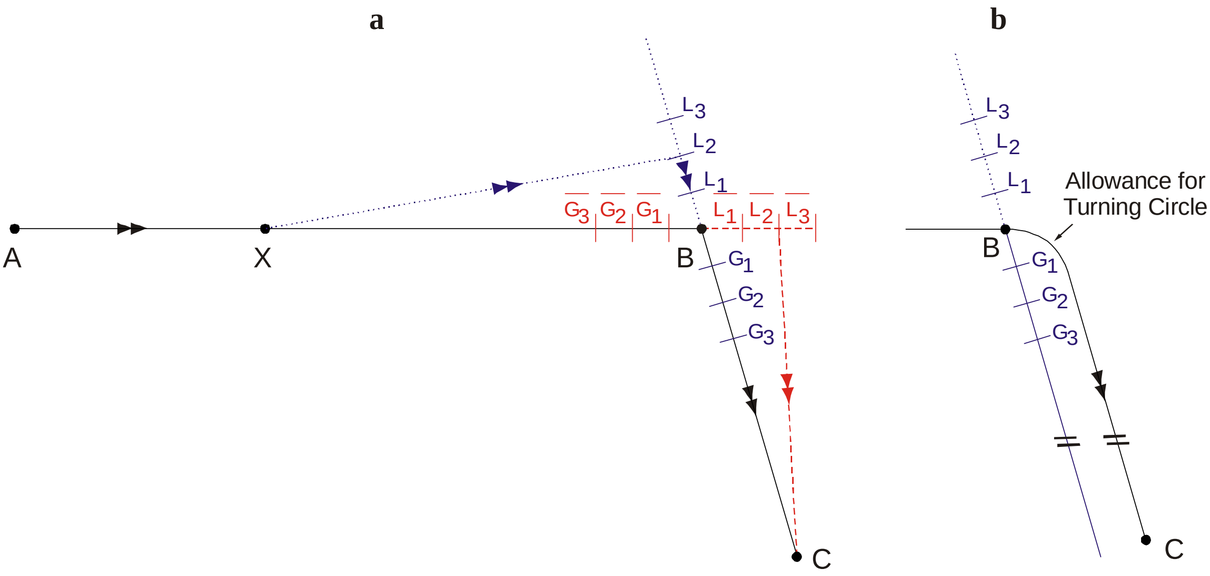
b. They can be inaccurate in losing time.

18. It is usually necessary for them to be followed by heading corrections, and if precision is required, by speed adjustments. They do, however, serve to lose a lot of time in a short distance along track, but at the expense of considerable deviation from the planned track - not always tactically acceptable.

Cutting the Corner

19. If there is a suitably large track alteration along the route, timing may be adjusted by extending or cutting the corner at that turning point. Two simple examples of this procedure are shown in Fig 5.

9-17 Fig 5 Timing by Adjustment of Track at a Turning Point



20. Given a route A-B-C (Fig 5a), timing is adjusted by adopting a new turning point in place of position B. As shown in Fig 5a, distances representing 1, 2 and 3 minutes of groundspeed are marked along the track B C and its reciprocal, and marked G_1, G_2 and G_3 (gaining time) and L_1, L_2 and L_3 (losing time). If at position X the aircraft were two minutes ahead of time, heading would be altered to fly the track X-L_2-C. Alternatively, the track AB may be extended beyond B and the 1, 2, and 3 minute marks placed on this extension for losing time ($\overline{L_1}$, $\overline{L_2}$ and $\overline{L_3}$) and on the reciprocal for gaining time ($\overline{G_1}$, $\overline{G_2}$, and $\overline{G_3}$). If running late, time may be gained by turning early to C from either $\overline{G_1}$, $\overline{G_2}$ or $\overline{G_3}$. If early, overflying B and turning towards C from $\overline{L_1}$, $\overline{L_2}$ or $\overline{L_3}$ will provide the appropriate number of minutes delay. However, since the track has changed so too will the groundspeed. Thus a revision of timing on the new leg will be necessary. Where turning circles have to be allowed for, and using the first method as an example, it is convenient to mark the timing points along a line parallel to the track from B to C, passing through the originally planned start turn point at B, as shown in Fig 5b. ETA start turn is then easily calculated.

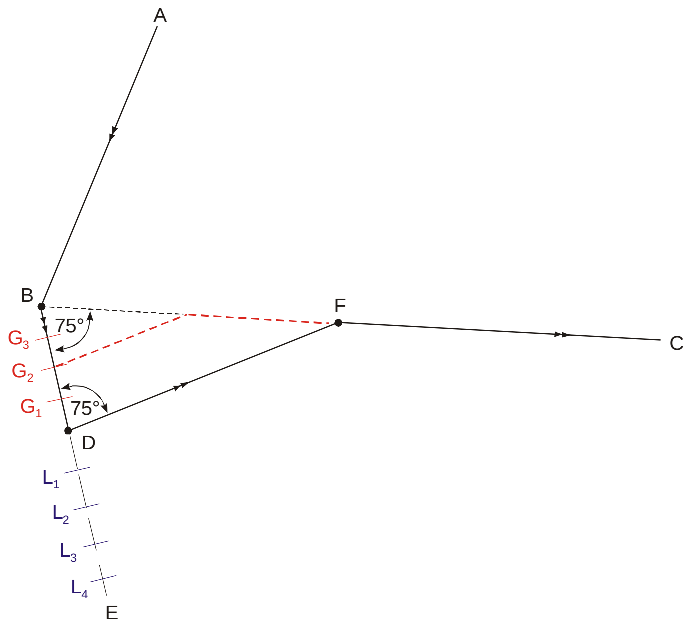
21. The technique of cutting short/extending at corners, described in Para 20, requires the turn angle at B to be close to 90°, so that, for example, the leg X - L_2 would be approximately equal to X - B.

Pre-computed Timing Leg

22. A more precise method of adjusting timing, by revising the distance to be flown, is to use pre-computed timing legs at any convenient turning point. Use is again made of the principle of isosceles triangles.

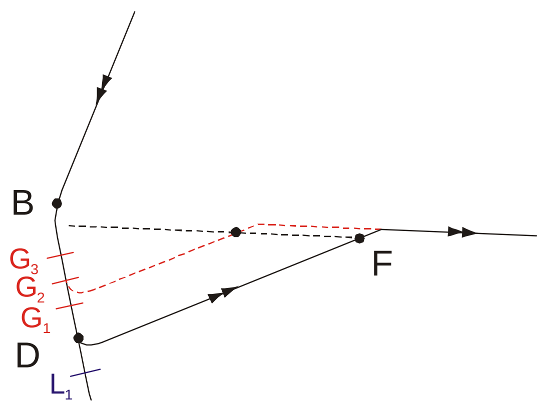
23. Fig 6 shows pre-computed timing legs constructed for the route A-B-C. At position B, a line BDE is drawn at an angle of 75° to track BC. The length of BD is the distance flown in, say, four minutes where three minutes is the longest period it is thought it will be necessary to make up at that turning point. Similarly, DE is the distance flown in the maximum time it will be necessary to lose. From D, line BDE is divided into units of distance flown in one minute, and marked G_1, G_2, L_1, L_2 etc as shown.

9-17 Fig 6 Pre-computed Timing Legs



24. A line DF is drawn at an angle of 75° to BD to intercept BC at F. A-B-D-F is now the 'on time' track, used in calculating the required set heading time when completing the flight plan. The dotted line in Fig 6 illustrates the track to gain two minutes. A method of construction when allowance must be made for turning circles is shown in Fig 7.

9-17 Fig 7 Pre-computed Timing Legs with Turning Circles



GENERAL CONSIDERATIONS

Accuracy

25. Accurate flying and navigation are essential to successful timing. Turns should be executed at the planned rate, and the aircraft flown at the correct airspeed and altitude. Track keeping is important; attempts to make up or lose time by speed adjustment will be negated if the aircraft is allowed to stray far from the planned track.

Early Remedial Action

26. The task of arriving at a target, or destination, on time will be simplified if any tendency to gain or lose time is quickly recognized, and if remedial action is taken before too big an error has accumulated. When the aircraft is early, care must be taken to ensure, before shedding all the time in hand, that the planned route for the remainder of the flight to the target, coupled with practicable speed adjustments, gives sufficient flexibility to make up any foreseeable subsequent loss of time.

CHAPTER 18 - FLIGHT PLANNING

Introduction

1. Fast jet operations are primarily concerned with the delivery of weapons onto a surface or air target, and the gathering of reconnaissance information. In the air defence role, air navigation will normally be carried out with direct reference to the air target rather than to geography, and with assistance or control from ground agencies, AWACS, or on-board sensors. Even so, an awareness of geographical position is vital so that adequate terrain clearance can be maintained and the aircraft fuel state in relation to base or diversion airfield can be monitored.

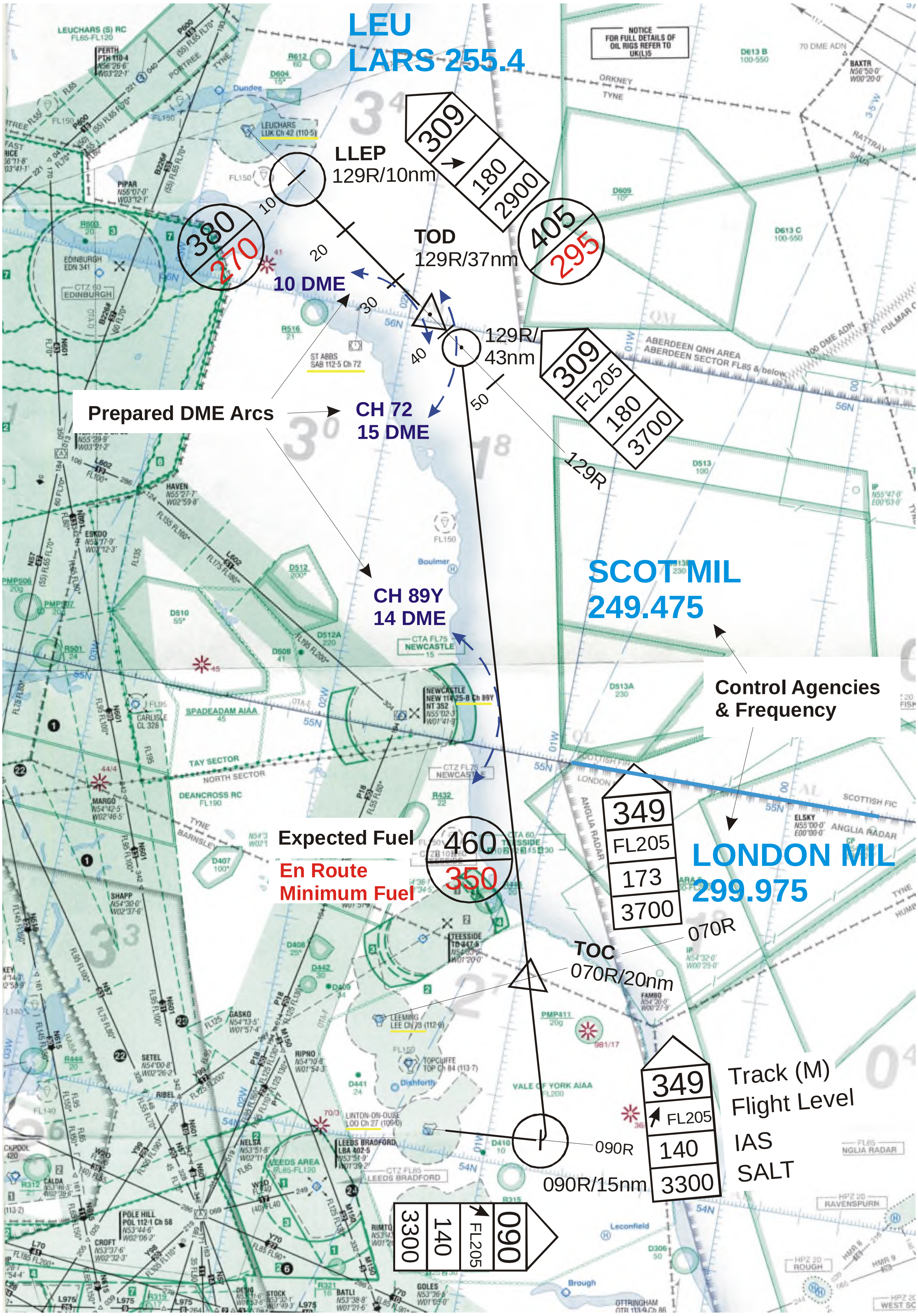
2. In addition to these specialized roles, there are occasions where some form of medium or high-level navigation techniques are appropriate, e.g. transit to a low-level entry point (LLEP) or exercise area, or a ferry flight. However, due to the limited cockpit space the techniques of Volume 9, Chapter 14 can rarely be used without amendment, particularly in single-seat aircraft; maximum use will be made of mental dead reckoning (MDR) techniques (Volume 9, Chapter 19) and radio aids (see Volume 9, Chapter 21). The particular case of airways flying is covered in Volume 8, Chapter 30.

Planning and Map Preparation

3. **Chart**. The en route series of charts (ERCs) are normally used for medium/high level navigation. Although the high-level chart will be used in the UK for any cruise portion of the flight above FL 245, reference will need to be made to the low-level chart for the climb and descent portions, to ensure that due account is taken of restricted and controlled airspace at the lower levels. It may be considered desirable to highlight any restricted airspace adjacent to track and emphasize its vertical extent. In addition, navigation beacons and any control frequencies may be emphasized. Other information which should be annotated includes safety altitude and pressure setting for the descent, and the contact frequency for any suitable air traffic control agency that might be able to provide assistance, particularly if in IMC.

4. **Route**. The route waypoints should be carefully selected and plotted. The tracks can be drawn between waypoints, ensuring that the appropriate turning circles for the TAS and rate of turn are correctly constructed. An information box may be drawn near the beginning of each leg as shown in Fig 1. Distance-to-go (DTG) marks are annotated along track, if required.

9-18 Fig 1 Medium Level Transit to LLEP (not to scale)



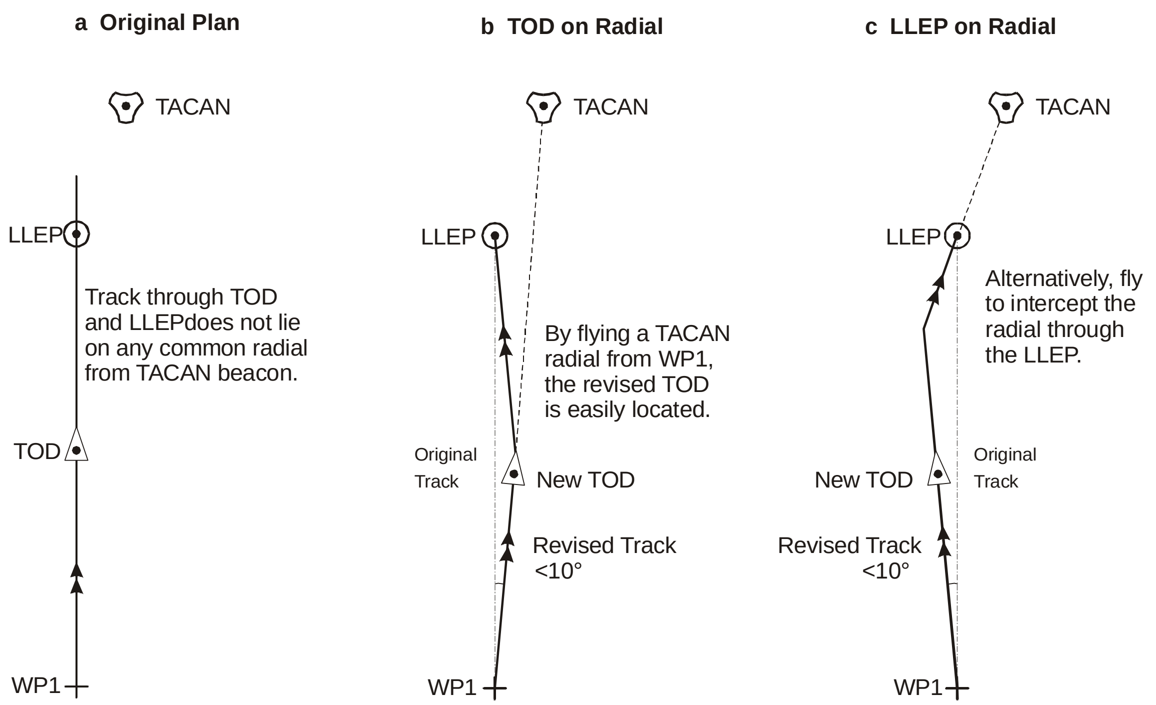
5. **Planning**. The top-of-climb (TOC) and top-of-descent (TOD) points are calculated and plotted using Operating Data Manual (ODM) or Flight Reference Card (FRC) information. The determination of

headings and groundspeeds for the climb, cruise and descent portions may be achieved using the DR Computer or MDR methods.

6. **Fixing**. To simplify matters in the air, especially for the single-seat operator, it will be beneficial to construct a selection of range circles and bearing lines from appropriate TACAN, VOR or DME beacons (Fig 1). Careful selection of beacons can assist navigation and reduce workload. TACAN or DME ranges from beacons on the beam will provide position lines to assist tracking. Beacons ahead or behind, aligned with track, offer many advantages - a VOR or TACAN bearing will assist with tracking; a DME or TACAN range will provide distance gone or distance to go information. The use of radio aids for navigation is covered in Volume 9, Chapter 21.

7. **Selection of Beacons for Descent**. It is especially beneficial to have one beacon aligned with track during the section from TOD to LLEP. This will help to ensure that the TOD and LLEP can be located accurately and with the minimum of effort, during a portion of the flight where the workload is liable to be high. Indeed, it may be worthwhile revising the descent track if a small change (perhaps 10º to 15º) will enable alignment with a beacon (see Fig 2). During the final stages of the descent, terrain screening and earth curvature (i.e. long range) are considerations, as they may cause the beacon to unlock.

9-18 Fig 2 Adjusting Track to make best use of TACAN Beacon



Fuel Planning

8. Fuel planning is accomplished using data from the ODM or FRCs as appropriate (see also Volume 9, Chapter 15). Many units will have locally produced, rapid planning guides to cover the normal load configurations and the common flight profiles. Minimum and expected fuel figures are calculated for TOC, TOD and, if appropriate, the LLEP. Conventionally, the figures are marked on the map in a circle

(Fig 1), the top figure being the expected fuel and the lower figure is the 'en route minimum fuel' (see para 9). In addition, for extended cruise sectors, fuel circles should be added, at medium level every 30 minutes and, at low level at convenient intervals such as 6 or 10 minutes.

9. **En Route Minimum Fuel**. The 'en route minimum fuel' is the amount of fuel required at a specific point, to enable the aircraft to complete the route as planned, arriving at the destination with the specified fuel reserves.

10. **Fuel Checks**. During the sortie, fuel checks should be taken at the planned points by comparing the aircraft's actual fuel remaining against the expected fuel. Regular and punctual fuel checks will assist the crew in identifying any deviation from the expected fuel flow rate.

11. **COMBAT and BINGO Fuels**. The following terms are commonly used to assist in-flight fuel management:

a. **COMBAT Fuel**. At any point en route, the difference between the aircraft's fuel remaining and the en route minimum fuel is termed COMBAT fuel. A positive COMBAT figure can be utilized for unplanned eventualities such as extra tasking, weather avoidance, timing adjustment by speed (if late), or actual combat. A negative COMBAT figure indicates that some fuel saving action is necessary.

b. **BINGO Fuel**. The term BINGO fuel is used to describe the minimum amount of fuel required at a point, to enable the aircraft to recover to base, or nominated airfield, utilizing the most economical route and profile from that point, to arrive with the specified fuel reserves. The ideal criterion for a BINGO profile is a direct route, with an unrestricted climb to the most efficient cruising level, followed by an unrestricted descent to land from the first approach. The BINGO calculation must include an allowance for any headwind. Furthermore, where there are foreseeable ATC restrictions in routeing or cruising heights, the BINGO fuel must include suitable allowance.

12. **Formation Sorties**. To assist with sortie management, the leader of a formation must be aware of the fuel situation of the other aircraft whilst airborne. The leader will normally brief the other pilots to declare when they first reach a specified fuel state; often termed 'JOKER' fuel. The pre-flight briefing should include fuel information calls tailored to the particular sortie, e.g.

JOKER 1 = 30 minutes of fuel remaining
JOKER 2 = 2,000 kg of fuel remaining

Prompt and diligent reporting of fuel states by formation members is essential.

CHAPTER 19 - MENTAL DEDUCED RECKONING

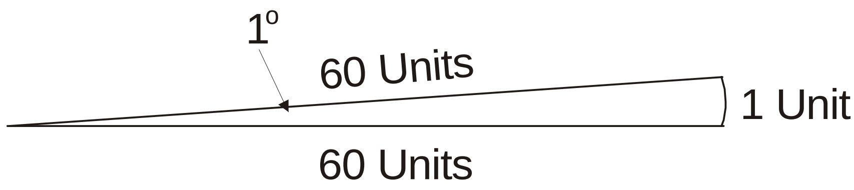
Introduction

1. The operating environment in a single or two-seat cockpit normally precludes the use of traditional plotting and calculating equipment. Further limitations may be imposed by system degradation or equipment unserviceability and, in some aircraft, the lack of navigation aids. There is, therefore, a requirement to be able to solve mentally, calculations involving speed, distance, direction, time and fuel. The ability to multiply and divide numbers mentally is an essential skill that users of Mental Deduced Reckoning (MDR) techniques must possess. As with any other skill, MDR needs to be practiced to the extent that it becomes second nature. This is particularly important in the airborne environment. An appreciation of the techniques of MDR can also be useful in checking the results from ground planning aids and aircraft navigation systems, thus avoiding gross errors.

The 1 in 60 Rule

2. The 1 in 60 rule is used as a method of assessing track error and closing angle, and has long been favoured as a MDR navigation technique because of its flexibility, ease of use and relative accuracy (up to about 40º). The 1 in 60 rule postulates that an arc of one unit at a radius of 60 units subtends an angle of one degree (see Fig l).

9-19 Fig 1 The 1 in 60 Rule



3. In practical use, this 1 in 60 rule may be applied equally well to a right-angled triangle. It may be accepted that, in a right-angled triangle, if the length of the hypotenuse is 60 units, the number of units of length of the small side opposite the small angle will be approximately the same as the number of degrees in the small angle (see Fig 2).

9-19 Fig 2 Application to a Right-angled Triangle

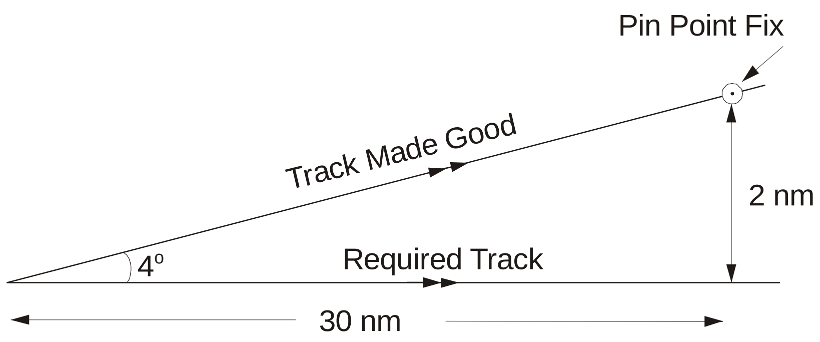
This approximation can be compared with the exact computation below:

Short Side	Sine of Angle	Angle
1 unit	1/60 = .0167	0º 57'
10 units	10/60 = .1667	9º 36'
20 units	20/60 = .3333	19º 28'
30 units	30/60 = .5000	30º
35 units	35/60 = .5833	35º 41'
40 units	40/60 = .6667	41º 49'

4. Furthermore, since the navigator is likely to have distances on the required track marked on his map, the approximation is just as good if the distance gone is measured along the required track (see Fig 3). In either case, the distance gone is compared with the distance off track and the ratio of one to the other is reduced to an angle.

$$\text{Track error (degrees)} = \frac{\text{Distance off Track x 60}}{\text{Distance along Track}}$$

9-19 Fig 3 Calculation of Track Error



Thus, an aircraft passing over a feature 2 miles port of the required track, after flying 30 miles has a track error of:

$$\frac{2}{30} \times 60 = 4^{\circ}$$

Estimation of Map Distances

5. With practice in using particular maps and their scale on the parallels of latitude, it should be possible to make reasonable estimates of distance by eye. This skill may be aided by one of the following techniques:

a. **Hand Measurements**. Map distances can be measured against a hand span, fist, or against the length from knuckle to tip of a finger or thumb. Wearing flying gloves will yield marginally different measurements over those made with the bare hand.

b. **Map Comparisons**. Pre-flight map preparation includes distance-to-go markers or time marks. These give distance values that can be used for comparison. Symbols on the map, such as a standard UK MATZ, or the latitude graticule can also be used for comparison.

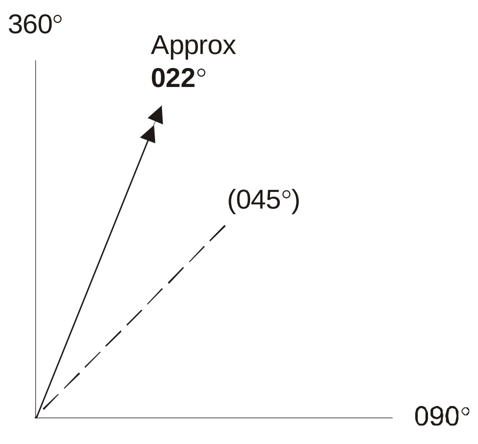
c. **Map Scale**. Any convenient straight edge can be marked, and the length measured against the latitude or map scale.

Estimation of Map Directions

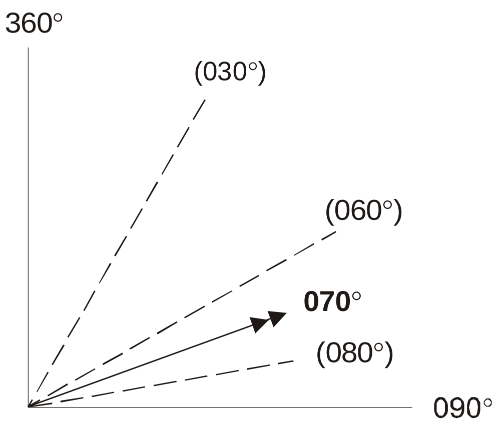
6. Changes of track may be required at short notice and the use of plotting instruments may be impractical. The ability to measure a direction 'by eye' is a skill that can be acquired with practice. Several techniques to estimate map directions are described in the following sub-paragraphs.

a. **Visual Inspection**. Most people can bisect or even trisect an angle by visual inspection quite accurately. Thus a 90° angle can be progressively broken down by bisection to 45°, 22° and 11° (see Fig 4), or by trisection to 30° and 10° (Fig 5). It is possible to combine these two techniques.

9-19 Fig 4 Visual Inspection to Bisect Angles



9-19 Fig 5 Visual Inspection to Trisect Angles



b. **1 in 60 Rule**. Use of the 1 in 60 rule to calculate angles (Para 2) can give results which are accurate to within 2°, up to about 40°. The rule can also be used to estimate tracks on a map as explained below (see Fig 6).

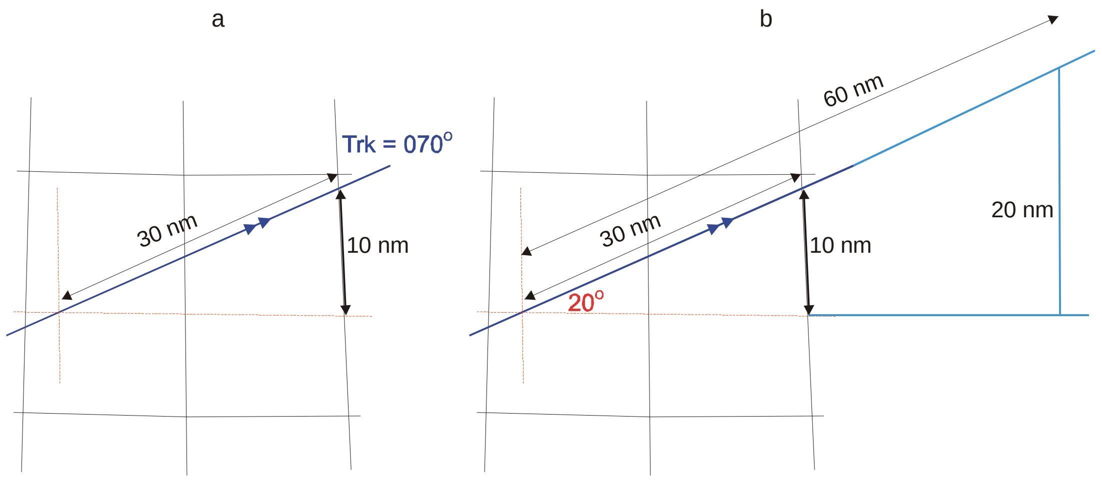
(1) Starting at a point where the track crosses a parallel of latitude (see Fig 6a), estimate a distance along the track which is a convenient fraction of 60. In this example, 30 nm has been used.

(2) From this estimated point, drop a vertical line to the parallel of latitude to form a right-angled triangle, as shown in Fig 6a.

(3) The length of this line is now measured (10 nm in this case) and the 1 in 60 rule applied to determine the angle (20°) (see Fig 6b).

(4) The track can now be estimated as 070° (90 – 20).

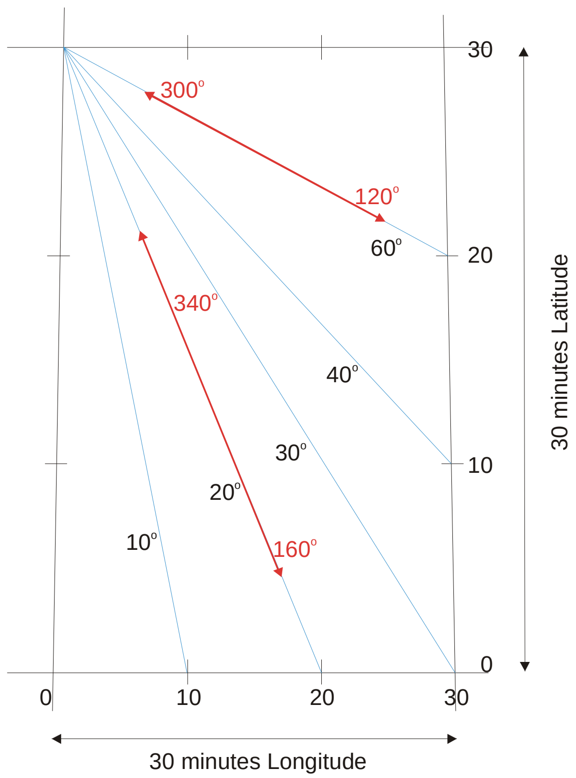
9-19 Fig 6 Using the 1 in 60 Rule to Estimate Track



c. **Map Comparison**. A required direction can often be estimated by comparison with other known directions on the map, such as drawn and measured tracks, airway centrelines, or overprinted VOR radials.

d. **Map Graticule**. The latitude and longitude graticule on the map can be used to estimate bearings and tracks. In Fig 7, the top left-hand corner of the box has been joined by lines to the 10-minute divisions of latitude and longitude. Measuring the angles these lines make with respect to true north, gives guidance which can be used to estimate tracks and bearings. This method can be used worldwide, but the example shown here applies to latitudes between 50° and 60°. Other latitudes will produce different angles to those shown. Users can construct an equivalent of Fig 7 for their normal operating latitudes.

9-19 Fig 7 Using the Map Graticule Between Latitudes 50°and 60° to Estimate Track



Estimation of True Airspeed (TAS)

7. Because of the rather complex effects of deviations from the standard atmosphere and of compressibility, there is no simple formula for the determination of TAS from either Calibrated Airspeed (CAS) or Mach number (see Volume 1, Chapter 1). Nevertheless, there are a few methods which can produce acceptable results within their limitations.

a. **Formula Method**. Up to about 25,000 feet, the TAS can be estimated by multiplying the CAS (in nm/min) by the altitude (in thousands of feet) and adding this figure to the CAS. This can be shown as:

TAS = CAS + (C x A)

Where C = CAS in nm/min

A = Altitude in thousands of feet

For example:

CAS = 210 kt (3 ½ nm/min), Altitude = 20,000 feet

TAS = 210 + (3.5 × 20)

TAS = 210 + (70) = 280 kt

b. **Mach Number Method**. At about 25,000 feet, the Mach number multiplied by ten is approximately equal to the TAS in nm/min, e.g. M 0.6 equates to 6 nm/min, which is 360 kt. For other heights a correction is applied to the TAS value as follows:

(1) If the indicated Mach number is M 0.6 or less, 1 kt is added to the TAS for each 1,000 ft below 25,000 ft, or, 1 kt is subtracted from the TAS for each 1,000 ft above 25,000 ft.

At 25,000 ft M 0.6 ≡ 6 nm/min ≡ 360 kt TAS

At 20,000 ft M 0.6 ≡ 360 + (1 × 5) = 365 kt TAS

At 35,000 ft M 0.6 ≡ 360 – (1 × 10) = 350 kt TAS

(2) If the indicated Mach number is greater than M 0.6, 2 kt are added to the TAS for each 1,000 ft below 25,000 ft, or, 2 kt are subtracted from the TAS for each 1,000 ft above 25,000 ft.

At 25,000 ft M 0.8 ≡ 8 nm/min ≡ 480 kt TAS

At 20,000 ft M 0.8 ≡ 480 + (2 × 5) = 490 kt TAS

At 35,000 ft M 0.8 ≡ 480 – (2 × 10) = 460 kt TAS

(3) Where the Mach number does not equate to a whole number of nm/min, the number of nm/min is multiplied by 60 to give the TAS; for example:

At 25,000 ft M 0.43 ≡ 4.3 nm/min ≡ 4.3 × 60 = 258 kt TAS

At 20,000 ft M 0.43 ≡ 258 + (1 × 5) = 263 kt TAS

At 35,000 ft M 0.43 ≡ 258 – (1 × 10) = 248 kt TAS

c. **Tabular Solution**. Table 1 shows the factor by which the CAS should be increased to approximate TAS at various heights.

Table 1 CAS to TAS Correction Factors

Height (ft)	Starting Value	% (Starting Value Squared)	Fraction of CAS to be added
40,000	10	100	1 × CAS
35,000	9	81	4/5 × CAS
30,000	8	64	2/3 × CAS
25,000	7	49	1/2 × CAS
20,000	6	36	1/3 × CAS
15,000	5	25	1/4 × CAS
10,000	4	16	1/6 × CAS
5,000	3	9	1/10 × CAS

The square of each 'starting value' gives a 'percentage' which is then used to give an approximate fraction by which the CAS should be increased. If the starting value of 10 for 40,000 ft is memorized, it is necessary only to reduce it by 1 for every 5,000 ft below.

For example:

CAS = 210 kt at 20,000 ft
From memory, starting value at 40,000 ft = 10.
Deduct 1 for every 5,000 ft below 40,000 ft.
Therefore, starting value at 20,000 ft = 6
6 squared = 36 % = approximately ⅓.
⅓ × CAS = 70 kt.
$\therefore$ TAS = 210 + 70 = 280 kt.

Four-step MDR Plan

8. The four-step MDR plan (Table 2) is a useful tool to enable the user to mentally determine, in a logical manner, navigational information within acceptable limits of accuracy. Subsequent paragraphs will explain the actions given in Table 2 and the reader should refer to the table as required.

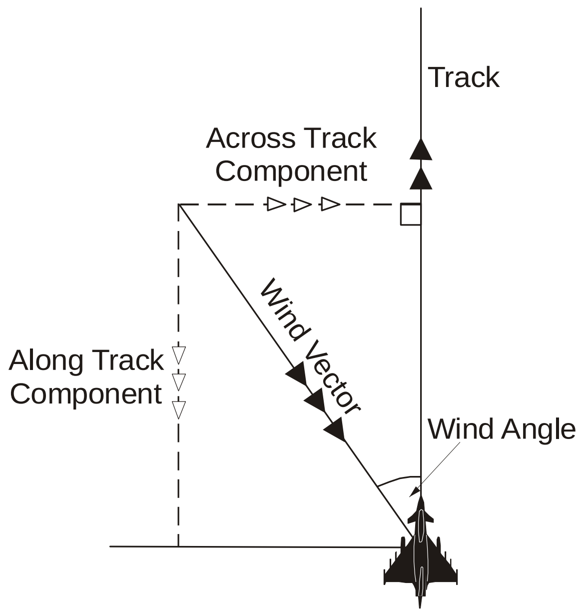
Table 2 The Four-step MDR Plan

Step	Action	Remarks
1	**PICTURE** Picture the situation, i.e. the triangle of velocities.	Visualising the vectors will assist in the correct application of drift and the head/tail-wind component.
2	**HEADING** Calculate Max Drift Actual Drift = Max Drift × Clock Analogy Fraction Apply Actual Drift to Track = Heading	Once the max drift is determined (Para 10), the clock analogy (Para 12) is used to find the actual drift. The picture of the situation ensures the drift is applied in the correct sense to the track to find the heading.
3	**GROUNDSPEED** Wind Speed × Clock Analogy Fraction (90-Wind Angle) = Head/Tail component. Apply (±) Head/Tail component to TAS = Groundspeed	The picture of the situation ensures the head/tail component is applied in the correct sense to the TAS to find the groundspeed.
4	**TIME** Time = Distance/Speed Distance/Groundspeed = Time	Use one of the four methods given in Volume 9 Chapter 20.

Wind and Track Vectors

9. **Vector Components of Track and Wind**. Fig 8 illustrates how the wind vector can be split into two component vectors at right angles to each other. One vector is across track and will affect drift. The other vector is along track and will affect groundspeed. For drift purposes, the size of the across track vector must be determined. Mathematically, this value varies in proportion to the sine of the wind angle.

9-19 Fig 8 Wind Vector Components



Estimation of Drift

10. **Maximum Drift**. To estimate the drift on a given track, it is first necessary to determine the maximum drift that could be experienced, i.e. if the wind was at 90° to the track. The maximum drift can be derived from the formula for the 1 in 60 rule. The 1 in 60 rule formula states that:

$$\text{Track Error (degrees)} = \frac{\text{Distance Off Track} \times 60}{\text{Distance Along Track}}$$

Relating this to drift:

$$\text{Max Drift} = \frac{\text{Wind Speed (kt)} \times 60}{\text{TAS (kt)}}$$

$$= \text{Wind Speed (kt)} \times \frac{60}{\text{TAS (kt)}}$$

$$= \text{Wind Speed (kt)} \div \frac{\text{TAS (kt)}}{60}$$

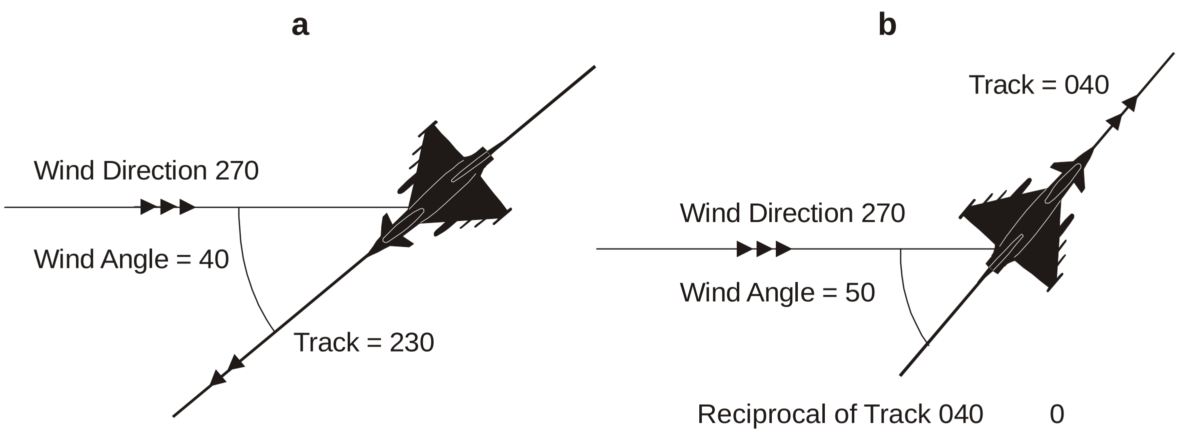
$$\therefore \text{Max Drift} = \frac{\text{Wind Speed (kt)}}{\text{TAS (nm/min)}}$$

Thus, maximum drift is easily calculated by dividing the wind speed by the TAS expressed in nm/min. For example, given a wind velocity of 200°/50 kt and a TAS of 300 kt (5 nm/min), the maximum drift is:

$$\text{Max Drift} = \frac{50}{5} = 10°$$

11. **Wind Angle**. The actual drift encountered can be considered to be a proportion of the maximum drift, depending on the angle at which the wind lies relative to the aircraft track. In this part of the calculation, the 'wind angle', which is the angle between the wind direction and the track, or its reciprocal, is determined (see Fig 9). If the wind angle is 0°, then the drift will be 0°. Conversely, if the wind angle is 90°, then the drift will be at a maximum value. The wind angle, therefore, determines the amount of drift, between zero and maximum drift. The proportionate calculation to determine drift value may be carried out mentally, using the 'clock analogy' (described in Para 12). With a track of 230° and a wind direction of 270°, as shown in Fig 9a, it can be seen that the wind effect will be from the right and the nose of the aircraft. This information is important in determining how to apply the calculated drift and groundspeed. The along track component will be into the wind and is referred to as a headwind component. Drift will be applied to the right of track and the headwind will result in a groundspeed that is less than the TAS.

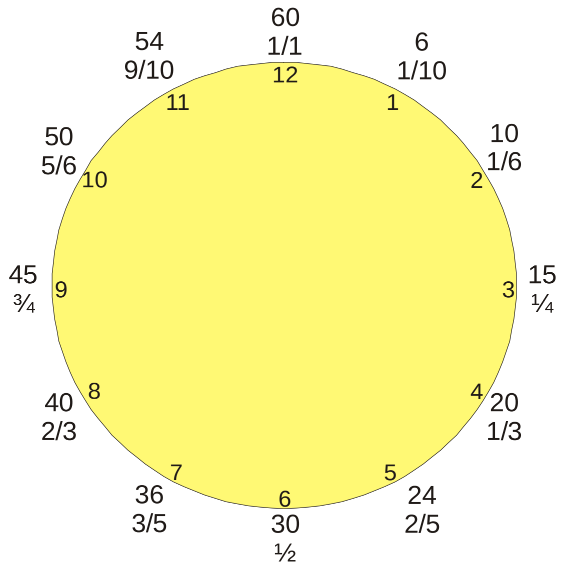
9-19 Fig 9 Wind Angle



With a track of 040° (Fig 9b), the wind effect will be from the left and tail of the aircraft. Thus, the drift will be applied to the left of track and the groundspeed will be greater than the TAS.

12. **The Clock Analogy**. The clock analogy is an MDR simplification of the sine function. It uses the fact that one full revolution of 60 minutes on a clock is equal to 1 hour, half a revolution of 30 minutes equals ½ hour, etc (see Fig 10). To use the clock analogy, take the wind angle (in degrees) and assume that figure to be minutes of time and thus a fraction of one complete revolution. For example, a wind angle of 15° would be regarded as 15 minutes of time, which equates to ¼ of an hour. Therefore, with a wind angle of 15°, ¼ of the maximum drift will be experienced. Likewise, a wind angle of 30° equates to one half of maximum drift, and 40° equates to two-thirds of maximum drift, etc. Where wind angles are between 60° and 90°, it is assumed that the aircraft will experience the full value of the maximum drift. It will be seen from Fig 10 that some approximations are used on the clock face. For example, 24 minutes is used instead of 25 minutes. If 25 minutes was used, it would produce a fraction of $^5/_{12}$, whereas 24 minutes produces the fraction $^2/_5$ which makes the mental manipulation of other numbers much easier. Where a wind angle lies between divisions, for example 32°, it should be rounded to the nearest 5 minute mark, in this case 30 minutes, and the fraction $^1/_2$ used. Depending on the accuracy required, the user may choose to use divisions of 10, 15 or 20 minutes only.

9-19 Fig 10 The Clock Analogy

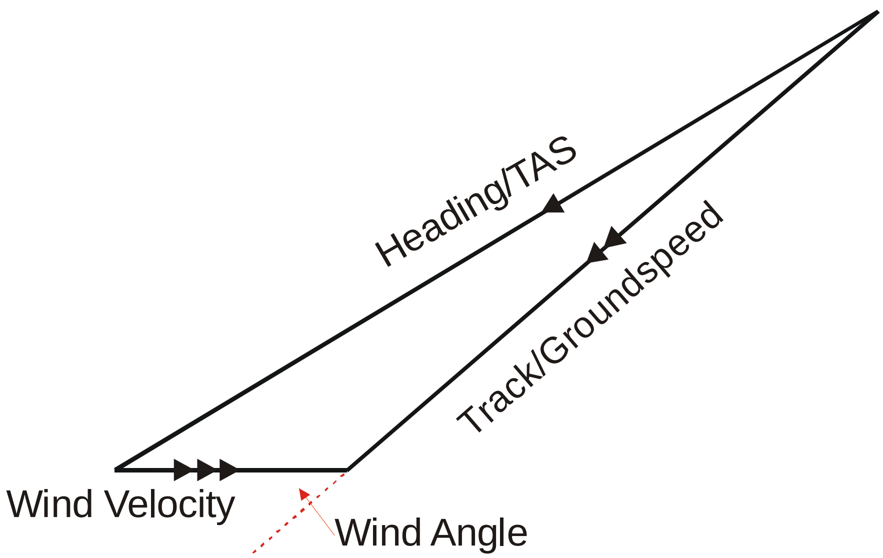


13. **Calculation of Drift**. To calculate the drift for a given track, using the following parameters:

Track 230°, TAS 300 kt (or 5 nm/min), W/V 270°/30 kt

a. The first step is to visualise the vectors, either mentally, by referring to the aircraft Horizontal Situation Indicator, drawing a sketch or by referring to a map. Fig 11 represents a sketch of the given example. Once the vectors are visualised, the effect of the wind can be determined. In this case, the wind is from the right giving a headwind component.

9-19 Fig 11 A Simple Sketch of the Vectors



b. The Wind Angle (the angle between the wind direction, 270°, and the track, 230°) is determined and its clock analogy fraction found.

$$\text{Wind Angle} = 40^\circ \equiv \frac{2}{3} \quad \text{By the clock analogy (See Fig 7)}$$

c. The maximum drift (see Para 10) is calculated as:

$$\text{Max Drift} = \frac{\text{Wind Speed (kt)}}{\text{TAS (nm/min)}}$$

Thus:

$$\text{Max Drift} = \frac{30}{5} = 6^\circ$$

d. From the visualisation of the vectors (Fig 11) it can be seen that the wind angle is from the right and nose of the aircraft. Thus, the drift is applied to the right of the track.

e. In the given example, the drift is calculated as follows:

$$\text{Actual Drift} = \text{Max Drift} \times \text{Clock analogy fraction}$$

$$\therefore \text{Actual Drift} = 6^\circ \times \frac{2}{3} = 4^\circ$$

14. **Calculation of Heading**. Having calculated the actual drift for a specific track, that figure can be applied mathematically, to determine the heading to fly to maintain that track. In this example, the wind vector is from the right and so the drift will be applied to the right of track giving a heading of 234°.

Heading = Track ± Actual Drift

Heading = 230° + 4° (from the right) = 234°

(Drift from the left is subtracted)

Estimation of Groundspeed

15. **Wind Angle**. Referring back to the vector components (Fig 8), the maximum wind effect on groundspeed occurs when the wind angle is 0°, giving either a maximum headwind or maximum tailwind component. The wind effect on groundspeed will fall to zero when it is at 90° to track.

16. **Use of the Clock Analogy**. Just as the amount of drift varies with the sine of the wind angle, so the groundspeed headwind/tailwind component will vary with the cosine of that angle. The relationship between cosine and sine is 90° out of phase, therefore $\cos \alpha = \sin (90 - \alpha)$. The same clock analogy can be used to solve this problem, but the entering argument must be 90° <u>minus</u> the wind angle. This

then generates the proportion of the wind speed to be added or subtracted from TAS to give groundspeed.

17. **Calculation of Groundspeed**. To calculate groundspeed for a given track, using the example in Para 10, the procedure is as follows:

a. Determine the value of wind angle.
With a wind vector of 270/30 and a track of 230° the wind angle will be 40° from the right (with a headwind component) (Fig 11).

b. Subtract wind angle from 90°.

Wind Angle = 40° degrees

90° – 40° = 50°

c. Use the clock analogy to calculate the head/tail wind component.

$$50^{\circ} \text{ applied to the clock analogy gives } \frac{5}{6} \quad \text{(Fig 10)}$$

d. Calculate the headwind or tailwind component by multiplying the wind speed by the clock analogy fraction, remembering that this example gives a headwind component.

$$30 \text{ kt} \times \frac{5}{6} = 25 \text{ kt (Headwind)}$$

e. Apply the head or tailwind component to the TAS, to give the groundspeed for that track. A headwind component will be subtracted from the TAS value while a tailwind component will be added. This step illustrates the importance of visualising the vectors and determining the effect of the wind at the start of the process (Para 13a) so that the calculated wind component is applied in the correct sense.

TAS = 300 kt – 25 kt (headwind) = 275 kt groundspeed.

Estimation of Time

18. The time taken to travel a certain distance is calculated using the following formula:

$$\text{Time} = \frac{\text{Distance}}{\text{Groundspeed}}$$

19. For the purposes of this chapter, the following parameters are used: distance (D) in nautical miles (nm), groundspeed (GS) in knots (kt) and time (T) in minutes. As knots are a measure of speed in nm/hr, to calculate T (in minutes), the above formula is multiplied by 60:

$$T = \frac{D \times 60}{GS}$$

This formula can be manipulated mathematically to give:

$$T = \frac{D}{\frac{GS}{60}}$$

Thus, time equals distance over groundspeed (in nm per minute):

$$T = \frac{D}{GS\ (\text{nm/min})}$$

20. Practical MDR methods should be easy to remember and produce valid answers. Four different MDR methods of determining time are described in Volume 9, Chapter 20. As all give valid results (to varying degrees of accuracy), users can select the one most suited to their needs.

Regaining Track

21. **Standard Closing Angle (SCA) Technique**. The SCA technique for regaining track is used when a position is fixed off track, but no on-track feature is available to assist regaining track, or when it is impractical to over-fly an on-track feature. The SCA is based on the 1 in 60 rule and is a closing angle determined by the speed of the aircraft. The SCA for any groundspeed can be found by dividing 60 by the groundspeed in nm/min.

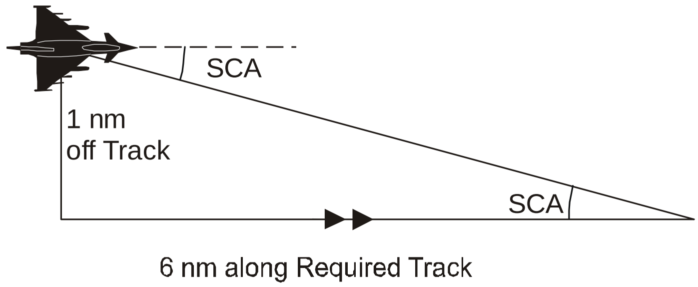
$$SCA = \frac{60}{GS\ (\text{nm/min})}$$

Fig 12 shows an aircraft with a groundspeed (GS) of 360 kt (6 nm/min), 1 nm to the left of track.

Thus:

$$SCA = \frac{60}{6} = 10^{o}$$

9-19 Fig 12 Standard Closing Angle at 360 kt



The SCA is used to regain track by altering heading through the SCA and maintaining this heading for a number of minutes equal to the number of miles off track. When it is estimated that track has been regained, the heading is altered to maintain the original track. In this example, being one mile off track, the aircraft, flying at 360 kt, turns 10° right, and after one minute will be back on track. Variations can be considered when necessary, e.g. by doubling the angle and halving the time or vice versa. However, using large angular corrections can lead to tracking errors due to the turning circle of the aircraft. Timing errors can also be introduced with large SCAs due to the extra distance flown and fact that the changing effect of the wind on the new heading is ignored. 20° is generally considered to be the maximum heading alteration that should be employed without adversely affecting the route timing (allowing for any change in wind, if necessary). The aircraft should be flown parallel to the required track before applying the SCA. This allows for the correct SCA to be applied and will provide the correct heading to turn on to once the required track has been regained.

Adjusting Time

22. **Adjusting Speed**. As well as maintaining track, it is often necessary to maintain the planned timing. Providing that the speed range of the aircraft permits, and the fuel penalty is acceptable, relatively small timing errors can be corrected by speed changes. One method of calculating the necessary adjustment is to adjust speed by the number of knots equal to the number of seconds late or early and maintain this speed for the number of minutes equal to the groundspeed in nm/min. For example, assuming a GS of 420 kt and the aircraft being 18 seconds late, the aircraft should be flown at 438 kt for 7 minutes before resuming 420 kt

Explanation:

Assume a distance to go of 79 nm at time 10:00 hrs, 420 kt groundspeed and 18 sec late.

The actual ETA is 10:11:18 (hrs:min:sec)
The planned ETA is 10:11:00
Thus, the aircraft is 18 seconds late

Fly at 438 kt for 7 minutes (420 kt ≡ 7 nm/min).
438 kt for 7 minutes ≡ 51 nm

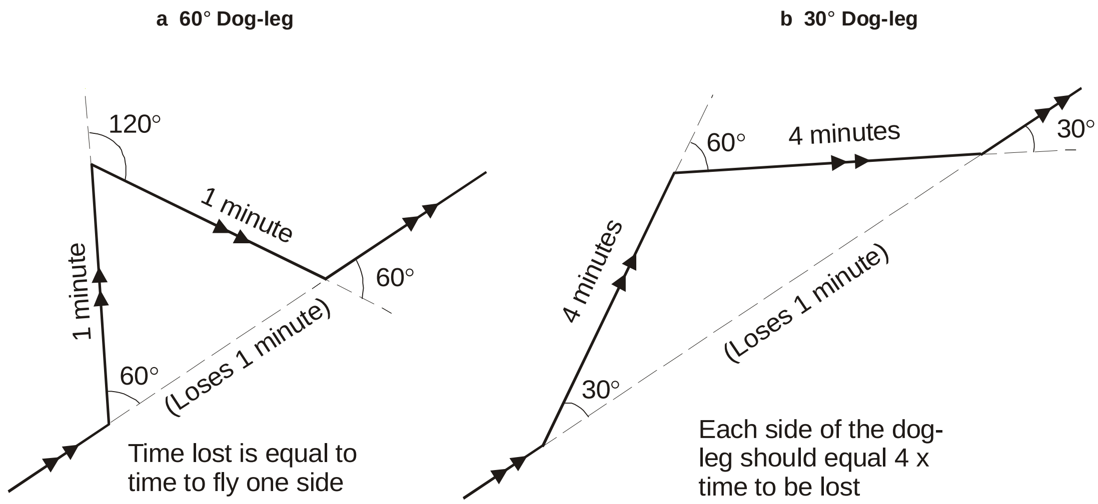
The distance remaining = 79 – 51 = 28 nm
28 nm at 420 kt = 4 minutes

51 nm at 438 kt + 28 nm at 420 kt = 11 minutes
10:00 hrs + 11 minutes = 10:11:00 = planned ETA

The speed adjustment can be halved and maintained for twice the time (or vice versa) if necessary. Should a turning point occur during the correction, the turn should be made, and the timing correction reassessed if necessary.

23. **Dog-legs**. Time can be lost by using standard dog-legs. A 60° dog-leg (Fig 13a) will lose the time equivalent to the time of each leg, whilst for a 30° dog-leg (Fig 13b), each leg needs to be flown for a time period equal to four times the time that needs to be lost. The use of the dog-leg for timing is described further in Volume 9, Chapter 17.

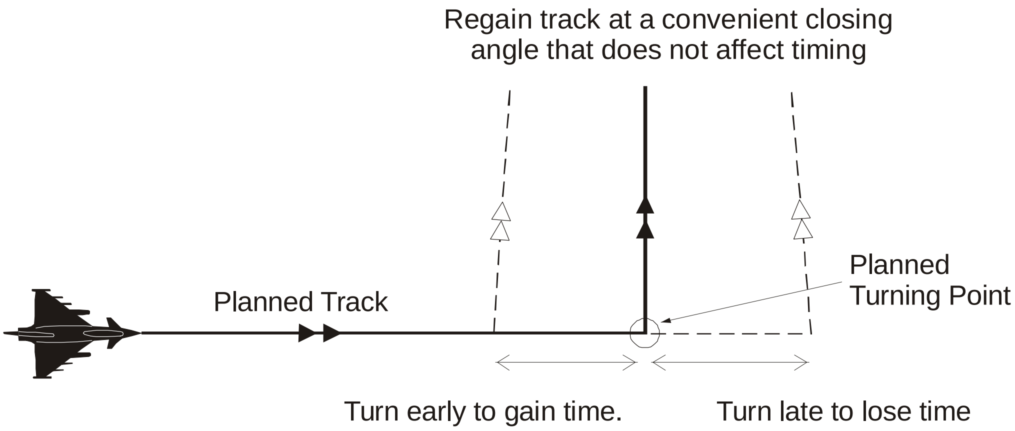
9-19 Fig 13 Losing Time by Use of Dog-legs



24. **90° Turns**. 90° turns, or large turns of about 90°, are extremely useful for solving timing problems accurately, and expediently. By simply extending at a turning point, time will be lost (see Fig 14).

Likewise, by turning early, time will be gained. After the turn, the aircraft should be flown back to track at a convenient closing angle that does not adversely affect the route timing. Large turns can be planned into a route and used, as necessary, to correct gross timing errors caused by external factors. As well as being useful to adjust timing, large turns, especially close to a target area, make the aircraft track less predictable to defending forces.

9-19 Fig 14 Saving/Losing time at 90° Turns



Estimation of the Crosswind Component for Take-Off or Landing

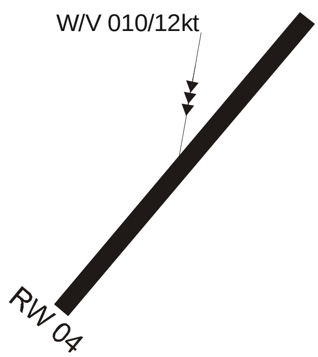
25. Runways are designated with a two-digit suffix to the nearest 10° magnetic, and so, for example, Runway 04 can be orientated between 035° M and 044° M. For the purposes of the crosswind estimation, 040° M is used. A wind vector from ATC is given in degrees magnetic whereas that from a TAF or METAR is given in degrees true. Variation must be applied when using a true wind vector. For the purposes of the following example, a magnetic wind direction is assumed. The resultant crosswind component is expressed as 'from the left/right at XX kt'. It is essential to determine the correct sense of the crosswind and the habit of picturing the situation is vital to ensure this.

26. Normally, take-offs and landings are flown into wind and so the crosswind vector will generally have a headwind component. Exceptionally, take-offs and landing may be made with a tailwind component and it is vital that this is determined because of the adverse implications on the aircraft performance.

Example: Runway 04, W/V 010°/12 kt.

a. The first step is to picture the situation, either mentally, by referring to the aircraft HSI, with a diagram (Fig 12), or by imagining that you are on the runway, heading 040°M.

7-27 Fig 1 Estimating the Crosswind Component



b. Once a picture of the situation is visualised, the direction (left/right) of the crosswind component can be established; in this example it is from the **left**. It can also be determined whether there is a headwind or tailwind component. In this example, there is a **headwind** component.

c. The wind angle is calculated (Para 11) and the clock analogy fraction (Para 12) is applied to determine the magnitude of the crosswind component.

Wind Angle = 040° (runway direction) - 010° (wind direction) = 30°

Clock analogy fraction: $30° \equiv {}^{1}/_{2}$

Crosswind speed: ${}^{1}/_{2} \times 12$ kt (wind speed) = 6 kt

Crosswind component: From the left at 6 kt

27. The method of establishing the crosswind component described in Para 26 is based on the assumptions that the runway direction is exactly that of its designation, and that the clock code analogy gives a precise result. There may be occasions when the estimated crosswind is out of limits for the aircraft to take off or land safely. In this case, the precise orientation of the runway can be obtained (from the appropriate En Route Supplement) together with an exact wind velocity from ATC. This information can be used to determine the exact crosswind value using the Crosswind Component Table in the Flight Information Handbook.

CHAPTER 20 - MDR Time Calculation Methods

Introduction

This chapter offers 4 methods of calculating time using Mental Deduced Reckoning (MDR) methods. At first glance they may appear to be quite complicated and unsuited to MDR in a fast-moving airborne environment. Careful reading of the methods will allow the user to understand each and choose the one that is best suited to their environment. It must also be stressed that each method will only be effective with practice such that they become second nature.

Estimation of Time Using the Percentage Adjustment Method

1. Practical MDR methods should be easy to remember and produce valid answers. For example, to multiply any number by 95 without using a calculator, multiply the number by 100 then subtract 5%. Consider an example of multiplying 8.1 by 95.

   a. By calculator:

   $$8.1 \times 95 = 769.5$$

   b. By MDR and approximation:

   $$\begin{array}{rcrcr} 8.1 & \times & 100 & = & 810 \\ \multicolumn{3}{r}{\text{Subtract 5\% of 800}} & = & -40 \\ 810 & - & 40 & = & 770 \end{array}$$

   Note: Numbers are chosen to ease the mental arithmetic process, thus in line two, 810 is adjusted down to 800 to make the percentage calculation easier.

2. Although the MDR answer is not absolutely correct, it is within acceptable levels of accuracy for most users. This method of MDR can be used across a wide range of applications and it will now be considered with respect to time calculations.

3. In the same way that an approximate answer of 810 was calculated by adjusting 95 up to 100 in Para 1, timing problems can be solved by approximating an answer (using a simple number) and then making an adjustment to improve the accuracy of the answer.

4. Time, in hours, is calculated from distance (D) in nautical miles (nm) and groundspeed (GS) in knots (kt).

$$\text{Time} = \frac{\text{Distance}}{\text{Groundspeed}}$$

To calculate time in minutes (T), multiply by 60:

$$T = \frac{D \times 60}{GS} = D \times \frac{60}{GS}$$

5. The 60/GS element of the above equation will produce a fraction that is the time, in minutes, taken to travel 1 nm. For example, using a groundspeed of 240 kt (4 nm/min):

$$\frac{60}{240} = \frac{1}{4}$$

Therefore, the aircraft will travel 1 nm in ¼ of a minute (≡ 4 nm/min). Referring to the equation in Para 4, if it takes ¼ of a minute to travel 1 nm, the total time in minutes can be found by multiplying ¼ by the total distance.

6. For the purposes of this method of time estimation, the fractions derived from the 60/GS element of the above equation are termed 'Basic Numbers'. In this context, useful Basic Numbers are considered to be easily manipulated fractions such as ⅓, ½, ⅔. These are derived from groundspeeds that give whole or half nm/min values, such as 300 kt (5 nm/min) or 210 kt ($3^1/_2$ nm/min). Single-digit decimal numbers, such as 0.4, are also considered to be Basic Numbers but these occur less frequently. In the speed range 100 kt to 600 kt, single-digit decimal numbers only occur at the following groundspeeds:

100 kt (0.6)	120 kt (0.5)	150 kt (0.4)	200 kt (0.3)	300 kt (0.2)	600 kt (0.1)

7. The equation, T(approximate) = D × Basic Number, is used to calculate an approximate time and then a percentage adjustment is applied to improve accuracy.

8. **Calculating Time**. To calculate an approximate time in minutes, the Basic Number derived from the standard groundspeed nearest to the actual groundspeed is used. A series of tables at the end of this chapter give a series of standard speeds and their associated Basic Numbers. For example:

D = 24 nm, actual GS = 132 kt, nearest standard groundspeed = 120 kt (2 nm/min).

From Table 1, the Basic Number (BN) for 120 kt is ½.

$$T\text{ (approximate)} = D \times BN = 24 \times \frac{1}{2} = 12.0\text{ min}$$

It is essential, for accuracy, that the approximate time is calculated to one decimal place (± 0.1 min). Having found an approximate time, an adjustment is made to produce a more accurate answer.

9. **Percentage Adjustment**. The adjustment is derived from the percentage difference between the actual groundspeed and the speed used to work out the approximate time. For example, consider an actual groundspeed of 132 kt. The nearest standard groundspeed to 132 kt to give a Basic Number is 120 kt. The difference between the two speeds is 12 kt which equates to 10% of 120 kt. The approximate time is calculated using 120 kt and a 10% adjustment is then applied to give a valid time for an actual groundspeed of 132 kt. The basic steps are:

$$T \text{ (approximate)} = D \times BN$$
$$T \text{ (actual)} = T \text{ (approximate)} \pm \text{adjustment}$$

It is vital that the percentage adjustment is applied in the correct sense. It must be noted before any calculations are done, whether the actual groundspeed is faster or slower than the speed chosen to work out the approximate time.

a. If the actual groundspeed is faster than the chosen standard groundspeed, it will take less time to cover the distance, so the percentage adjustment is subtracted from the approximate time (GS **faster** = **less time**, therefore **subtract** the adjustment from the approximate time).

b. If the actual groundspeed is slower than the chosen standard groundspeed, it will take more time to cover the distance, so the percentage adjustment is added to the approximate time (GS **slower** = **more time**, therefore **add** the adjustment to the approximate time).

10. The following sub-paragraphs show some examples of applying 5% and 10% adjustments:

a. **Example 1**. Assume D to be 20 nm and the actual groundspeed to be 132 kt. From Table 2, the nearest standard groundspeed to 132 kt that gives a Basic Number is 120 kt which gives a BN of ½. It is noted that the actual groundspeed (132 kt) is **faster** than the chosen groundspeed (120 kt).

$$T \text{ (approximate)} = 20 \times \frac{1}{2} = 10.0 \text{ min}$$

132 kt is exactly 10% **faster** than 120 kt which means the adjustment is **subtracted** from the approximate time.

10% of 10.0 min = 1.0 min

T(actual) = 10.0 – 1.0 = 9.0 min

The answer derived using a calculator is 9.09 min.

b. **Example 2**. Assume D to be 36 nm and actual groundspeed to be 256 kt. From Table 3, the nearest standard groundspeed to 256 kt that gives a Basic Number is 270 kt, which gives a BN of $^2/_9$. It is noted that the actual groundspeed (256 kt) is **slower** than the chosen groundspeed (270 kt).

$$T \text{ (approximate)} = 36 \times \frac{2}{9} = 8.0 \text{ min}$$

256 kt is just over 5% **slower** than 270 kt which means the adjustment is **added** to the approximate time.

5% of 8.0 min = 0.4 min

T(actual) = 8.0 + 0.4 = 8.4 min

The answer derived using a calculator is 8.44 min.

11. This MDR time calculation technique is accurate to within a few percent using 0%, 5% and 10% adjustments except in the extremes of slow speeds (below 80 kt) and/or long distances when accurately worked percentage adjustments are required. The tables at the end of this chapter give guidance, in the form of tables and notes, on which standard speeds to use and their 0%, 5% and 10% values. Study of Tables 2, 3 and 4 will show that:

a. Above 180 kt, only 0% and 5% adjustments need be used. It can be seen from the tables that above 180 kt, the 10% values of the standard groundspeeds impinge on the speed ranges of adjacent standard groundspeeds and so are not needed.

b. Above 330 kt, only the nearest whole nm/min groundspeed need be used. It can be seen from the tables that above 330 kt, the 5% values of the standard whole number nm/min groundspeeds can be used instead of the ½ nm/min groundspeeds.

c. The converse argument, to that in sub-paragraph b above, is that below 300 kt the closest ½ nm/min groundspeed, or whole number groundspeed, should be used.

d. The application of percentage adjustments greater than 10% degrades the accuracy of the estimated time. It can also be seen, from the tables, that adjustments greater than 10% impinge on the speed ranges of adjacent standard groundspeeds and so are not needed.

12. **Choosing 0%, 5% or 10% Percentage Adjustment**. Although at first glance the above process may seem to be complicated, there is no need to work out the percentage adjustment for every occasion. It is sufficient to work out the approximate time, as described above, and then to pick the closest 0%, 5% or 10% value to the actual groundspeed and complete the calculation.

13. Operators need only remember a small range of numbers applicable to speeds flown by their particular aircraft. It is generally quicker and easier to recall a few fixed numbers rather than to calculate percentage adjustments each time they are needed. Table 1 is an extract from Table 4 and illustrates a range of numbers that may be needed for an aircraft that usually cruises at 420 kt. The standard groundspeeds and their Basic Numbers are memorized along with the groundspeeds relating to the respective 5% values. The actual groundspeed is compared to the memorized table and the appropriate Basic Number and percentage adjustment selected.

Table 1 - Percentage Adjustments Examples

Speed to use closest to actual GS	360	378		399	420	441		456	480
Basic Number (Time in minutes to travel 1 nm)	$\frac{1}{6}$				$\frac{1}{7}$				$\frac{1}{8}$
% adjustment of time	0	-5		+5	0	-5		+5	0

14. The following sub-paragraphs show two examples of choosing the closest percentage adjustment to the actual groundspeed.

a. **Example 1**. Assume an actual groundspeed of 402 kt. From the above table, the nearest speed giving a Basic Number is 420 kt. The closest 0% or 5% value to 402 kt is 399 kt which is 5% slower. Now, assume D to be 28 nm. The approximate time is worked out using $^1/_7$. Since the actual groundspeed (402 kt) is **slower** than the chosen groundspeed (420 kt), the percentage adjustment will be **added**.

$$\text{T (approximate)} = 28 \times \frac{1}{7} = 4.0 \text{ min}$$

5% of 4.0 min = 0.2 min

T(actual) = 4.0 + 0.2 = 4.2 min

The answer using a calculator is 4.18 min.

b. **Example 2**. Assume an actual groundspeed of 435 kt. The nearest speed giving a Basic Number is 420 kt. The closest 0% or 5% value to 435 kt is 441 kt which is 5% faster. Now, assume D to be 44 nm. The approximate time is worked out using $^1/_7$. Since the actual groundspeed (435 kt) is **faster** than the chosen groundspeed (420 kt), the percentage adjustment will be **subtracted**.

$$\text{T (approximate)} = 44 \times \frac{1}{7} = 6.3 \text{ min}$$

5% of 6.3 min = 0.3 min

T(actual) = 6.3 - 0.3 = 6.0 min

The answer using a calculator is 6.07 min.

Estimation of Time to the Nearest Whole Minute

15. If a tolerance in the order of plus or minus one whole minute is acceptable to the user, a modified version of the percentage adjustment method is used. The approximate time is still calculated accurately to ± 0.1 min in accordance with the instructions in the previous paragraphs. The actual groundspeed is still noted as faster or slower than the speed used to work out the approximate time, but instead of applying a calculated percentage adjustment, the approximate time is adjusted down or up in the correct sense to the next nearest whole minute.

a. Assume D to be 40 nm and the actual groundspeed to be 164 kt. The nearest speed to 164 kt to give a basic fraction is 150 kt or 2½ nm/min (see Table 2). Thus, the approximate time is calculated using $^{2}/_{5}$. It is noted that 164 kt is **faster** than the basic fraction speed of 150 kt.

$$T \text{ (approximate)} = 40 \times \frac{2}{5} = 16.0 \text{ min}$$

164 kt is faster than the basic fraction speed.

GS **faster** = **less time**, therefore **subtract** from the approximate time, and so the answer is **adjusted down** to next nearest whole minute. Note: where the approximate time results in a whole number of minutes, it is adjusted to the next whole minute, up or down as appropriate.

$$T = 16.0 \approx 15 \text{ min (adjusted down)}$$

The answer using a calculator is 14.63 min. Care is required with the application of rounding when speeds used to work out the approximate time are derived exactly from half or whole nm/min groundspeeds. If the actual speed in this example had been exactly 150 kt, rounding would have been inappropriate.

b. Assume D to be 134 nm and the actual groundspeed to be 405 kt. The nearest speed to 405 kt to give a basic fraction is 420 kt or 7 nm/min (see Table 4). Thus, the approximate time is calculated using $^{1}/_{7}$. It is noted that 405 kt is **slower** than the basic fraction speed of 420 kt.

$$T \text{ (approximate)} = 134 \times \frac{1}{7} = 19.1 \text{ min}$$

405 kt is slower than the basic fraction speed.

GS **slower** = **more time**, therefore **add** to the approximate time, and so the answer is **adjusted up** to next nearest minute.

$$T = 19.1 \approx 20 \text{ min (adjusted up)}$$

The answer using a calculator is 19.85 min. Large errors can be introduced by adjusting. Consequently, use of this method may be inappropriate, and the method of calculating a percentage adjustment should be used.

16. Great care must be taken when calculating fuel used based on times derived from this method. The accumulative effect of adjusting, where the actual time is greater than the adjusted time, will result in the actual fuel used being greater than the planned fuel.

Estimation of Time Using the Interpolation Method

17. Another method of estimating time is to calculate the time taken to cover a distance at two groundspeeds, giving whole number nm/min values, that bracket the actual groundspeed. The required answer is then determined by interpolating between the two-time values. This process is described below.

18. Assuming a groundspeed of 275 kt, and a distance of 86 nm, the time is determined, by calculator, as 18.76 minutes or 18.8 minutes (to 1 decimal place).

19. 275 kt is bracketed by 240 kt (4 nm/min) and 300 kt (5 nm/min) and so:

$$\text{At 240 kt} \quad \frac{86\text{ nm}}{4\text{ nm/min}} = 21.5\text{ minutes} \qquad \text{At 300 kt} \quad \frac{86\text{ nm}}{5\text{ nm/min}} = 17.2\text{ minutes}$$

The difference between the 240 kt and 300 kt times is 21.5 – 17.2 = 4.3 minutes. The groundspeed of 275 kt equates to a proportion of that difference as shown:

<table>
<tr><td>240 kt</td><td colspan="2">275 kt</td><td>300 kt</td></tr>
<tr><td colspan="4">Total difference between 240 and 300 = 60</td></tr>
<tr><td colspan="2">Difference = 35</td><td colspan="2">Difference = 25</td></tr>
<tr><td colspan="2">35/60 = 7/12 of the total difference</td><td colspan="2">25/60 = 5/12 of the total difference</td></tr>
<tr><td colspan="2">7/12 of 4.3 minutes = 2.5</td><td colspan="2">5/12 of 4.3 minutes = 1.8</td></tr>
</table>

Thus, by adjusting the 240 kt time we get: 21.5 – 2.5 = 19.0 minutes. Alternatively, the 300 kt time can be adjusted to give 17.2 + 1.8 = 19.0 minutes. This explanation shows both whole number nm/min groundspeeds being adjusted. In practice only one needs to be adjusted to arrive at the answer, but, care must be taken to ensure that the adjustment is applied in the correct sense. When this result is compared to the calculated time of 18.76 minutes, it can be seen that this method of interpolation introduces an error of less than 2% which is acceptable for the purposes of MDR.

20. Although the interpolation method can give acceptable results, it involves more calculations than the percentage adjustment method. Meticulous application of this method is required to ensure that the time adjustment is applied correctly, or large errors will occur.

Estimation of Time Using the Fractional Proportion Method

21. Where the groundspeed is not a multiple of 60, the nm/min value is often difficult to manipulate mentally. For example, a groundspeed of 300 kt is divisible by 60 to give an equivalent speed of 5 nm/min, whereas a groundspeed of 287 kt, when divided by 60, gives an equivalent speed of 4.78 nm/min. One method of solving this problem is to increase, or decrease, the groundspeed to a multiple of 60 kt and adjust the distance in proportion. It is important at this stage to note whether the assumed groundspeed is faster or slower than the actual groundspeed. For example:

a. Assuming a groundspeed of 287 kt and a distance of 98 nm. As 287 kt is not a multiple of 60, the groundspeed is assumed to be 300 kt. To calculate the time correctly, the distance must be increased by the same proportion as the groundspeed. The proportional adjustment is calculated by:

(1) Dividing the actual groundspeed, by the difference between the actual groundspeed and the assumed groundspeed.

$$\frac{\text{Actual Groundspeed}}{\text{The difference between the actual groundspeed and the assumed groundspeed}}$$

$$= \frac{287}{(300\text{-}287)}$$

$$= \frac{287}{13} = 22 \quad \approx 20$$

Note: Numbers may be adjusted to make subsequent calculations easier.

(2) Dividing the distance by the number found at (1), to give the proportion to be added, or subtracted, from the original distance.

$$\frac{98}{20} = 4.9 \quad \approx 5 \text{ nm}$$

If the assumed groundspeed is **faster** than the actual groundspeed, the difference is **added** and vice versa.

(3) In this example, the proportional difference is added to the distance to give an adjusted distance:

$$98 + 5 = 103 \text{ nm}$$

b. The distance adjustment calculation can be summarized as:

$$\text{Adjusted Distance} = D \pm \frac{D}{X} \text{ nm}$$

Where:

D = Actual distance.

X = Actual groundspeed divided by the difference between the actual groundspeed and the assumed groundspeed (adjusted as necessary).

c. The time is calculated as:

$$\text{Time} = \frac{\text{Adjusted Distance}}{\text{Assumed Groundspeed (nm/min)}}$$

$$= \frac{D \pm \dfrac{D}{X}}{\text{Assumed GS}}$$

Thus, in the above example, the time is calculated based on the adjusted distance of 103 nm and the assumed groundspeed of 300 kt.

$$\text{Time} = \frac{103 \text{ (nm)}}{5 \text{ (nm/min)}} = 20.6 \text{ min}$$

d. Using a groundspeed of 287 kt and a distance of 98 nm, the answer by calculator is 20.5 min.

The tables below contain the numbers and speed ranges of Whole and Half nm/min GS, and their Basic Numbers, used in the MDR calculation of an approximate time (T(approximate)). The 0%, 5%, and 10% values applicable for each speed are also tabled.

Formula: $$\textbf{T(minutes)} = \textbf{D} \times \frac{\textbf{60}}{\textbf{GS}}$$

($^{60}/_{GS}$ = Basic Number)

T (approximate) = D x Basic Number
T(actual) = T(approximate) ± % adjustment

Table 2 - Nearest Half or Whole nm/min GS below 180 kt with 0%, 5% and 10% speed values for ± adjustment of time

Speed range	75						105						135						165
Speed to use closest to actual **GS**		**81**	**86**	**90**	**95**	**99**		**108**	**114**	**120**	**126**	**132**		**135**	**142**	**150**	**158**	**165**	
Standard GS nm/min				**1½**						**2**						**2½**			
Basic Number				$\frac{2}{3}$						$\frac{1}{2}$						$\frac{2}{5}$			
% adjustment of time		**+10**	**+5**	**0**	**-5**	**-10**		**+10**	**+5**	**0**	**-5**	**-10**		**+10**	**+5**	**0**	**-5**	**-10**	

Table 3 - Nearest Half or Whole nm/min GS above 180 kt with 0% and 5% speed values for ± adjustment of time

Speed range	165				195				225				255				285				315		
Speed to use closest to actual **GS**		**171**	**180**	**189**		**199**	**210**	**221**		**228**	**240**	**252**		**256**	**270**	**284**		**285**	**300**	**315**		**314**	**330**
Standard GS nm/min			**3**				**3½**				**4**				**4½**				**5**				**(5½)**
Basic Number			$\frac{1}{3}$				$\frac{2}{7}$				$\frac{1}{4}$				$\frac{2}{9}$				$\frac{1}{5}$				$\frac{2}{11}$
% adjustment of time		**+5**	**0**	**-5**		**+5**	**0**	**-5**		**+5**	**0**	**-5**		**+5**	**0**	**-5**		**+5**	**0**	**-5**		**+5**	**0**

Table 4 - Nearest Whole nm/min GS above 300 kt with 0% and 5% speed values ± adjustment of time

Speed range	330				390				450				510				570				630			
Speed to use closest to actual **GS**		**342**	**360**	**378**		**399**	**420**	**441**		**456**	**480**	**504**		**513**	**540**	**567**		**570**	**600**	**630**		627	**660**	693
Standard GS nm/min			**6**				**7**				**8**				**9**				**10**				**11**	
Basic Number			$\frac{1}{6}$				$\frac{1}{7}$				$\frac{1}{8}$				$\frac{1}{9}$				$\frac{1}{10}$				$\frac{1}{11}$	
% adjustment of time		**+5**	**0**	**-5**		**+5**	**0**	**-5**		**+5**	**0**	**-5**		**+5**	**0**	**-5**		**+5**	**0**	**-5**		**+5**	**0**	**-5**

Table 5 - Single Digit Decimal Numbers taken from 100, 120, 150, 200 and 300 kt with 0%, 5% and 10% speed values for ± adjustment of time

Speed to use closest to actual **GS**	90	95	100	105	110	108	114	120	126	132	135	142	150	158	165	180	190	200	210	220	270	285	300	315	330
$\frac{60}{GS}$			$\frac{60}{100}$					$\frac{60}{120}$					$\frac{60}{150}$					$\frac{60}{200}$					$\frac{60}{300}$		
Basic Number Time for 1 nm (mins)			0.6					0.5					0.4					0.3					0.2		
% adjustment of time	+10	+5	0	-5	-10	+10	+5	0	-5	-10	+10	+5	0	-5	-10	+10	+5	0	-5	-10	+10	+5	0	-5	-10

In Table 4, percentage adjustments of 10% are given for speeds above 180 kt. This is because of the greater interval between standard speeds (200 kt – 300 kt) in the Table than in Tables 1, 2, and 3.

Table 6 - Basic Numbers for GS below 80 kt requiring exact % adjustments of time

Speed to use closest to actual **GS**	10	15	20	24	30	36	40	45	50	54	60	70	75	80	81	86	90	95	99	90	95	100
$\frac{60}{GS}$	$\frac{60}{10}$	$\frac{60}{15}$	$\frac{60}{20}$	$\frac{60}{24}$	$\frac{60}{30}$	$\frac{60}{36}$	$\frac{60}{40}$	$\frac{60}{45}$	$\frac{60}{50}$	$\frac{60}{54}$	$\frac{60}{60}$	$\frac{60}{70}$	$\frac{60}{75}$	$\frac{60}{80}$			$\frac{60}{90}$					$\frac{60}{100}$
Basic Number Time for 1 nm (mins)	6	4	3	$\frac{5}{2}$	2	$\frac{5}{3}$	$\frac{3}{2}$	$\frac{4}{3}$	$\frac{6}{5}$	$\frac{10}{9}$	1	$\frac{6}{7}$	$\frac{4}{5}$	$\frac{3}{4}$			$\frac{2}{3}$					0.6
% adjustment of time	*exact*	*exact*	*exact*	*exact*	*exact*	*exact*	*exact*	*exact*	*exact*	*exact*	*exact*	*exact*	*exact*	*exact*	+10	+5	0	-5	-10	+10	+5	0

Example using Table 3

D is 32 nm and Actual GS is 280 kt

nearest Standard GS is 270 kt & Basic Number is $^2/_9$

T (approximate) = 32 x $^2/_9$ = 7.1 min

Example using Table 5

D is 58 nm and Actual GS is 325 kt

nearest Standard GS is 300 kt & Basic Number is 0.2

T (approximate) = 58 x 0.2 = 11.6 min

284 kt = Closest percentage speed to Actual GS ≡ 5% faster than 270 kt

5% of 7.1 min = 0.4 (faster, less time, subtract)

T(actual) = 7.1 – 0.4 = 6.7 min (*Calculated 6.86 min*)

Example using Table 4

D is 67 nm and Actual GS is 395 kt

nearest Standard GS is 420 kt & Basic Number is $^1/_7$

T (approximate) = 67 x $^1/_7$ = 9.6 min

399 kt = Closest percentage speed to Actual GS ≡ 5% slower than 420 kt

5% of 9.6 min = 0.5 (slower, more time, add)

T(actual) = 9.6 + 0.5 = 10.1 min (*Calculated 10.18 min*)

330 kt = Closest percentage speed to Actual GS ≡ 10% faster than 300 kt

10% of 11.6 min = 1.2 (faster, less time, subtract)

T(actual) = 11.6 – 1.2 = 10.4 min (*Calculated 10.71 min*)

Example using Table 6

D is 17 nm and Actual GS is 28 kt

Nearest Standard GS is 30 kt & Basic Number is 2

T (Approximate) = 17 × 2 = 34 min

Actual GS = 28 kt; Standard GS = 30 kt; Difference = 2 kt;

2 kt = 7% of 28 kt (The exact percentage difference is used)

7% of 34 min = 2.4 min. 28 kt is slower than 30 kt ∴ Add the adjustment

T(actual) = 34 min + 2.4 min = 36.4 min *(Calculated 36.4 min)*

CHAPTER 21 - USE OF RADIO AIDS IN NAVIGATION

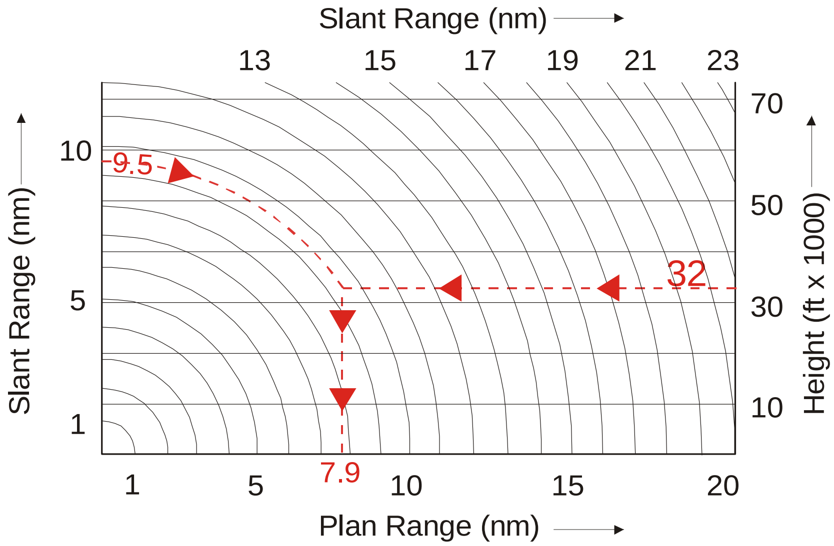
Position Fixing

1. Most operational fast jet aircraft will be equipped with comprehensive integrated navigation systems and displays which can continually portray present position, either as geographical coordinates or on a map display. In addition, the system will calculate the track or heading, distance and time to any designated waypoint. These systems will vary between aircraft, but typically will use information derived from radar, radio navigation aids (e.g. TACAN), inertial, and Doppler equipments. Information may also be derived from satellite navigation systems and terrain profile matching techniques.

2. In less sophisticated aircraft, or in certain phases of a flight (e.g. a procedural instrument pattern), the pilot or navigator will be required to interpret the raw radar or radio data to determine position and deduce the required heading, distance and time. The aids most commonly available to the fast jet crew are:

a. **Mapping Radar**. Mapping radar may be used for fixing, provided that a terrestrial feature can be identified. Whereas the identification of coastal features is fairly straightforward, some skill and practice is needed in other situations. The scanner and display is normally aligned with the aircraft axis, so a relative bearing will be obtained which must be added to heading and the reciprocal plotted (taking care to distinguish between true and magnetic bearings). Range will be slant range which may be corrected to plan range using the graph at Fig 1. However, in practice the error is usually ignored unless the aircraft is at high level and the range is short.

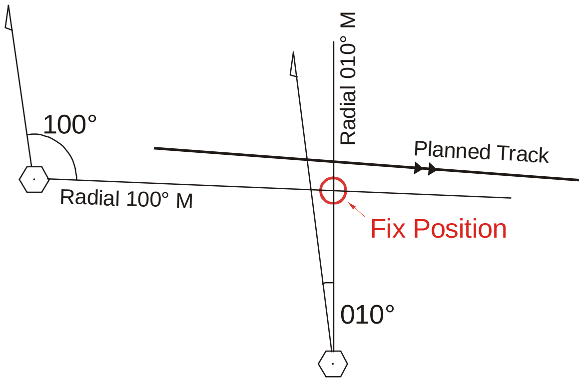
9-21 Fig 1 Slant/Plan Range Conversion Graph



b. **VOR/DME**. VOR provides the magnetic bearing of the aircraft measured from the VOR beacon. DME provides slant range from a DME beacon, which may be corrected to plan range if required using the graph at Fig 1. Each element on its own can only provide a single position line. In many cases, VOR and DME ground stations are collocated and so two mutually right-angled position lines (range and bearing) can be obtained simultaneously to produce a fix. Where this is not the case, or where the aircraft is fitted with only VOR or DME equipment and not both, then other techniques must be used:

(1) **VOR/VOR**. A two-position line fix can be obtained by tuning to two VOR beacons sequentially such that the two position lines are approximately at 90°. Ideally, one position line should be near parallel to track and this position line should be obtained first, followed by the line at 90° to track. The bearing of the first position line, aligned parallel to track, will not change significantly during the time taken to re-tune and acquire the second bearing (Fig 2).

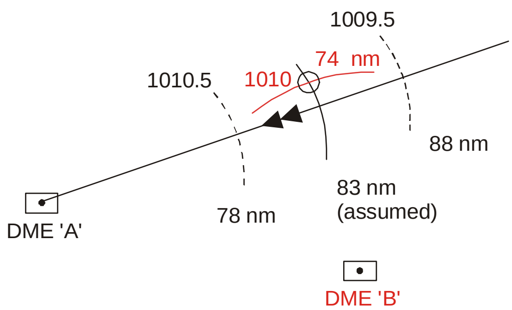
9-21 Fig 2 VOR/VOR Fix



(2) **VOR/VOR/VOR**. Where two VORs at 90° are not available, it may be possible to find three beacons to give bearings spaced approximately 60° apart. The time taken to obtain the three bearings should be kept to a minimum but, inevitably, there will be some loss of accuracy.

(3) **DME/DME**. Two DME beacons generating position lines approximately 90° apart can be used to give a fix. The 'sandwich' technique usually gives the best result. The range of the first beacon is noted on a half-minute, the range of the second beacon on the full minute, and the first beacon again on the next half-minute. The first and third ranges are averaged and plotted with the second range to give a fix, timed at the full minute (Fig 3).

9-21 Fig 3 DME/DME 'Sandwich' Fix



c. **TACAN**. TACAN gives an instantaneous range and bearing from a single beacon and is generally the preferred radio fixing aid in fast jet aircraft.

d. **V/UDF**. It is possible for an ATC unit to measure the direction of a VHF or UHF radio transmission from an aircraft and transmit the information by radio to the aircraft. The information will be in the form of a true bearing of the aircraft from the ground station, or as a magnetic track from the aircraft to the ground station. Clearly, in order to obtain a fix, at least two such bearings would be necessary, and the time taken to achieve this makes the technique cumbersome and inaccurate. Nevertheless, the service can be valuable when it is required to fly to the overhead and no other navigation data is available.

e. **Auto-triangulation**. Auto-triangulation is an emergency service, within the United Kingdom, based on a network of UDF stations. The service is only available on the emergency frequency of 243.0 MHz. The service can provide a geographical position in latitude and longitude or, more usually, relative to a known ground position, such as an airfield. Details of the coverage of the system are contained in the Flight Information Handbook.

f. **ATCRUs**. Air Traffic Control Radar Units can provide navigation information and assistance, provided they have identified the aircraft on radar.

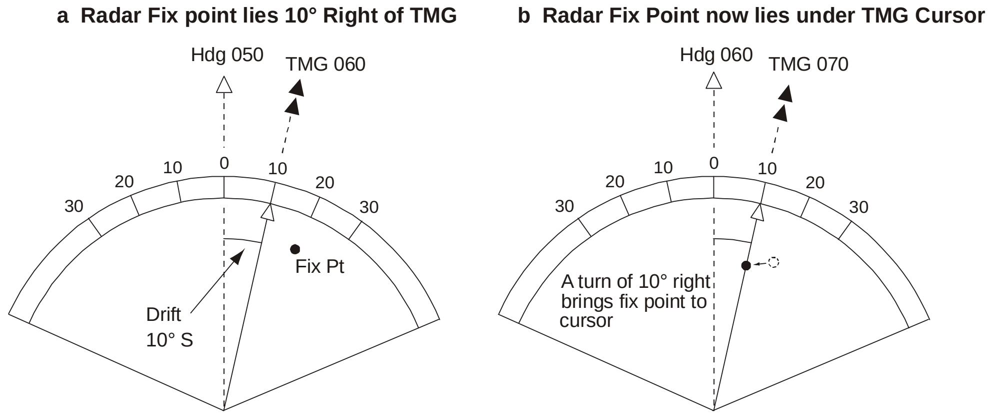
Homing

3. There is often a requirement to fly directly overhead a radar fix point or ground beacon, both in general en route navigation and when flying a procedural instrument pattern. The bearing of a line joining the aircraft to the fix point defines the track to fly to that fix point, and so the requirement is to fly that track by selecting a heading to compensate for drift. In practice, small changes in drift, especially if height is changed, and the inherent system inaccuracies will cause slight changes in the bearing and so small corrections to the heading will usually be needed. The process is known as homing.

4. Homing can be carried out using any navigation aid which is capable of giving a continuous indication of bearing, and thereby the required track. Suitable aids are radar, VOR, TACAN, and navigation computers (e.g. TANS); it is also possible to carry out a visual homing.

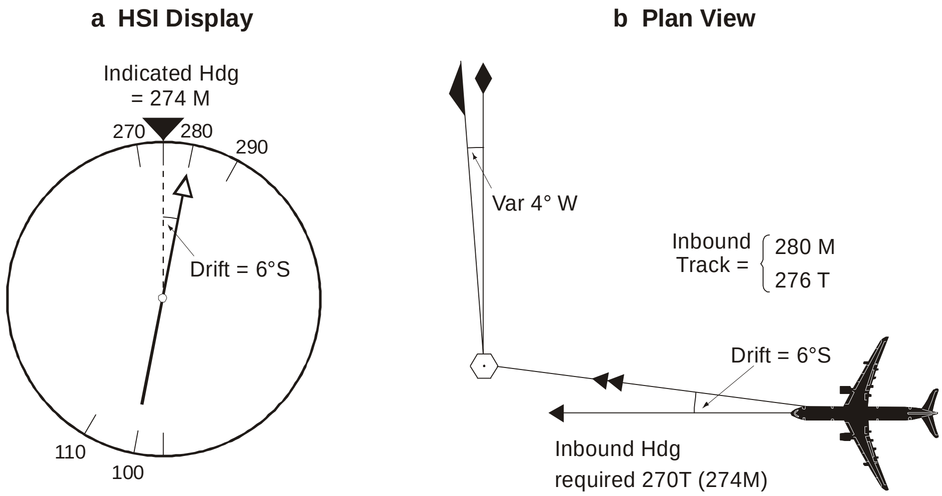
5. **Radar**. Airborne mapping radars are usually aligned with the fore-and-aft axis of the aircraft, so the centre line of the display represents aircraft heading. However, most systems allow track to be displayed by means of a cursor, fed from Doppler or inertial drift or from a manual control set to the known or estimated drift value. To home to an identified fix point, it is simply necessary to turn the aircraft so that the fix point lies underneath the track cursor (Fig 4). Unfortunately, radar contact will be lost as the overhead is approached and thus, when this occurs, it is necessary to maintain the last heading and determine the overhead from ETA or from another system.

9-21 Fig 4 Radar Homing



6. **VOR/TACAN**. VOR and TACAN indicate the magnetic track from the aircraft to the beacon against the pointed end of the indicator needle. When using a Radio Magnetic Indicator (RMI) or Horizontal Situation Indicator (HSI), it is only necessary to fly a heading such that the drift angle is shown between the heading pointer and the VOR/TACAN needle (Fig 5). As the overhead is approached, the needle will oscillate before swinging rapidly through 180°. It should be noted that although TACAN (or DME) range will decrease as the beacon is approached, the displayed range is slant range and, therefore, will not normally reach zero; in the overhead the range will equate to the aircraft's height.

9-21 Fig 5 TACAN/VOR Homing



7. **Navigation Computer**. A navigation computer can calculate the required track to any designated waypoint and thus, by applying drift, the appropriate heading can be flown. Accuracy will depend largely on the preciseness with which the system knows present position; the system can only give the track to its estimate of the destination's relative position, which may, of course, not be the true position.

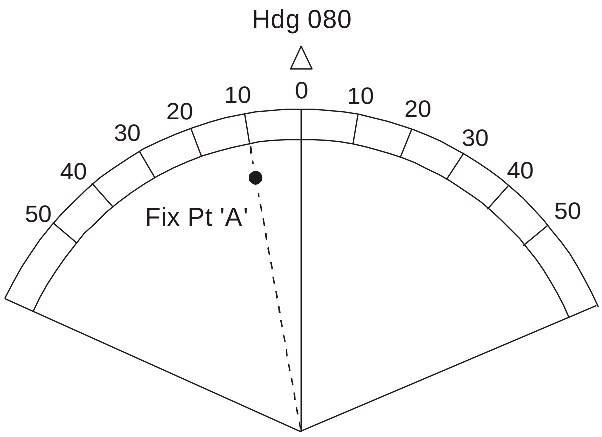
8. **Visual Homing**. In suitable weather, a visual homing can be carried out by flying to a visually identified feature, making an allowance for drift. However, the accuracy with which the overhead position can be determined decreases with increasing altitudes, and may only be satisfactory below about 5,000 ft.

Homing on a Nominated Track

9. On some occasions, it is necessary to home to a position on a specific track; SIDs and STARs are examples.

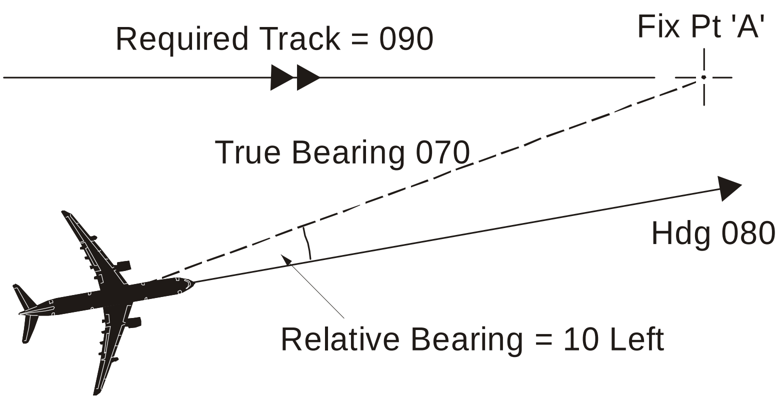
10. **Radar**. Consider the case where it is necessary to home to a fix point 'A' on a given track of 090° T, and on initial contact the radar screen shows the situation as depicted in Fig 6, with 'A' identified at 10° left; the aircraft heading is 080° T with a drift of 5° S.

9-21 Fig 6 Radar 'On-track' Homing - Initial Identification of Fix Point 'A' 10° Left



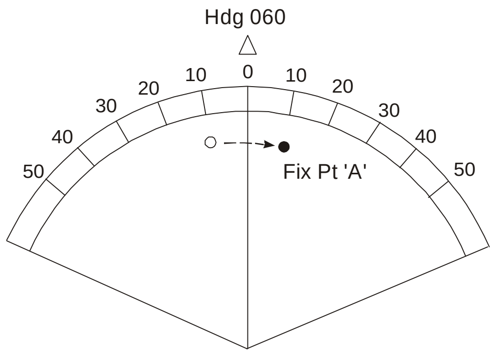
In order to home directly, it would only be necessary to turn the aircraft 10° left to bring 'A' on to the nose, and then a further 5° to allow for the drift. This, however, would result in the aircraft approaching 'A' on a track of 070° T which is 20° removed from the required track of 090° T. At present, the true bearing of 'A' from the aircraft is 070° and, as the required track is 090° T, the aircraft must be to the right of the required track (Fig 7).

9-21 Fig 7 Radar 'On-track' Homing - Plan of Initial Situation



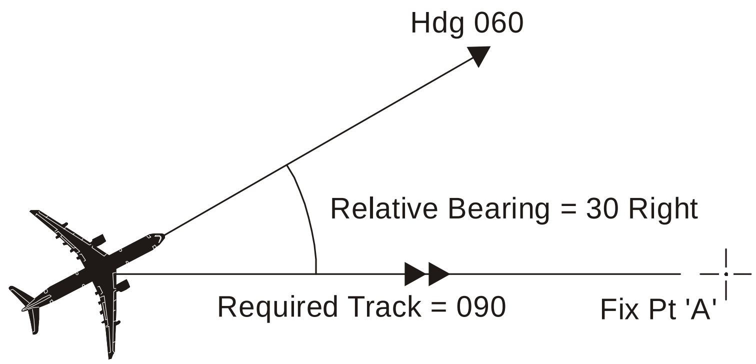
It is therefore necessary to turn left in order to intercept the required track. There is no set rule as to how large a turn should be made. A small heading change will entail a long time to intercept track, while too large a heading change will result in the fix point disappearing off the edge of the radar screen. In general, a turn in the range of 20° to 40° is usually adequate, and the procedure becomes simpler if the alteration is a multiple of 10°. As an example, consider a turn of 20° left onto a heading of 060° T, i.e. 30° left of the required track of 090° T. When the turn is complete, the radar picture will be as shown in Fig 8, in which it will be seen that 'A' has moved 20° across the screen.

9-21 Fig 8 Radar 'On-track' Homing - Radar Picture after 20° Left Turn

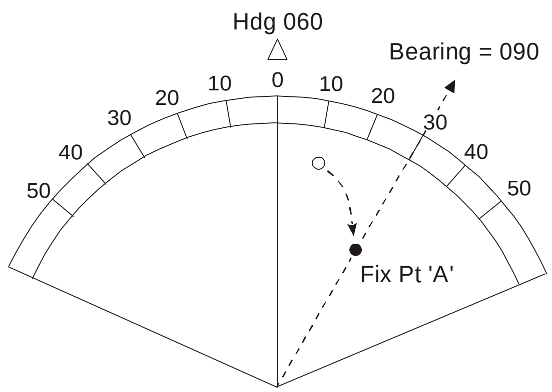


The requirement now is to determine when the 090° T track has been intercepted. In plan form, the situation at this time will be as illustrated in Fig 9, and on the radar 'A' will appear 30° right of the centre line (Fig 10). As this point is reached, the aircraft can be turned onto a heading to maintain a 090° T track, and the homing can be continued as discussed in para 5.

9-21 Fig 9 Radar 'On-track' Homing - Plan View on Intercepting Track



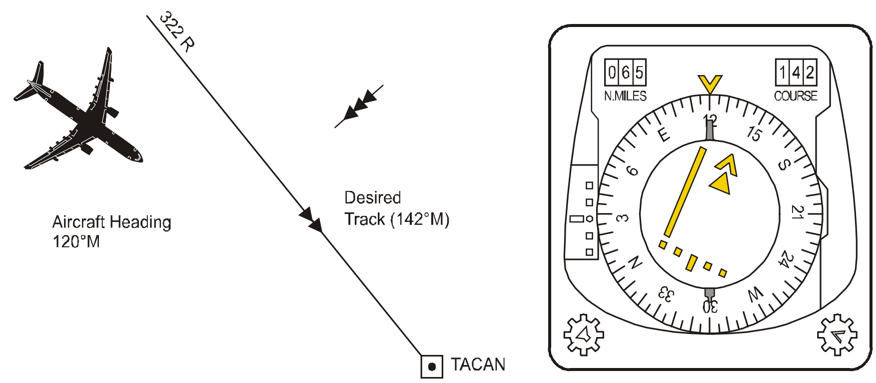
9-21 Fig 10 Radar 'On-track' Homing - Radar Picture on Intercepting Track



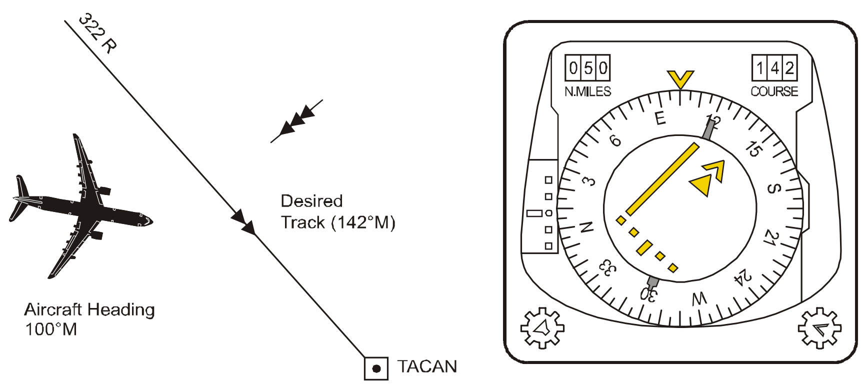
11. **VOR/TACAN**. A similar procedure can be used when it is necessary to track on a predetermined VOR or TACAN radial. The task is somewhat simpler, as the indicator continually shows the current magnetic track. Thus, it is only necessary to determine which side of track the aircraft lies and turn an arbitrary amount to intercept that track. The bearing indication will change as track is approached, and the aircraft can be turned onto the required track and a heading assumed to allow for drift. With an HSI presentation, the required track can be inserted into the instrument and the deviation bar will then indicate the relative position of track and will centralize as track is approached (Fig 11).

9-21 Fig 11 TACAN/HSI Homing on Desired Track

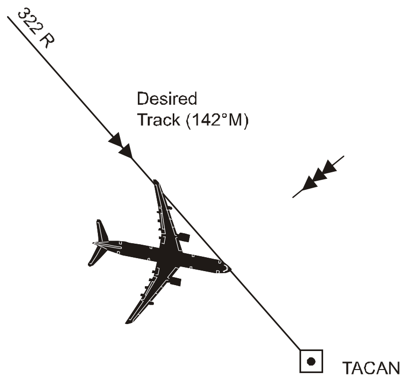
a. Aircraft Right of Track and Heading Directly Towards TACAN Beacon. Wind from North-east

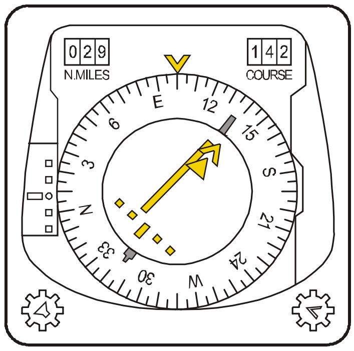


b. Aircraft Turned 20° Port to Intercept Desired Track

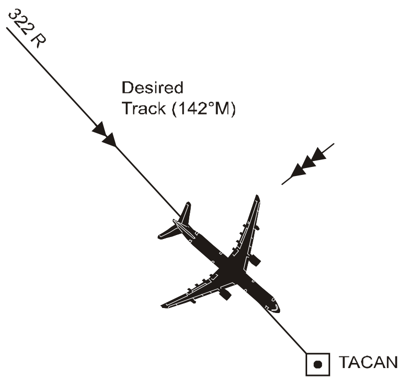


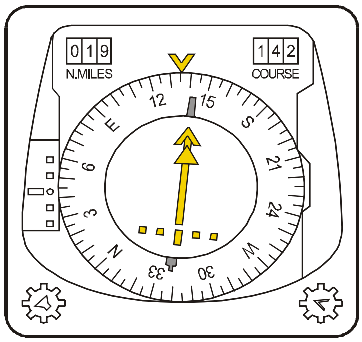
c. Aircraft About to Intercept Desired Track. Deviation Bar Nearly Central





d. Aircraft Established on Desired Track. Deviation Bar Central.
Heading Selected to Account for Drift





TACAN/VOR Point-to-point Navigation

12. It is sometimes necessary to fly from a point on one radial of a TACAN or VOR beacon to another point, without first having to overfly the beacon or having to follow a range arc. It is, of course, possible to achieve this by plotting the two positions on a map and working out the track and distance. However, this can be cumbersome, particularly for a single-seat operator, and an alternative technique can be employed using an RMI or HSI presentation, which is regarded as a circular map.

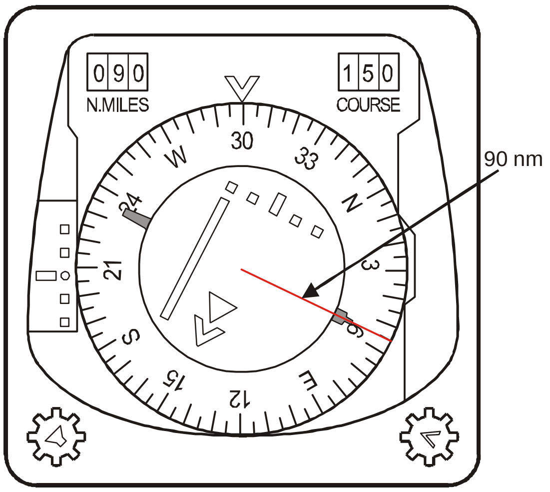
13. The map is orientated with the aircraft heading at the top and the beacon at the centre. The scale of the map is variable, and the aircraft lies along the bearing pointer towards the tail end, the exact distance depending upon the chosen scale.

14. The principle of the technique is best described by example. Consider an aircraft on the 055° M radial at a distance of 90 nm, steering a heading of 301° M, and suppose that it is required to fly to a position 60 nm on the 330° M radial. Fig 12a shows the appearance of the HSI, and it is necessary to imagine a line drawn from the centre of the display towards the tail of the TACAN needle. The length of this line is scaled to represent the aircraft's range from the beacon, ie 90 nm. A further line is imagined to be drawn from the centre of the display along the desired radial. The length of this line is proportional to the length of the desired range, in this case the desired range is 60 nm and, thus, this line extends 60/90, i.e. 2/3, of the

way to the circumference (Fig 12b). A third line is now imagined joining the ends of the first two lines (Fig 12c). The length of this line is proportional to the distance to the destination (100 nm in this example). By imagining a final line parallel to the previous line, drawn outwards from the display centre, where this intersects the display circumference indicates the required track (Fig 12d). MDR techniques can then be used to determine the heading and time to reach the destination. Where the aircraft is closer to the beacon than the destination, the destination distance determines the scale of the display. This case is shown in the example of Fig 13 a - d where the aircraft is on the 315° M radial at 25 nm heading 330° M and it is necessary to reach a position 75 nm on the 030° radial.

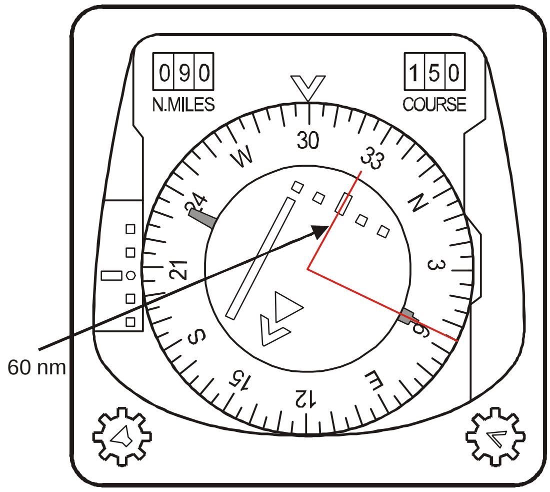
9-21 Fig 12 TACAN Point-to-point Navigation

a



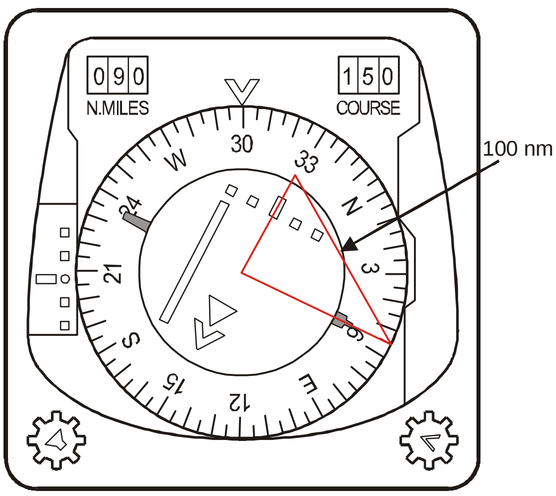
Imagine a line 90 nm long, drawn from the centre of the display toward the tail of the TACAN needle as shown above

b



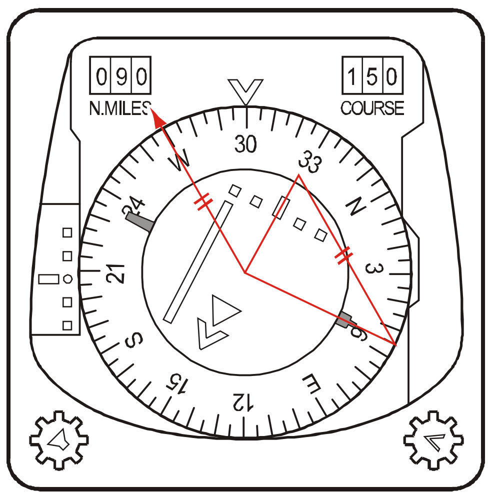
Imagine a further line 60 nm long, drawn from the centre of the display along the 330° radial

c



Imagine a line joining the ends of the original lines. The length of the line gives the range to the required point (100 nm)

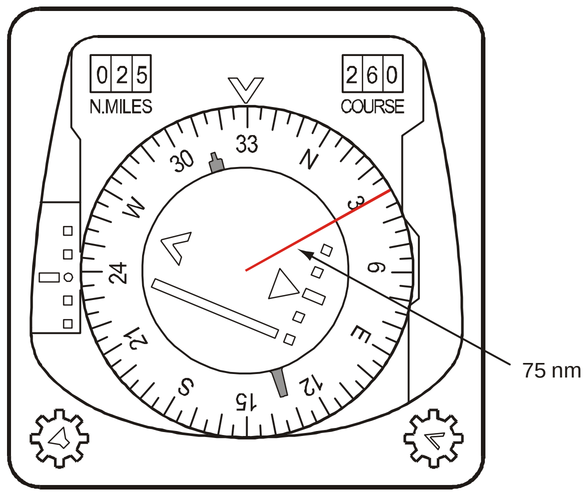
d



Imagine a final line parallel to the previous line. The point where this intersects the circumference of the display is the required heading (270°)

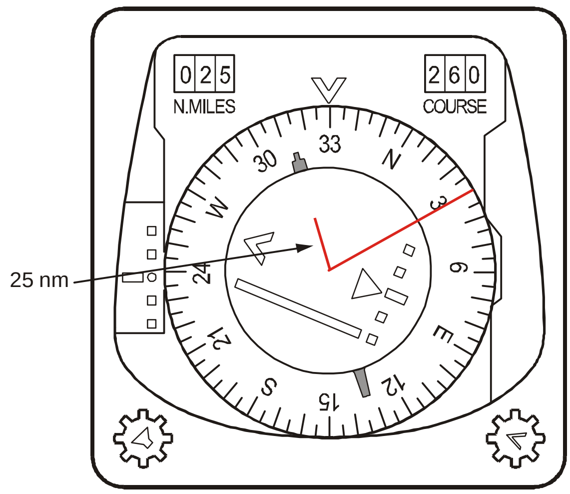
9-21 Fig 13 TACAN Point-to-point Navigation. Aircraft Closer to Beacon than Destination

a



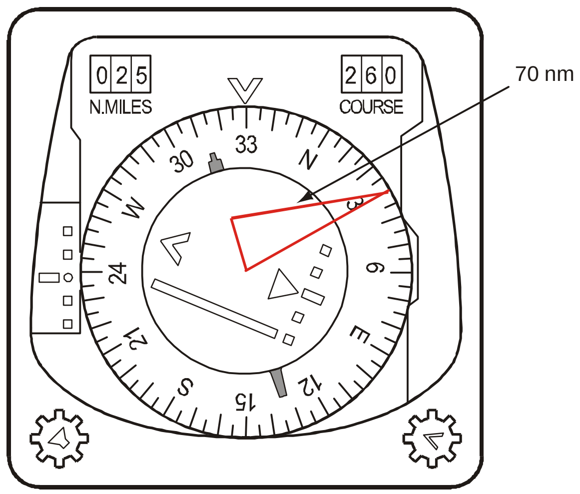
Imagine a line, 75 nm long, drawn from the centre of the display along the 030   Radial, as shown above

b



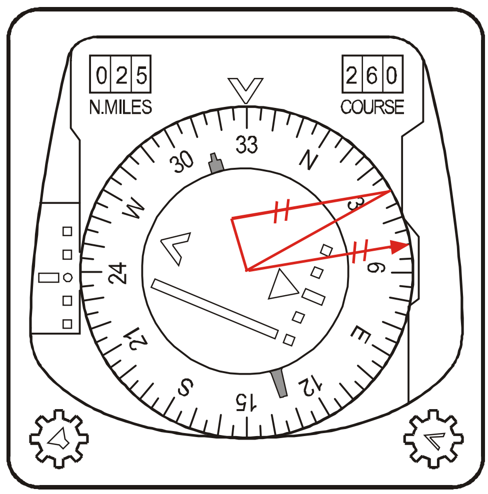
Imagine a further line 25 nm long, drawn from the centre of the display towards the tail of the TACAN needle

c



Imagine a line joining the ends of the original lines. The length of the line gives the range to the desired point (70 nm)

d



Imagine a final line parallel to the previous line. The point where this intersects the circumference of the display is the required heading (050°)

CHAPTER 22 - MAPS

CHAPTER 22 - MAPS

The Choice of Maps

1. The choice of which map to use for low level visual navigation should be dictated by considerations of the scale, the clarity with which appropriate features are shown, and the depiction of aeronautical information such as Danger Areas and Controlled Airspace. In practice, availability and common usage may be overriding factors.

2. The three series of maps commonly used within the UK, and described within this chapter, are:

a. **Low Flying Charts**. For most routine low-flying navigation tasks, the 1:500,000 scale Low Flying Charts (LFC) are used.

b. **UK Special Air Charts**. Where speeds are relatively low, or if more detail is required, the 1:250,000 scale UK Special Air Charts (M5219-Air) are used.

c. **UK Ordnance Survey Maps**. For applications where greater accuracy or detail is required, e.g. for identifying targets, the Ordnance Survey (OS) maps at a scale of 1:50,000 are used.

3. Generally, equivalent maps are available for other geographical areas of operation. Furthermore, maps to other scales are available, if required, for particular purposes.

Depiction of Relief on Maps

4. Four methods are used to show the height and shape of the land-form: spot heights, layer tinting, contours, and hill shading. Most maps will use at least two methods (commonly contours and spot heights); some maps will use all four techniques.

a. **Spot Heights**. Spot heights show the highest elevation in a region. They are simply shown as a black dot with the elevation above mean sea level printed alongside. Although normally in feet, it should be noted that spot heights are shown in metres on the 1:50,000 OS series. The only information they convey is the position and height of the highest point; there is no information as to land shape.

b. **Layer Tinting**. Layer tinting shows different bands of height in different colours; the deeper the colour the higher the land. A key on the map will show the height band corresponding to each colour. As well as showing height, layer tinting also gives an impression of land shape.

c. **Contours**. Contours are lines joining points of equal height above sea level and are drawn at regular intervals of height. Figures, stating the contour height (in feet or metres), are printed periodically along them. Closely spaced contour lines represent steep gradients and, conversely, widely spaced lines indicate gentle gradients. Thus, contours can give a good impression of both height and shape.

d. **Hill Shading**. Hill shading is a technique which imagines that the land is illuminated from one direction. For example, one side of a ridge will be illuminated while the other will be in shadow. Hill shading gives no indication of height but can give a fair impression of hill shape. Hill shading is never used in isolation.

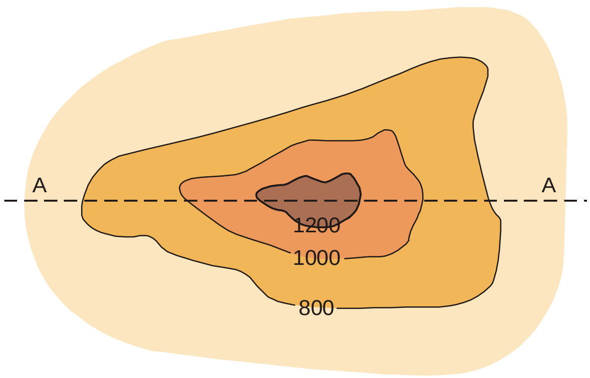
Recognizing Relief Features

5. The interpretation of a map to establish the landform takes practice and experience. There are, however, a number of features that occur regularly, sometimes in isolation, but most often in association with others. Five such features are illustrated below, both as sketch diagrams and as real features on example maps. The sketch diagrams illustrate the four methods of showing relief.

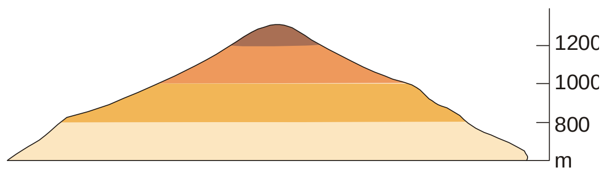
a. **Conical Hill**. The conical hill (Fig 1) is characterized by a series of closed contour lines in a roughly circular or oval pattern. The summit may or may not be shown as a spot height. For flight safety reasons, when no spot height is shown, the highest ground should be assumed to be at the level of the next contour interval. Thus, in the example (Fig 1a), with a 200-metre contour interval, the highest ground should be assumed to be 1,400 metres.

9-22 Fig 1 Conical Hill

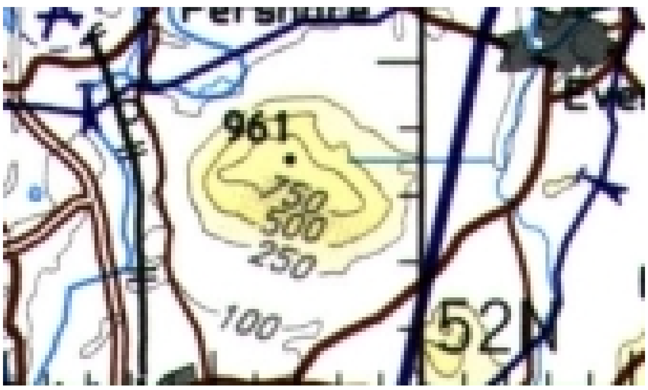
a – Contours and Layer Tinting



b – Cross Section A – A'



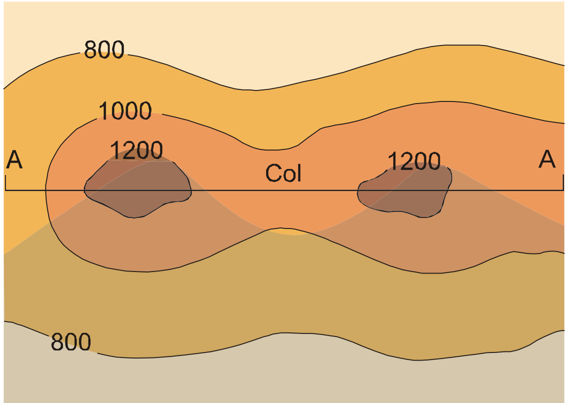
c - Example from 1:500,000 Chart



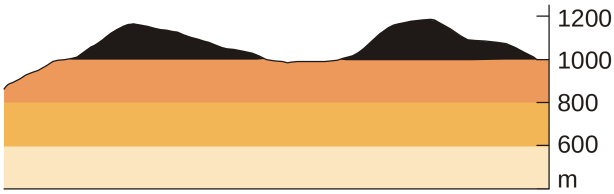
b. **Col**. A col (Fig 2) is a depression in a line of hills. It often forms a pass across the range and so, on occasions, will have a road running through it. It is characterized by a localized narrowing of the contour lines.

9-22 Fig 2 Col

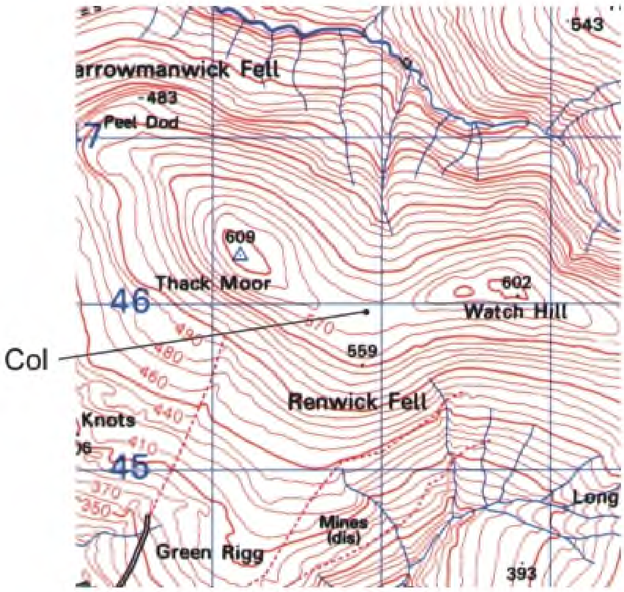
a – Contours, Layer Tinting and Hill



b – Cross Section A – A'



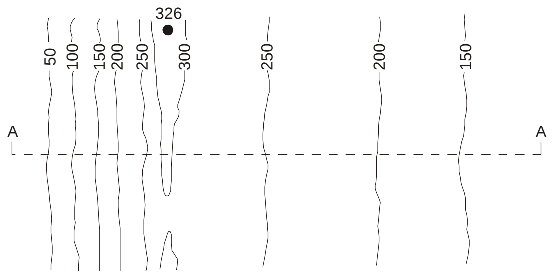
c - Example from 1:250,000 Chart



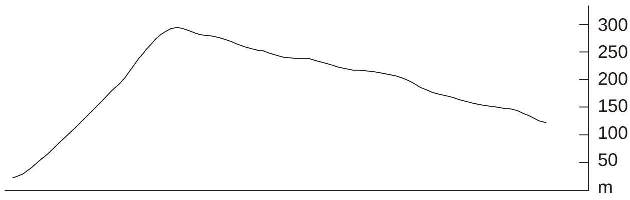
c. **Escarpment**. An escarpment (Fig 3) is a linear range of hills with a steep slope along one side and a gentler slope along the other. It can be recognized by the close contour spacing on the steep side and the wider spacing on the more gently sloping side.

9-22 Fig 3 Escarpment

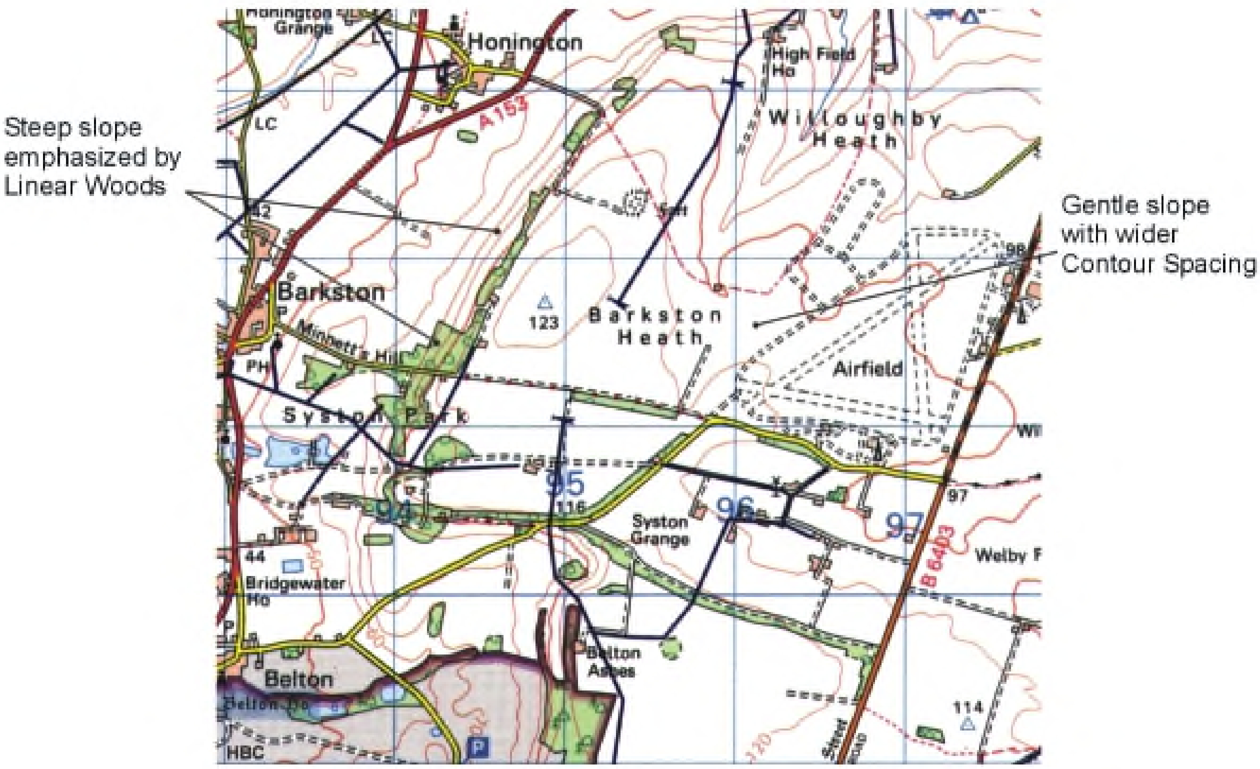
a – Contours and Spot Height



b – Cross Section A – A'



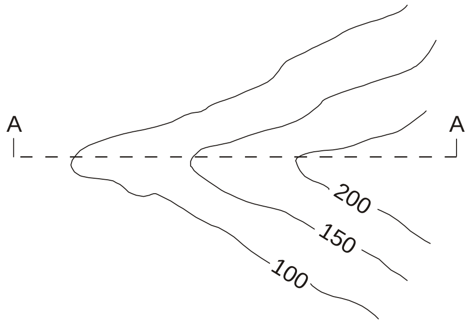
c - Example from 1:50,000 Ordnance Survey Map



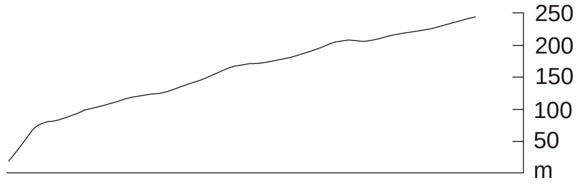
d. **Spur**. A spur (Fig 4) is a promontory of higher land penetrating into a valley. The contours show a triangular form. Spurs are frequently found where a river meanders through a hilly region. The inside of each bend is occupied by a spur, thus spurs project alternately from each side of the valley (interlocking spurs). It should be noted that in the case of the spur, the broad end of the triangle of contour lines lies on the higher ground. The reverse of this, with the broad end on lower ground, indicates a narrow descending valley (typically occupied by a river and often wooded.)

9-22 Fig 4 Spur

a – Contours



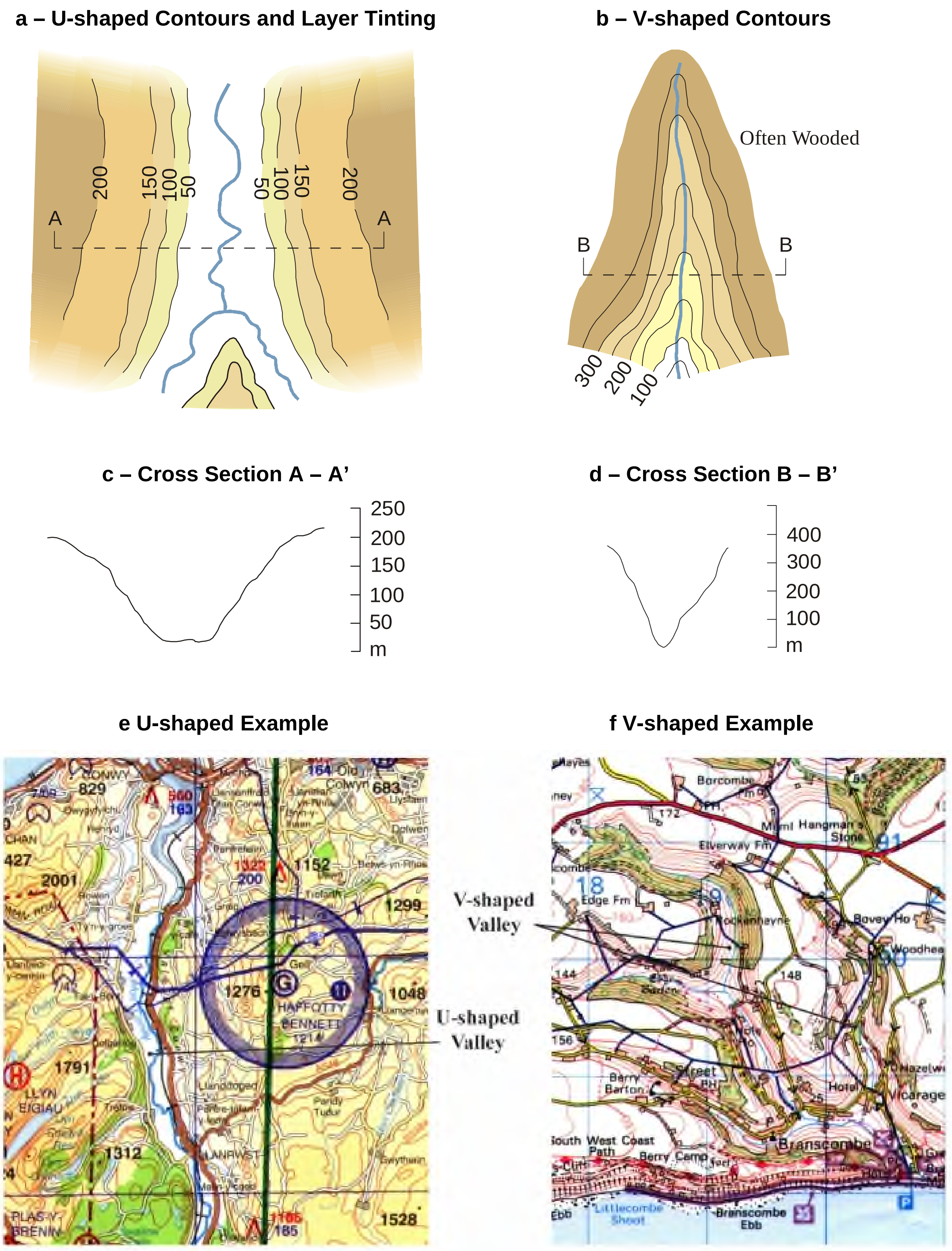
b – Cross Section A – A'



c - Example from 1:50,000 Ordnance Survey Map

e. **Steep-sided Valley**. A steep-sided valley can take one of the two forms, known as V-shaped or U-shaped (Fig 5). The V-shaped valley, which is formed by the erosive effect of a river, has a narrow floor, whereas the U-shaped valley, which is a result of glacial erosion, has a broader, flatter base. In both cases, the valley walls are characterized by closely spaced linear contours. In the case of the U-shaped valley there will be a band of wider spaced, or few, contours along the bottom of the valley walls and along the valley centre. Often, the floor of a U-shaped valley will be in a markedly different tint from the surrounding land.

9-22 Fig 5 Steep-sided Valley



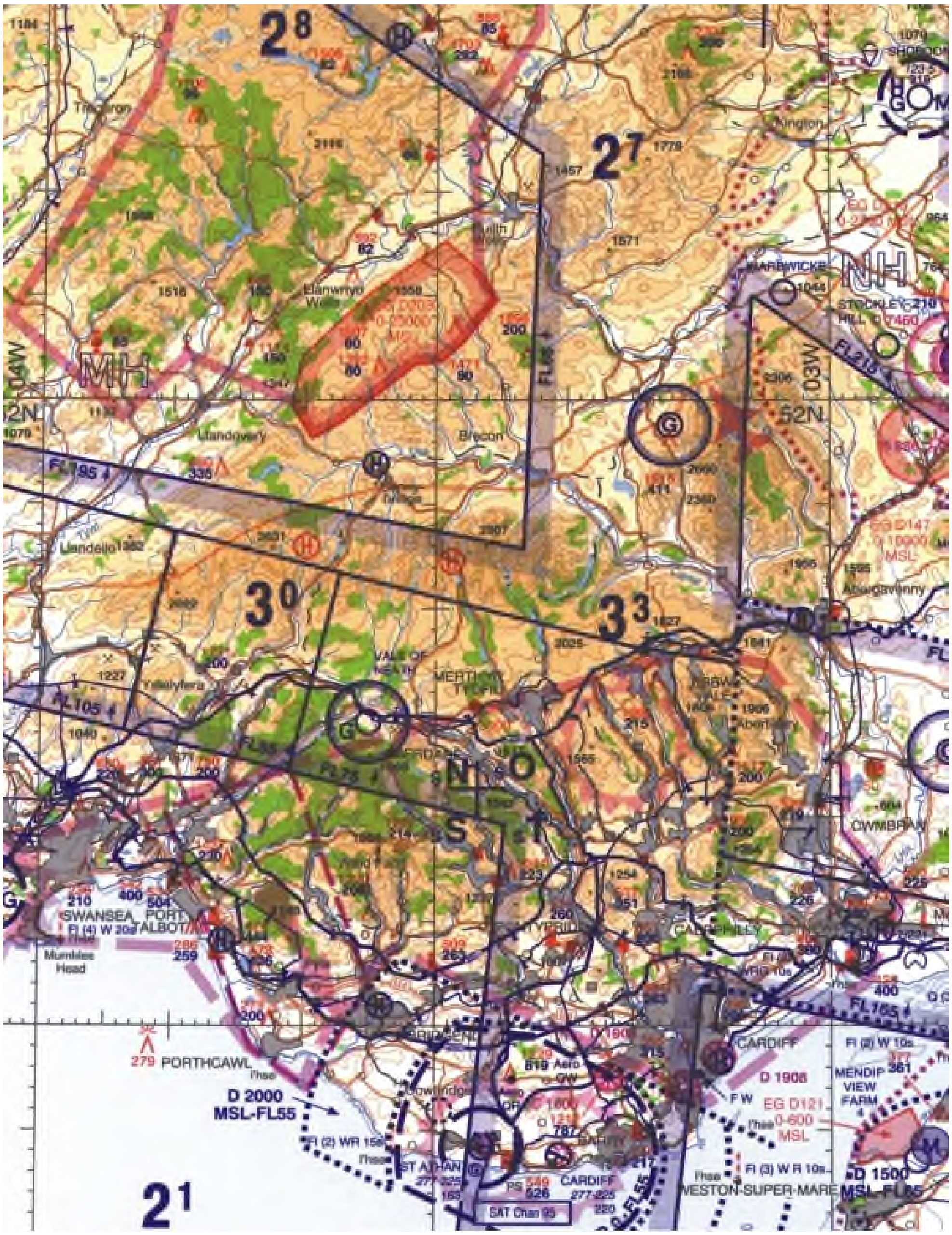
The Low Flying Chart (LFC) Series (1:500,000)

6. The Low Flying Chart (LFC) maps are constructed on a Lambert's Conformal Conic projection and therefore scale can be considered constant. Three sheets cover the UK, whilst further sheets cover the RAF's frequent areas of operation in NW Europe.

7. Amendments to the LFC sheets are promulgated to users in the Chart Amendment - Low Flying (CALF) (see Volume 9, Chapter 13).

8. The depiction of man-made features follows a conventional pattern (see Fig 6). Thus, for example, railways are shown as black lines (with one or two cross hatches to show single or multiple track stretches), roads and motorways as single or double brown lines, towns as grey areas approximating to their outline, villages as small black circles.

9-22 Fig 6 Extract from Low Flying Chart (1:500,000)



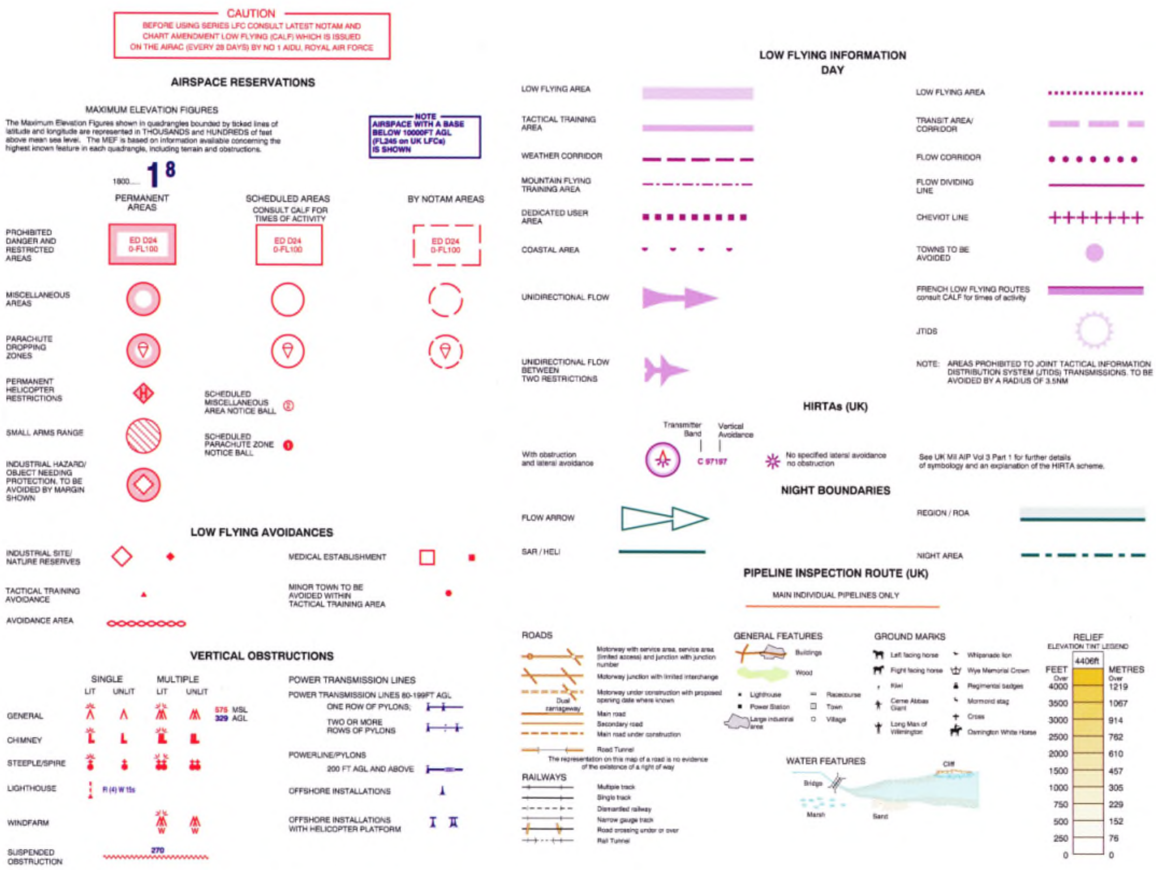
9. The manner in which natural features are shown is also conventional. Water features are shown in blue and are easily interpreted; equally, wooded areas are shown in green, although some caution is necessary as woods are sometimes harvested, and new plantations established. All four methods are

used to show landform: spot heights (in feet), layer tinting, contours (at vertical intervals of 250 ft), and hill shading.

10. It is possible to construct a reasonable impression of a region from the LFC. For example, Fig 6 shows an area around Brecon, most of which is layer tinted in deep or medium tone, so it is clearly an area of generally high ground. The high ground is divided by a number of valleys, shown in a lighter tone and often emphasized by the presence of rivers, roads and railways. A major valley can be seen from Llandovery, through Brecon to Abergavenny (River Usk). Another valley (with a railway in it) runs north-east from Llandovery towards Builth Wells. A further valley runs north-east from Brecon, eventually joining the major valley of the River Wye. To the south and east of Brecon, the land rises steeply, but to the north-west it rises less steeply. The range of hills aligned East-West, to the South of Brecon is punctuated by a number of small, steep-sided valleys running predominantly north-south. South of the 2907 spot height the land falls away more gently towards the more populated areas to the north of Cardiff.

11. A legend explaining the depiction of aeronautical information (e.g. controlled airspace, restricted areas, obstructions and low flying boundaries) is available as a separate sheet (see Fig 7).

9-22 Fig 7 Legend (Extract) – Low Flying Chart and Special Air Chart



UK Special Air Charts (1:250,000)

12. The UK Special Air Charts (M5219-Air) are to a scale of 1:250,000 and are designed for use as low flying charts. They are based on a transverse Mercator projection; therefore, scale can be considered constant. The charts are overprinted with Latitude and Longitude and the National Grid Reference System (10 km squares). Both of these overlays are adjusted to the WGS 84 datum (see Volume 9, Chapter 2).

13. Amendments to the UK Special Air Charts are promulgated to users in the Chart Amendment - Low Flying (CALF).

14. The chart shows aeronautical information including Regional Pressure Setting (RPS) areas, Low Flying Areas and hang glider sites (for legend, see Fig 7). The chart also has a power line and obstruction overprint.

15. Topographical information is based on Ordnance Survey data, and man-made features are shown using conventional Ordnance Survey symbology. Terrain is shown by spot heights, layer tinting, and contours. Elevations are in feet with a contour interval of 200 ft.

16. With double the scale of the LFC series, more gradual change in colour of the layer tinting, and the increase in the number of contour lines, it is possible to visualize the terrain depicted on the chart clearly and accurately. A comparison of the 1:250,000 map at Fig 8, with the 1:500,000 map at Fig 6, will reveal the similarity of major features such as valley lines, towns, road/rail links, and major wooded areas. However, the 1:250,000 chart reveals extra information, particularly in the detail of contours and minor roads.

9-22 Fig 8 Extract from Special Air Chart (1:250,000)

Ordnance Survey (OS) Maps (1:50,000)

17. The OS maps at 1:50,000 scale are based on a transverse Mercator projection and, for all practical purposes, the maps can be considered to be of constant scale. These maps are overprinted with the National Grid Reference System (1,000 metre squares), based on the 1936 OSGB Datum. A comprehensive legend explaining symbology is included on each sheet. The maps are available with an overprint of power lines and obstructions (Series GSGS 5215).

18. The difference between True North and Grid North, at the corner of each map, is stated in the legend. The difference between Grid and Magnetic North, together with the annual change, is also quoted in the legend and indicated at the top of each sheet.

19. Relief is shown by contour lines and spot heights. The contour lines are at vertical intervals of 10 metres; spot heights are shown to the nearest metre. The lack of layer tinting and hill shading means that the interpretation of relief will often need more care and study. Nevertheless, with practice and experience, it is possible to interpret the topography with a high degree of accuracy.

20. Fig 9 shows an extract from a 1:50,000 sheet, in which several areas of close contours can be identified. In the north-west corner is part of a conical hill (the same as that depicted in Fig 1). Notice that

the contours on the lower part of the hill are closer than those near the top, showing that the hill has a rounded profile. In the centre of the map, near the village of Dumbleton, is a conical hill with three distinct summits: Alderton Hill, Dumbleton Hill and spot height 162 m. The contours between these hilltops show the narrowing characteristic of cols. A spur can be identified on the right-hand side of the map, running northward from Toddington, with the land descending towards Wormington. It shows the typical triangular pattern of contours and the shape is emphasised by the rivers on either side.

9-22 Fig 9 Extract from Ordnance Survey Map (1:50,000)

21. In many of the examples in Fig 9, the hill line is, in part, accompanied by woodland which has a tendency to follow the general trend of the contours; a not uncommon feature. Woods are also a common feature of steep-sided river valleys, making them easier to identify; an example is to be found in the north-west corner, along two streams running north from Overbury.

22. Over most of the rest of this map extract, the contours are fairly widely spaced and form no readily identifiable patterns. Investigation of the contour and spot height values shows that the ground varies between about 25 and 60 metres, ie it is gently undulating. Thus, it is possible to build up a picture of the area - a low, undulating plain, interrupted by several conical hills, with a ridge to the south-east.

Maximum Elevation Figure (MEF)

23. On aeronautical charts, a Maximum Elevation Figure (MEF) is printed for designated quadrangles (quadrangle sizes vary with chart scale and latitude - typically, 1:500,000 maps have thirty-minute quadrangles). The MEF is calculated in the following manner:

a. The highest terrain elevation within the quadrangle is determined. A safety factor for mapping accuracy, and a Non-Represented Allowance (NRA) are added. The total is rounded up to the next 100 ft. (The NRA allows for obstructions not portrayed on the chart because they fall below the requirements of the chart specification. In UK, the NRA is 300 ft.)

b. The elevation of the highest man-made obstruction in that quadrangle is determined and, after adding a safety factor for data accuracy, is rounded up to the next 100 ft.

c. The MEF is the higher figure, from a or b.

On the map, the MEF is depicted by two sets of figures; one represents thousands of feet, the other hundreds of feet above mean sea level (AMSL). For example:

$$12\ ^{5}$$

represents 12,500 feet AMSL.

Note: MEF refers to highest elevation and is not to be confused with Safety Altitude (see Volume 9, Chapter 23).

Summary

24. For the majority of low flying tasks within the UK, and the normal operational regions in NW Europe, routine low level navigation is carried out using the LFC 1:500,000 series or the Special Air Chart 1:250,000 series, while detailed work, such as targeting, is accomplished using the 1:50,000 OS Maps (or their national equivalents in Europe). It is, therefore, essential for aircrew to become familiar with these maps. Learning the legend is a straightforward task, but interpreting the topography takes a considerable amount of study and practice. Without doubt, the airborne experience of matching the mapped features to reality greatly improves this skill.

CHAPTER 23 - PLANNING

Introduction

1. Planning for a low level flight can take a variety of forms. For example, of necessity, it may take only minutes, and involve using a china graph pencil on a plastic covered map whilst sitting in the cockpit of a tactical aircraft. Alternatively, it may take 1 or 2 hours to plan a co-ordinated, multi-aircraft interdiction mission in a well-equipped Flight Planning section. It is beyond the scope of this manual to cover the particular techniques required for these special cases. Instead, this chapter will be concerned with the elementary techniques and considerations which form the basis of all low level route planning.

2. It will be assumed that the 1:500,000 LFC or the 1:250,000 chart will be used for routine navigation, and the OS 1:50,000 maps for target planning. The discussion will be on the basis of planning for a single aircraft executing a low level navigation sortie, with a simulated level attack on a target. Nevertheless, some of the factors to be considered when planning for a formation of aircraft will be mentioned.

3. The aim of low flying is to arrive safely, and ideally undetected, at an objective; typically a target. In practice, the target planning will be done before the route planning. However, as low level navigation may occasionally be undertaken without a target element, this chapter will first look at planning the route.

ROUTE SELECTION AND PLANNING

Initial Considerations

4. **Route.** The low level route should normally be the shortest, safest, practical route to the target and back to base or destination. In particular, the time spent in 'enemy' territory should be kept to the absolute minimum. Long, straight legs are easier to fly, particularly if in formation. The following points should be considered when planning the route:

a. **Airspace Reservations**. Controlled and restricted airspace must be avoided. Certain hazards and sensitive areas on the ground must be avoided, eg hospitals and built-up areas (such avoidance has its parallel in a tactical situation where enemy defences or friendly 'weapons free zones' (WFZs) must be considered). Additionally, the UK Low Flying System regulations impose some route restrictions, such as flow arrows in congested areas.

b. **Low Level Turning Points and Check-features**. The selection of easily identified turning points and 'check-features' or 'check-points' (significant features selected to assist navigation) are essential to a successful low level sortie. This subject is discussed in detail in Volume 7, Chapter 31.

c. **Visibility**. Visual perspective and range to the horizon reduce as height reduces; it will be necessary to fly directly over most pre-selected check-points. Visibility into sun can be poor, particularly when the sun is low on the horizon. The area downwind of a large industrial complex is often associated with poor visibility and therefore should be avoided. Visibility in hazy/misty conditions and industrial pollution are all worsened when combined with a low sun.

d. **High Ground**. The crossing of high ground should be avoided for tactical reasons. The highest ground should also be avoided for meteorological reasons; it is more likely to be enshrouded in low cloud, and turbulence is often present on the lee side.

e. **Birds.** Flying adjacent to coastlines and estuaries should be kept to a minimum as these areas tend to have higher than average bird concentrations.

f. **Nuisance.** To reduce undue noise nuisance, towns and villages should be given as wide a berth as is practical. If this is not practical, then the transit height must be increased. It should be noted that, when flying in formation, other aircraft may be displaced laterally. Adequate horizontal clearance must therefore be planned for all aircraft.

g. **Natural Features**. Landmarks with vertical extent which rise above the surrounding terrain make excellent turning points or check-features. Natural line features (ridges, rivers etc) provide useful assistance when orientated along track. Multiple line features can be used as a guide, or 'funnel', to lead into a destination, turning point or visual fix-point.

5. **Speed**. Low level navigation exercises for fixed-wing aircraft are normally planned and flown on the basis of maintaining a constant groundspeed. For convenience, this groundspeed is usually a multiple of 60 kt so that it equates to an integral number of nautical miles per minute. On the other hand, rotary wing aircraft often fly close to V_{max}, and therefore a constant airspeed is flown during a navigation sortie. For most practical purposes it can be assumed that IAS = TAS at low level and thus the only necessary adjustment for speed will be to account for the wind effect. Clearly, if operations are to take place over regions considerably above sea level, the IAS/TAS relationship may need to be considered.

6. **Height.**

a. **Fixed Wing (FW).** In the majority of cases low flying will be carried out between 250 and 500 feet minimum separation distance (MSD). Excursions outside of this bracket, between 100 and 2000 feet MSD, will normally need little change to planning methods, although there may be some need to adjust the low flying techniques.

b. **Rotary Wing (RW).** Low flying frequently takes place at 50 feet above ground level (AGL) with an associated minimum separation criteria (MSC), even down to hover taxi height in some cases.

7. **Track Orientation**. The low level plan is usually made on a 'still air' basis, and so directions are annotated in terms of track, either true or magnetic, rather than heading. Adjustments are made on the day, by rule of thumb methods, to account for drift and thus determine required heading to maintain each track.

Map Preparation

8. **Maps.** It is important that maps are updated using the latest CALF, CHAD, CHUM and NOTAMs. It should be remembered that NOTAMs may be issued after planning is complete and so must be consulted immediately prior to flight so that any necessary amendments to the plan can be made.

9. **Track.** The track should be drawn on the map in such a way that it is easily seen even in turbulent conditions, ie in a deep colour and boldly, but so that it does not obscure significant detail. Gaps can be left in the track line so that fix points along track are obvious. The track direction should be clearly annotated near the start of each leg. Straight line tracks are not mandatory. Although the straight line represents the shortest distance between two points, it is not necessarily the most appropriate route; for example it will often be preferable to follow a valley rather than fly the direct line over hills. In this situation, 'mean' tracks for sections of the valley should be measured as guides to direction.

10. **Timing Reference Marks**. Time provides the prime reference system for low level visual navigation. The tracks on the chart should therefore be marked at intervals representing the distance flown in one minute (or two minutes if preferred and appropriate). The ETA at turning points, and at other significant features, should also be annotated on the map. Several methods of providing a timing reference are possible using stopwatch or real time; this subject will be dealt with in Volume 7, Chapter 31.

11. **Other Information**. Other information, which should be annotated on the chart, clearly, includes:

a. Safety altitude(s) for the route or area of operation.
b. Altimeter setting region boundaries.
c. Radio frequencies, for assistance from radar units and airfields.
d. Heights of controlled airspace and other restricted airspace.

Safety Altitude

12. A safety altitude (SALT) provides aircrew with a safe height at which to fly, when visual safe separation from the ground is not possible. The SALT is calculated by:

a. Determining the elevation (i.e. height above mean sea level (AMSL)) of the highest ground or obstacle over which there is any possibility of the aircraft passing.
b. Adding an increment of one thousand feet.
c. Rounding up the sum of a and b, to the nearest hundred feet.

Where the flight takes place over mountainous terrain - defined as terrain of 3,000 ft AMSL or higher - the increment is increased to a minimum of 2000 ft. When severe turbulence is anticipated, consideration should be given to further increasing the SALT. The instructions pertaining to SALT are contained within the MAA RA 2307(1).

13. A common method of applying safety altitude is for a separate SALT to be calculated for each track of the planned flight. Alternatively, a route might be divided into several areas, each with its own SALT. Finally, it is feasible for a route to have one 'blanket' safety altitude for its entirety, from departure to destination.

14. When determining the highest elevation on which to base the SALT, it is usual to allow a safety factor in distance around the planned track. This will allow for unplanned deviations from route and navigation errors. Command and Group Orders will normally specify the criteria for such safety factors.

Fuel Planning

15. The exact fuel planning procedure will depend upon the aircraft type, the nature of the exercise, and local requirements. In general, the route should be marked at regular and convenient intervals (perhaps every 5 or 10 minutes), and at the point furthest from base, showing in each instance:

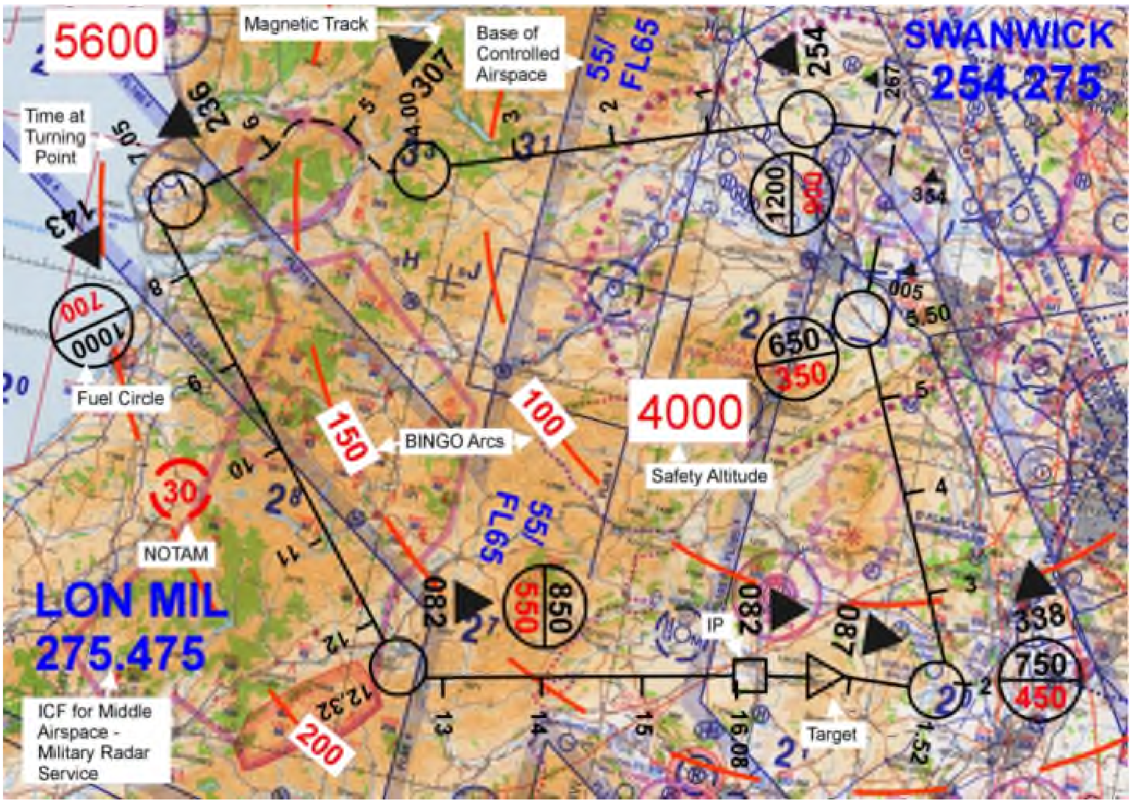
a. The anticipated fuel remaining.
b. The en route minimum fuel' (see Volume 7, Chapter 26).

16. When operating on a return-to-base route, it is often convenient to draw 'BINGO arcs' on the map showing the amount of fuel needed to return to base from that range, by the most direct and practicable route, to arrive with the necessary minimum fuel. The calculation of the BINGO figure (see Volume 7, Chapter 26) may be on the basis of remaining at low level, or on flying the profile which is most economic on fuel. These arcs should take into account the wind on the day.

Route Examples

17. Fig 1 shows an example of a route for a fixed-wing aircraft, to fly at low level from base, to a target, and back. Drawn on a LFC, it illustrates many of the items mentioned in the foregoing paragraphs. There is no definitive way in which the chart should be annotated with information; operating authorities may specify in some cases, but much will be left to personal preference. Some aspects of this example route are explained below:

7-30 Fig 1 Low Level Route Plan (not correct scale)



a. **Route***.* The route is designed to be about 30 minutes in duration, to have one target (a level attack), and to include flight over varied terrain, including some valley flying. As far as is practical, the route is confined to the lower ground in any area.

b. **Start/Stop Points**. Shawbury is the operating base, and it is assumed that there are standard departure and arrival procedures. The low level plan therefore starts and stops at points in accord with those procedures.

c. **Timing*.*** The route has been planned at a constant groundspeed of 420 kt (7 nm/min), utilizing one stopwatch. The stopwatch is started at the low level start point and is run continuously to the Initial Point (IP) for the target run. At the IP, the stopwatch is zeroed, and restarted. The stopwatch is then left to run until the route stop point. Timing marks are annotated on the chart at one minute intervals; the elapsed time is also annotated at each turning point.

d. **Tracks*.*** Tracks are magnetic. In the north-west corner of the route, the track follows the valleys, and has been drawn in a broken line to indicate this. Notice the flow arrows, which constrain the route in this area, in accordance with the low flying system.

e. **Fuel*.*** Circles highlighting fuel figures are drawn at intervals, showing the anticipated fuel remaining in black and the 'en route minimum fuel' in red. In this example, the aircraft uses 100 kg of fuel every 4 minutes. The general fuel plan is to take a fuel check every 8 minutes from the start of low level. Whilst some fuel circles are conveniently located at furthest points from base, note that the check due near the IP was brought forward 2 minutes, to spread the workload. BINGO arcs are in red, at 100 kg, 150 kg and 200 kg. In this example, these figures represent the fuel required to transit back to base in a straight line, maintaining speed at 420 kt and remaining at low level. The minimum fuel required at destination (which may change, depending on the weather and diversion plans) must be added to the BINGO figures during the flight.

f. **NOTAMs**. One NOTAM has been plotted to the north of Tregaron. This notifies a prohibited area of 2 nm radius, up to 3,000 feet above mean sea level, around the point.

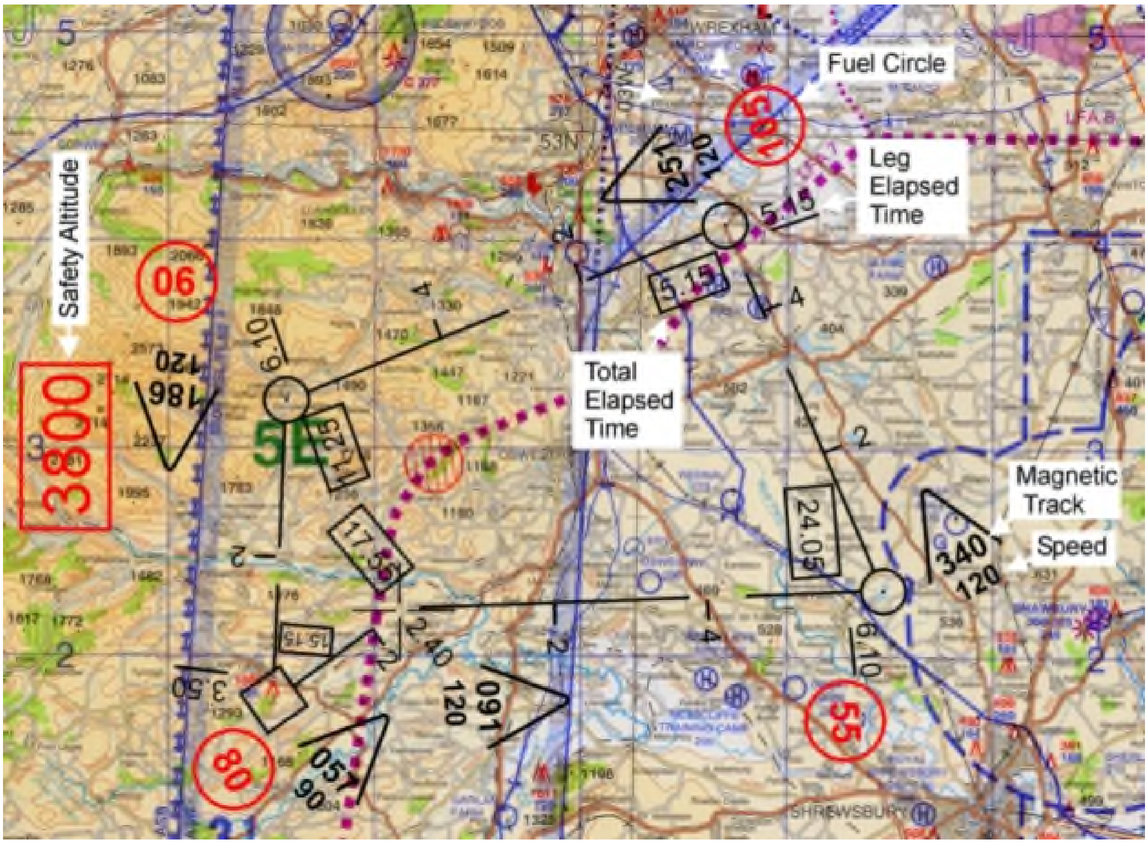
h. **Safety Altitude**. In this example route, a SALT of 5,600 ft (based on Snowdon, elevation 3,560 ft) has been calculated for the extreme NW portion of the route, to the west of the dam on Llyn Elyrnwy. For the remainder of the route, a SALT of 4,000 ft has been calculated (based on the spot height of 2,975 ft, NE of Dolgellau). Both SALTs are annotated on the chart in red.

i. **Controlled Airspace**. The height/altitude of the base of controlled airspace has been emphasized on the chart. Aircrew flying at low level should be aware, at all times, of the base height of controlled airspace above them, and this should be compared with the SALT. If the SALT is higher than the base of the controlled airspace, then the procedures for penetrating the controlled airspace must be investigated at the planning stage. Initial Contact Frequencies (ICFs) for radar assistance should be annotated on the chart.

j. **Target and Initial Point**. The triangle to the east of Leominster marks the simulated target. The square box on track to the south of Leominster represents the associated Initial Point (IP). The techniques of target planning will be covered in the next section of this chapter.

18. Fig 2 shows an example helicopter low level route plan to a landing point (LP) and back to Shawbury. Drawn on a UK Special Air Chart, this route illustrates some of the differences between RW and FW map preparation, and is described below.

7-30 Fig 2 Low Level Route Plan - RW



a. **Timing.** The main route is planned at 120 kt, and at 90 kt for the IP to LP leg. Timing marks are made at 2 minute intervals along legs. Elapsed times for each leg are marked (and underlined) at the end of the leg to the right of the turning point (TP). Total elapsed time is marked (surrounded by a box) to the left of each TP or IP. Helicopters equipped with GPS or other navigation systems may mark distance gone, or to go, instead of timing marks. Depending on the route and scale of map, timing marks may be at 1, 2, or even 5 or 10 min intervals. Some routes may lend themselves to times at significant features.

b. **IP***.* An IP is marked by a square drawn parallel to the IP-to-LP run.

c. **LP.** An LP is marked by 4 lines radiating from the grid reference.

d. **Fuel***.* Fuel circles are normally drawn at the start of each leg, or at 10 minute intervals on longer legs. The circles only show, in red, the minimum fuel plus minimum landing fuel required to complete the task and return to base or refuel point.

e. **Significant Features.** Significant features selected along the route should be indicated on the map with the elapsed time. Ideally, they should be at 3-5 minute intervals on long legs, or near half-way on shorter legs.

TARGET PLANNING

Introduction

19. Whilst flying a route, a slight tracking error of one or two miles is unlikely to be of any cause for concern, unless it leads to the infringement of an area to be avoided. However, much greater accuracy is required when attacking a target; an error of a few metres may result in missing it. Because of this, target planning is normally carried out using OS 1:50,000 maps which provide the required amount of detail. Change-over of operation, from the en route map to the target map, is accomplished by means of an Initial Point (IP) - a feature whose position is identifiable on both maps and which has a high probability of being identified at the appropriate stage of flight. The selection of an IP will be covered later; first the approach to the target should be considered.

Line of Approach

20. The best line of approach to any target must be decided on an individual basis. However, there are some general factors which should be considered. Fig 3 and Fig 4 show two typical targets (each a bridge) which will be used to illustrate some of these factors.

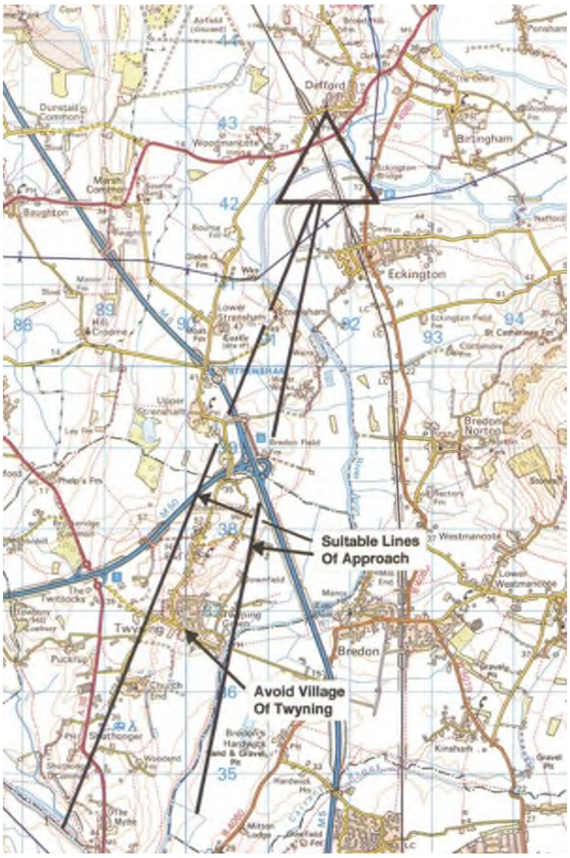
7-30 Fig 3 Bridge Target in Steep Sided Valley

21. The bridge in Fig 3 is aligned north-south, crossing a river which runs east-west. A study of the contours in the vicinity of the bridge shows that the hills to the north and south of the bridge are steep, ie the bridge is at the bottom of a steep-sided valley. If an approach were to be made from the north or south the target could not be seen until the very last moment; indeed there must be considerable doubt as to whether the target would be seen at all. The village of Alton with its church, and the Alton Towers Leisure Park, would provide some clues to the position of the bridge but nevertheless the problems of late acquisition make this an unsatisfactory line of approach. The sensible direction is east-west (or vice versa) along the valley. Approaching from the east provides a longer stretch of straight valley before the target and is therefore the preferred option. The valley and the river constitute a line feature leading directly to the target and so acquisition is unlikely to be difficult once the valley has been identified. There are no similar bridges in the

vicinity; there are a few smaller bridges before the target but the target bridge is directly abeam the village of Alton with its church and castle. Although the approach from the east has been shown as a straight line in Fig 3, it would probably be best, in practice, to fly a slightly curved approach in order to follow the line of the valley more closely. As an alternative, it would be possible to make an approach from the north-west, from the village of Oakamoor, following the valley and making the turn onto east just prior to the target. This may be preferable if the target were defended, as the aircraft would not be visible until late in the attack. However, although the bridge would not be appreciably more difficult to locate, there may be weapon aiming constraints with such a late turn onto the target.

22. Fig 4 shows another bridge target, this time a railway crossing a river. Both the river and the railway constitute line features leading directly to the bridge. It is not always necessary, or desirable, to fly along such line features; instead they can be used to direct the eyes once in the vicinity of the target. Whereas the previous example was in a steep-sided valley, this bridge is situated on a broad river flood plain in fairly open ground.

7-30 Fig 4 Rail/River Bridge Street



23. An approach from the south-east would entail crossing the high ground of Bredon Hill. Although, in this instance, the hill is not hiding the target, it is not generally recommended to approach a target from high ground as it means that the aircraft is more exposed to any defences. To the north-west of the target is a disused airfield, and study of the 1:500,000 LFC reveals that this is the site of a High Intensity Radiation Transmission Area (HIRTA), and so may need to be avoided. Other approach directions, from the north-east and south-west quadrants, impose no special restrictions. The one other

factor which may need to be considered is the direction of the sun. Where there are no other constraints, it is normally preferable to approach out of sun, especially when the sun is low on the horizon. The best line of approach is therefore probably from the south or south-west. Approach lines from the region of Tewkesbury could put the M5/M50 motorway junction or the church at Strensham on, or very close to track, thus providing good check features. To aid final visual acquisition, the railway and river would appear to converge on the target.

24. Although the approach to the target has been discussed in some detail in these two examples, the departure from the target area should not be neglected. It may well be the case that the optimum line of approach would involve the aircraft infringing a restricted area beyond the target. More importantly, the presence of high ground or obstructions immediately beyond the target must be considered. The example in Fig 3 shows this to an extent; depending upon the height of the aircraft, it may be necessary to climb or turn to avoid the southern valley wall.

25. One factor which is beyond the scope of this chapter, but may be overriding, is the constraint imposed by a particular weapon delivery profile.

The Initial Point (IP)

26. The manner in which the transfer between the LFC or UK Special Air Chart and the OS map is accomplished is by use of an 'Initial Point' (IP), the position of which should be identifiable on both charts. The ideal IP should exhibit the same characteristics as that of a good visual fix or check-feature. It should:

a. Be easily found, by dint of being big (or part of a big feature) or offering good contrast to its surrounds.
b. Be unique or unambiguous within the area.
c. Ideally, have some vertical extent.

27. The ideal IP is rare, and inevitably some compromise will have to be accepted. Although there can be no hard and fast rule, experience has shown that in most cases the distance from IP to target should be:

a. **Fixed Wing Aircraft**: Between 30 seconds and 90 seconds.

b. **Training Aircraft**: A maximum distance of 8 nm to 10 nm, with a 2 minute run-in.

c. **Helicopters*:*** A maximum distance of 3 nm to 5 nm, with a run-in of 2 minutes to 3 minutes.

It may be necessary to have a pre-IP some distance from the target in order to locate a less than ideal IP nearer the target. Short IP to target times allow little opportunity for errors to be corrected; long IP to target times can lead to unwieldy maps and demand an unnecessarily long period of high concentration.

28. Although the choice of an IP should be dictated by the most appropriate line of approach to the target, and not vice versa, the availability of a good IP can be the deciding factor between approaches which are otherwise equally suitable.

Planning from IP to Target

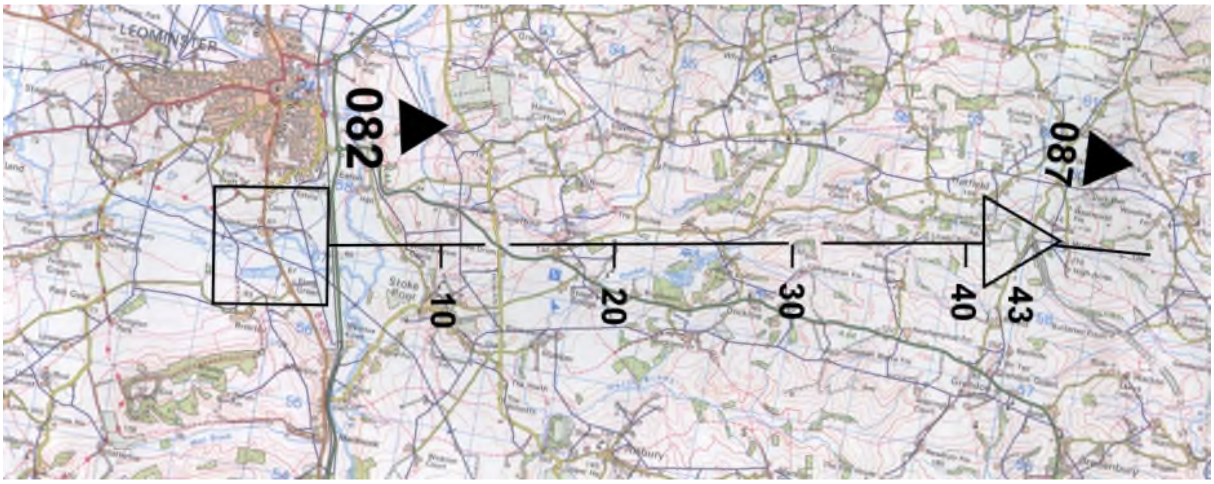
29. Planning the IP to target part of the mission is not significantly different from planning the route. The line of intended track should be clearly drawn on the OS 1:50,000 map, although it may be desirable to omit sections to permit the user to read mapping detail in parts. The map should be clearly annotated with the track direction from the IP. The track line should be annotated with timing marks, normally every ten seconds for FW, every minute for RW, together with the total elapsed time from the IP to target. It is usually advantageous to mark the 'escape' track details, post-target.

30. OS 1:50,000 maps (other than Series GSGS 5215) do not carry any aeronautical information, therefore any relevant restrictions will need to be transferred from the LFC. It may also be desirable to highlight any obstructions (eg power lines and masts) and any other significant features.

31. In the normal course of events, once the IP to target has been planned, work can commence on planning the route. The route should be arranged so that the approach to the IP is on approximately the same track (within 20º to 30º) as the IP to target. Large turns prior to, or at, the IP almost inevitably lead to error, and therefore should be avoided.

32. Fig 5 shows the OS map, prepared for the IP to target portion, incorporated into the route shown at Fig 1. Some notes on this plan are presented below:

7-30 Fig 5 IP to Target Plan (not correct scale)



a. **Line of Approach**. The target is a 90º bend in a track, adjacent to woods. Visual acquisition would be poor on approaches from the south, or the north, due to high ground and woods, respectively. On an approach from the west, the road rises into the target, which is on a slight ridge. The sun would not present any problem for an approach from the west/south-west, except in the early morning.

b. **IP**. There are several possible features for an IP in the area of Leominster. On the chosen line of approach, the town itself should be clearly visible, with the River Arrow converging from the left. The selected IP is the bridge where the road, running south from the town, crosses over the river. There are numerous lines of small pylons in the area, presenting more of an avoidance problem than an aid to navigation.

c. **Features to Assist Tracking**. Once the IP is visually identified, the stopwatch is zeroed, to be re-started directly overhead the IP. Time will then assist with the identification of several features that can be utilized to maintain the aircraft's tracking towards the target. These features include a road junction at 13 seconds, and the leading edge of a wood, left of a hill fort, at 30 seconds. The group of small lakes at 23 to 26 seconds will assist overall confidence. Also, in several places, portions of road and disused railway, running close to the planned approach track, could be utilized.

d. **Additional Information**. The IP to Target map shown at Fig 5 is relatively uncluttered, having just the bare essential information required during flight. Depending upon requirements, the planner may wish to highlight extra mapping detail, or annotate further information. Information required by some operators includes distance-to-go markers in nautical miles (for nav/attack systems), aide memoirs, or weapons checklists.

Concealed Approaches and Departures (CAD)

33. Support Helicopter (SH) operations often require an approach and departure to be made to a landing site (LS) whilst flying a profile that will keep the helicopter hidden from enemy ground forces. This usually requires ultra-low flying using terrain, trees and other vertical features to achieve concealment. Factors to be considered during CAD operations include:

a. **Planning**. The relative position of the enemy from the pick-up point (PUP) or drop point (DP) will dictate the direction of approach. The planning process is essentially the same as an IP to target run with one difference; the route is selected by working back from the DP along the lowest ground towards the IP. The best departure is generally the reciprocal of track, but it is not always the case, so the departure should be considered separately. Forecast windspeed is an important consideration as the low groundspeed required for concealed approaches and departures may be outside the wind/airspeed limits for the helicopter and therefore a compromise track may have to be selected.

b. **Map marking**. Contour analysis is the key to good map reading. At 100 ft AGL, a 10 m contour is significant, whereas at 200 ft AGL such a contour may be invisible. It is vital to study the contours around the LS; a 10 m contour can hide most helicopters. The procedure is to work back from the enemy position looking for valley contours and water indications, as water generally flows in the lowest ground. One point to note is that trees grow along river and stream beds, but they are not shown on the OS 1:50,000 map; they can aid concealment but may present a problem if they need to be crossed. If the contours are difficult to see, then highlighting them can help in visualising the valley shape, but highlighting more than one contour can lead to confusion. Once the direction of approach is selected, then the map should be marked as shown in Fig 6, using a dashed track line so that the map detail can be clearly seen. Tracks and timing marks (appropriate to the planned speed) should be marked, and prominent features highlighted. The general rule is to fly as fast as possible whilst maintaining the height required to remain concealed. The aim should be to reduce speed and height as range to the DP reduces, typically 2 kt per 1 ft of height (e.g. 30 kt/15 ft AGL).

7-30 Fig 6 Concealed Approach and Departure

c. **General**. Map reading and communication between the crew whilst flying at ultra low level are obviously problems, but can be overcome by good planning, effective cockpit management and foresight.

Map Folding

34. Having completed all the planning, the maps require folding so that they can be conveniently handled in the air. It is not normally a good idea merely to cut out the required portion of the sheet as the resulting map will be too flimsy for use in the cockpit.

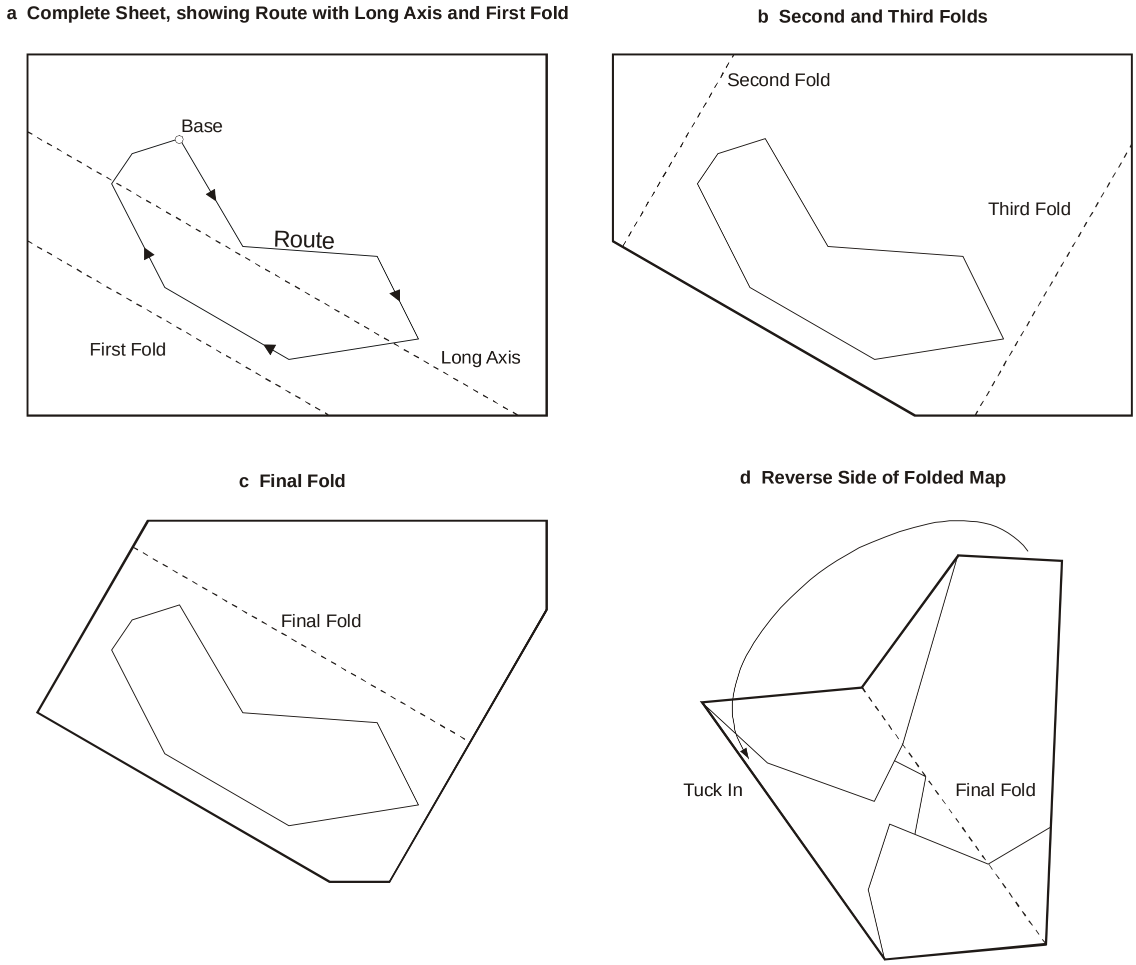
35. A suggested method of folding is outlined below and illustrated in Fig 7:

a. Decide which is the long axis of the route. On a nearly square route this decision will be arbitrary. Make the first fold, outside of the route, parallel to the long axis.

b. Fold in the two ends at right angles to the long side.

c. Fold over the remaining long side parallel to the long axis. The excess map of this last fold can be tucked into the pocket formed by the first three folds, having been trimmed if necessary.

7-30 Fig 7 Folding the Map



CHAPTER 24 - MAP READING AND NAVIGATION TECHNIQUES

Introduction

1. Modern aircraft avionics systems are quite capable of performing the routine navigation tasks necessary in a low level mission. However, like all computer systems, they are unable to think, or automatically instigate changes to a plan when conditions vary from those expected. Moreover, although reliability is generally high, such systems do occasionally fail or become degraded. Particularly in the final stages of an attack, it may become necessary to refine the system's navigation solution by direct visual reference to the outside world. Furthermore, there are still many aircraft, especially in the training role, without sophisticated navigation systems. There is, therefore, a continuing need to develop the skills of low level navigation using the basic aids of map, compass, stopwatch, eye, and brain.

2. The aim of low level navigation is to get the aircraft to an objective safely and, ideally, undetected. There is therefore a need to blend accurate navigation, both in space and time, with skilful flying, sound airmanship, and tactical awareness. The general rules regarding the operation of aircraft in the low level environment are dealt with in Volume 8, Chapter 19. This chapter will be concerned primarily with navigation techniques at low level. It complements Volume 9, Chapter 23, which should be read in conjunction with it.

Map Reading

3. The art of map reading consists of visualizing the physical features represented on the map by symbols, thus forming a complete mental picture of the ground by relating the features one to another (this is known as 'map to ground' technique). It is also necessary to perform this analysis in reverse, ie seeing an arrangement of features on the ground and being able to recognise the relevant portion of the map ('ground to map' technique). Expertise at low level map reading demands much practice but there are a number of factors which can make the task easier. The most important of these are thorough flight planning and pre-flight route study. When in flight, maintaining track and time should be a prime aim; errors should be recognised and acted upon early, but concentration on navigation to the detriment of other tasks must be resisted. It is equally important to keep a good look-out to reduce collision risks, to detect any enemy activity, to be aware of any potential weather problems, and to manage the aircraft systems. To this end, significant features (known as 'check features') should be selected at the planning stage at perhaps 3 to 5 minute intervals, and the in-flight technique should be to identify these features as early as possible and fly with reference to them. Check features need not be exactly on track; a good feature close to track will usually be better than a poor feature on track, and it is a relatively simple matter to fly the appropriate distance away from the feature.

4. **The Ideal Check Feature**. The ideal check feature will have the following properties:

a. **Big**. The check feature should be big, or be part of a big feature. However, it must not be so big that a precise point is indistinguishable.

b. **Unambiguous**. The feature must be selected to ensure that no other similar feature is nearby.

c. **Vertical Extent**. At low level, a feature such as a hilltop, mast or chimney may well be visible from several miles away.

d. **Easily Identified**. The check feature should be seen and identified easily, to minimize time spent searching for it.

Only rarely will a feature possess all of these attributes and some compromise will be necessary. The value of any type of feature to navigation will depend on circumstances; minor roads may be poor features in built-up areas but may become very significant in an otherwise barren landscape.

5. **Selection Considerations**. The following considerations must be borne in mind when selecting a check feature:

a. **Terrain**. Careful map study is necessary to ensure that the feature will be seen. For example, if crossing a valley at 90º, any feature in the valley may be visible for 5 to 10 seconds. A feature on the near side of the valley may not be seen until it has been passed.

b. **Contrast**. A feature that contrasts with its natural surroundings will be easily identifiable.

c. **Lead-in Features**. The presence of features that lead towards the check feature can be used to draw the eyes to the area. A lead-in is essential for small check features.

6. **Choice of Check Features**. Some of the ground features suitable for visual map reading are discussed below. However, only rarely is any one feature used in isolation; it is the relationship of one feature to another that provides confident identification:

a. **Coastlines**. Coastlines generally offer an excellent opportunity for fixing. There is usually some associated feature such as a river estuary, headland, or inlet to enable position to be fixed with reasonable accuracy.

b. **Water Features**. Large rivers, estuaries, canals and lakes normally show up well. However, they naturally tend to occupy the lowest ground in the area and so may be hidden from view by the surrounding terrain. This is particularly true of lakes in mountainous regions; it is quite possible to fly within a mile or two of a mountain lake and not see it. Smaller rivers are often tree-lined; the trees can assist in locating the line of the river, but can also tend to hide the detail so that particular features of the river may not be seen.

c. **Mountains and Hills**. As the observer's height above ground decreases, the terrain contours take on considerably more significance. However, the interpretation of topography for mountains and hills from the map is more difficult than the interpretation of water and man-made features. Isolated and prominent hills provide the best opportunity for check features. Terrain which undulates fairly uniformly is extremely difficult to use unless there are additional features such as significant woods or transmission masts. Wherever there are mountains and hills there will be valleys and these can be extremely valuable features. They can usually be identified with confidence from their orientation and from the presence of roads, railways and settlements, and they provide a line feature for navigation and a route away from the highest ground.

d. **Masts**. Masts, with their vertical extent, can provide good visual clues to position at low level. However, they should not be selected as turning points, as they are difficult to see in poor visibility. Larger masts often have guide stays, therefore horizontal avoidance is essential.

e. **Towns and Villages**. Because the over-flight of towns and villages should be avoided at low level, they cannot be used for accurate pin-pointing on their own. However, they are useful as general indicators of position and for directing the eyes to suitable features nearby. The identification of a town or village must normally be done by relating it to other features in the vicinity, e.g. roads, railways, rivers and hills.

f. **Railways**. In areas of dense population and industry, the identification of railway lines can sometimes prove difficult. However, in more rural areas they provide an excellent line feature and, if there is some unique aspect to the line such as a junction, station, or conspicuous bridge, a pin-point can be obtained.

g. **Roads**. The usefulness of roads as check features is extremely variable, depending on the nature of the surrounding landscape. Motorways can be particularly distinctive if viewed lengthways or from height, but if approached at 90º at very low level, they can be obscured by trees or by being located in cuttings. By comparison, a single-track, narrow road might prove extremely significant in open country, especially over barren mountainous terrain. In general, the larger the road the more use it is likely to be.

h. **Woods**. Like roads, woods can vary between excellent and useless. Although woods may appear to have a particularly distinctive and identifiable shape on a map, this shape will not normally be apparent from a low level viewpoint. The exception is when the wood is on a facing slope, e.g. on the far side of a valley. In this situation, woods can prove extremely valuable check features. Although there can be some change to wood shapes due to felling and afforestation, the impact of this activity is normally fairly obvious. Nevertheless some care is needed.

i. **Miscellaneous Features**. Many other features can prove to be satisfactory navigation checks. Power transmission lines can act as line features, and can provide pin-points where they cross each other or other line features. Power stations, airfields, transmission masts, lighthouses, monuments, and follies are all worthy of consideration.

7. **Seasonal Variation**. The time of the year may affect the appearance of many features:

a. **Winter**. Lakes may be iced over, and snow cover may hide smaller roads and isolated railway tracks. Conversely, cleared roads may become more apparent due to their increased contrast with the surroundings. In the Northern Hemisphere, the sun is lower for longer periods of the day.

b. **Spring**. Any flooding will change the shape of water features, and indeed, the landscape.

c. **Summer**. Heavy foliage may obscure roads and railway lines. A period of drought will change the shape and water level of reservoirs. Rivers in many regions of the world will dry up.

d. **Autumn**. Deciduous woods may apparently change shape and importance.

8. **Accuracy of Map Features**. Three types of map detail are always plotted in their correct geographic positions on maps. These are:

a. Coastlines
b. River centrelines
c. Tops of Hills (Spot heights/Trig points)

To avoid being superimposed, all other features are likely to have adjusted positions. In making the adjustments, the cartographer takes care to display the detail correctly relative to adjacent features. Thus, for example, a mast will always be depicted on the correct side of the motorway even though accurate plotting would show it in the fast lane. In this case, it is the standard motorway feature which takes up more space on the map than its actual width demands. Such minor errors in position are unlikely to pose difficulties in the visual navigation environment, but must be considered during operational planning.

Timing

9. The intelligent use of the watch and stopwatch is perhaps the most valuable aid to low level navigation. Provided that the correct heading and speed are flown, time will provide a relatively accurate means of reckoning position, and the refinement of this position by reference to map and ground will be considerably eased. Time can thus be used to resolve any ambiguity of features. For low level navigation, several timing methods are available.

10. **Continuous Timing**. Continuous timing is a simple timing method. It requires the stopwatch and the route timing marks to be started from zero at the navigation start point (or take-off point), and both to run continuously to the navigation stop point (or landing). The technique is for the aircraft to be kept as close as possible to the elapsed time on the map, principally by MDR speed adjustment. Continuous timing facilitates simple planning for ETA, fuel etc. Where targets are included in the route, it will usually be preferable to zero the stopwatch, and re-start it overhead each IP (see Volume 9, Chapter 23, Fig 1). This enables the IP to target run to be navigated as a separate entity and with no accrued errors.

11. **Leg Timing**. Leg timing is also a simple timing technique. It can be used for routine navigation, and consists of starting the stopwatch at the beginning of every track (see Volume 9, Chapter 23, Fig 2). Leg timing requires a degree of certainty of finding the turning points. Furthermore, leg times must be added together to produce overall planning figures (ETA, etc). Leg timing can be reverted to if an aircraft is forced off the planned track - the stopwatch is started when the aircraft leaves track and again whenever a significant feature is found. Thus the technique provides a means of reckoning aircraft position relative to a series of known 'most recent' fixes.

12. **Hack Timing**. This method is a variation of continuous timing and can be used when it is necessary to achieve a 'real' (rather than elapsed) time on target (TOT). At the planning stage, the elapsed time from take-off to TOT is measured. By subtracting elapsed time from TOT, the take-off time is determined. The stopwatch is started (hacked) at this calculated take-off time regardless of the actual aircraft position. The aircraft is then flown to achieve the timing marks on the map. Large errors should be corrected early by cutting short the route. Smaller residual errors can be corrected by MDR speed adjustment.

13. **Real Time**. If the intent is to be overhead a selected point at a precise time, then the marking of real time against low level timing marks on the chart provides the ultimate comparison of where the aircraft is, against where it should be. However, operating totally in real time has few other advantages, and indeed is extremely inflexible. Many operators will therefore employ a combination of stopwatch and real time in order to achieve a TOT. For example, the stopwatch systems described in paras 10 to 12 can be augmented by annotating the real time required against each turning point.

14. **Selection of Timing Method**. Each of these methods has its advantages, disadvantages, and adherents. Any continuous timing technique works well, particularly if it is necessary to achieve a TOT, unless circumstances divert the aircraft off track. If the aircraft is forced off the planned track, the technique of leg timing can be reverted to. Leg timing is very flexible and lends itself to stopping and starting in flight as any significant features are noted. It can thus provide very accurate navigation between fix or turning points as accrued errors are not carried forward, and it lends itself to off-track navigation. A decision on the timing method to be employed will be made on the basis of the flight objectives, the probability of staying on track, and on personal preference.

Estimation of Drift and Required TAS or Groundspeed

15. The essence of successful low level visual navigation lies in the ability to stay on track and on time. To do so, account must be taken of the effect of wind velocity. If the aircraft is equipped with doppler or inertial systems, a continuous display of track and groundspeed is available and corrections can easily be made. Without these aids more elementary methods must be employed, normally employing mental dead reckoning (MDR).

16. **Wind Velocity at Low Level**. At the planning stage, and initially when airborne, the forecast wind velocity for the route or area of operation will be relied upon. Refinement of this may be possible by observing smoke plumes along the route. Generally, smoke blowing almost horizontally indicates a wind

of approximately 25 kt. Smoke at about 60º to the vertical indicates a wind speed of about 15 kt. Given the wind speed and direction, it is possible to use MDR techniques in order to resolve the velocity into approximate components of head/tailwind and crosswind. Low level flight is usually not undertaken in wind speeds greater than 40 knots, therefore the approximate methods are normally adequate.

17. **MDR Techniques**. MDR techniques are explained fully in Volume 9, Chapter 19. By applying MDR to the low level wind velocity, it is possible to estimate:

a. The drift on a particular heading.

b. The headwind or tailwind component on a particular heading. This component can then be used in one of two ways:

(1) If flying to maintain a planned groundspeed, the head/tailwind component can be applied to the TAS, to derive the required airspeed to fly.

(2) If flying to maintain a constant IAS/TAS, the head/tailwind component can be used to derive the resulting groundspeed.

Regaining Track

18. Inaccuracies in planning, in wind estimation and in maintaining heading will inevitably cause the aircraft to deviate from track. It is usually desirable to regain track as soon as possible as this makes map reading easier and avoids infringing avoidance areas. Regaining track can be achieved by any of the following methods:

a. By identifying a feature that is on track, and altering heading to fly over it.

b. By following a line feature back to track.

c. By using the Standard Closing Angle (SCA) technique (see Volume 9, Chapter 19).

Regaining Time

19. The same errors that lead to the aircraft deviating from track can lead to deviations in time. The techniques of dog-legs, cutting corners and pre-computed timing legs outlined in Volume 9, Chapter 17 can be applied to the low level environment. Providing that the speed range of the aircraft permits it, and the fuel penalty is acceptable, relatively small timing errors can be corrected by speed changes. A method of calculating the necessary adjustment, suited to low level, is described in Volume 9, Chapter 19.

20. Helicopters cruise close to their maximum permitted speeds and, although it is easy to lose time, gaining time along the route by increasing speed can be difficult. If one or more legs of the route are planned at a speed lower than the normal cruise speed, then time can be gained by flying the 'slow' legs at normal cruise speed. The amount of time to be gained by this method can be calculated by subtracting the leg time flown at normal cruise speed from the leg time at the slower speed.

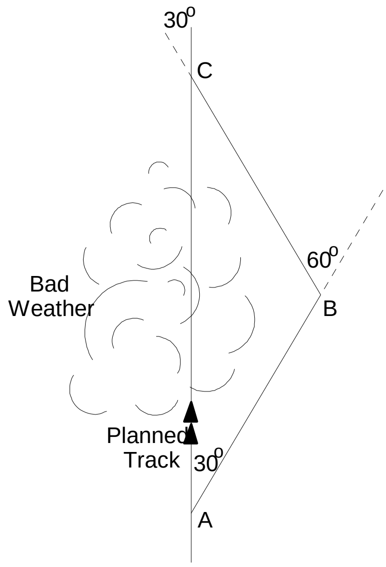
Weather Avoidance

21. Should bad weather be encountered during low level flight, there are four options available; lateral avoidance, vertical avoidance, turn back, and emergency low level abort. The extent and nature of the weather, together with the nature of the terrain and the objectives of the flight, will determine which course of action is appropriate. An early appreciation of impending poor weather will reduce the chances that the last option has to be resorted to, and provide more thinking time to implement one of the other options.

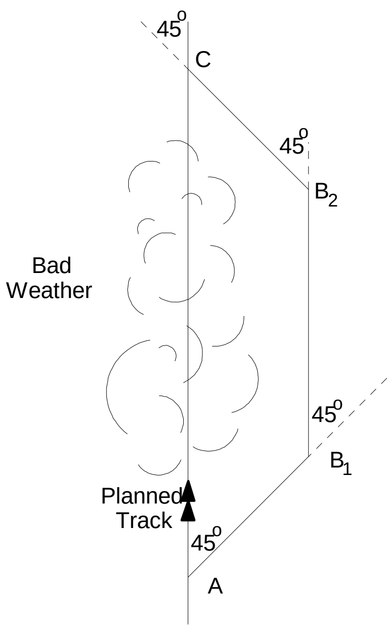
22. **Lateral Avoidance**. Lateral avoidance is by far the preferred method as low level flight is maintained and the sortie objectives stand a greater chance of being achieved. It may be possible to follow a valley or line feature that avoids the weather and returns the aircraft on, or close to, track. Equally, it may be possible to fly from one significant landmark to another, around the weather, and back to track. If these options are not practicable then a procedural technique, known as the 'dog-leg', can be used.

23. **The Dog-leg**. The dog-leg provides a simple procedural technique for avoiding a patch of poor weather on track whilst ensuring that the aircraft will return back onto, or close to, track. Fig 1 illustrates the principle. The aircraft is turned at a point (A) by an amount sufficient to avoid the weather. The time is noted, and this heading is maintained until the weather is cleared (B). The time from A to B is noted and the aircraft is turned back towards track, through twice the original heading change. This second heading is maintained until time BC equals time AB. At point C, a turn back on to the original track is made. Although track will be regained, time will be lost due to the greater distance flown. For a 30º dog-leg, the time lost will be a quarter of the time taken to fly the leg AB; for a 45º dog-leg it will be about half of the time, and for a 60º dog-leg it will be approximately equal to the time. A variation on the simple dog-leg technique is to turn back to a track parallel to the planned track for a period of time, before turning to regain track (Fig 2).

9-24 Fig 1 Simple Dog-leg



9-24 Fig 2 Dog-leg with Parallel Section



24. **Vertical Avoidance**. If the lateral extent of the weather cannot be determined, or if lateral avoidance is precluded by restricted airspace, it may be necessary to climb on track to maintain VMC or to level at safety altitude. Position above the planned route can be maintained by flying accurate speeds and headings, and making turns on time. If the weather clears later, it should be possible to identify a ground feature and make a return to low level. As the IAS/TAS ratio increases with height, it will be necessary to adjust the IAS to maintain the planned groundspeed. The simple method is, for every 1,000 ft climbed, to reduce the IAS by an amount equal to the number of nautical miles travelled in one minute at the desired TAS. For example, if trying to maintain a TAS of 360 kt, reduce IAS by 6 kt per 1,000 ft height increase. This approximation is sufficiently accurate up to about 10,000 ft. If it is necessary to fly above cloud for a

lengthy period, then DR accuracy will be degraded and it may be necessary to resort to radio aids, radar assistance or to discontinue the sortie. Particular attention should be paid to the base altitude or level of any controlled airspace that crosses the route. The vertical avoidance option is not always available to helicopters due to aircraft operating limitations such as icing.

25. **Turn Back**. If the lateral and vertical extent of the bad weather is such that none of the techniques described in paras 22 to 24 are practicable, or if climbing on track would mean penetrating controlled airspace, then the best option is to turn 180º and retrace the track already flown, as this is known to be clear of bad weather. It is important that the decision to turn back is made early enough so that the turn can be completed in VMC. It may be possible, once in clear weather, to re-plan in the air to reach a target or destination, but often the sortie will have to be abandoned. In helicopters, it is first possible to reduce height and speed to maintain visual contact with the ground before considering a turn back.

26. **Emergency Low Level Abort**. Should unacceptable weather be flown into, an emergency low level abort must be carried out. The flying technique will vary with aircraft type but, in essence, it is necessary to level the wings and then achieve the maximum angle of climb in order to avoid any high ground or obstructions. The climb will be continued until VMC above cloud, or until safety altitude, whichever is the lower. If the aircraft is likely to penetrate controlled airspace on climb out, then it is necessary to squawk emergency and call for assistance on 243 MHz as soon as is practicable. The low level abort should be a rare occurrence; good look-out and sound airmanship should allow one of the other options to be executed in good time. The helicopter technique is to perform a quick stop manoeuvre to bring the aircraft to the hover. If the bad weather precludes a turn back then the helicopter can be landed to await a weather improvement.

Lost Procedure

27. Thorough planning, careful route study and accurate planning should drastically reduce the possibility of becoming lost. Among the most common causes of uncertainty are missing a turning point and flying on regardless, or having to re-route to avoid bad weather. Checking for gross errors in heading and timing may resolve the problem, but should uncertainty persist, it is important to recognise the problem as early as possible and take positive remedial action.

28. In peacetime, the first action will be to climb to increase the area of view, and then to fix position by the best available means; visually, using radio aids, or with radar assistance. Should this not be possible, then use of the emergency organization will be necessary. An assessment of fuel state and safety altitude must be made.

29. If it is necessary to remain at low level, or if radio contact cannot be established, then other courses of action will be needed. It should be possible to deduce an approximate position based on the time and position of the last known fix, and the speed and heading flown subsequently. Clearly, the accuracy of the compass system and of the speed flown should be considered, as should the wind velocity in relation to that expected. Checks of these factors may well reveal the cause of the uncertainty and may give more clues as to position. The general topography may provide additional information, i.e. is the terrain flat,

hilly, or mountainous; is the region rural or urban? Having established a DR position, a circle of uncertainty can be drawn around it. A sensible radius for the circle of uncertainty might be equal to 10% of the air distance flown since the last fix. The technique now should be to maintain visual contact with the ground and to set heading towards a line feature (e.g. coastline, railway, motorway) outside of the circle of uncertainty, whilst map reading from ground to map. On reaching the line feature, it can be followed until a further feature allows a pin-point to be established.