Navigation

Introduction

This chapter provides an introduction to cross-country flying under visual flight rules (VFR). It contains practical information for planning and executing cross-country flights for the beginning pilot.

Air navigation is the process of piloting an aircraft from one geographic position to another while monitoring one's position as the flight progresses. It introduces the need for planning, which includes plotting the course on an aeronautical chart, selecting checkpoints, measuring distances, obtaining pertinent weather information, and computing flight time, headings, and fuel requirements. The methods used in this chapter include pilotage—navigating by reference to visible landmarks, dead reckoning—computations of direction and distance from a known position, and radio navigation—by use of radio aids.

NAVIGATION

From the beginning of time, the art of navigation has challenged man. The basic methods used have changed very little over the years, but the use of electronic aids allows us to navigate more accurately and more simply than ever before. Today, due to the ever-increasing number of aircraft sharing the sky in these modern times, the demand for precision and flexibility is increasing to ensure safety and economy. So apart from becoming simpler, it has also become more demanding.

Introduction

1. Navigation is the art and sciences of determining one’s position so as too safely and efficiently travel to a desired destination, DIRECTION, POSITION, SPEED & TIME are the fundamentals of Navigation.

2. Speed, time, distance, direction (and the influence of wind!!!) are all basics which are coupled with electronic aids and one’s individual skill to make up the art of modern air navigation. As in most subjects related to flying, this is very broad, and must be condensed. Only the essential aspects and performance standards will be covered.

THE EARTH

Form of the earth

3. Navigation is carried out above the surface of the earth, so knowledge of the shape and form of the earth is essential and makes for a good starting point. The earth, the surface the pilot works out his problems, is not a sphere, but is actually an oblate spheroid. Due to its rotation, centrifugal force has expanded the earth at the equator, which has resulted in a slight flattening of the poles. The flattening is called compression and in the case of the earth it is approximately 0.3% (1/300). For navigational purposes it is assumed that the earth is a perfect sphere.

4. If we take a perfect sphere and cut it in half, the cut will pass through the middle of the sphere and the circle cut onto the surface will be the largest circle that could be drawn on that sphere. This is called a Great Circle. Any other circle formed by a cut through a plane which does not pass through the centre of the sphere is called a Small Circle as will be explained later. Because we regard the earth as a “perfect” sphere, the same applies to any circle drawn on its surface. Segments of a circle are called arcs, and are measured in degrees, minutes, and seconds. If the circumference of any circle, be it a great circle or a small circle is divided into 360 equal units, each of the curved arcs would be 1° (1 degree) in length. Each degree is then divided into a further 60 units, called minutes, and each minute divided into 60 seconds. In our metricated, decimal world, the number 360 is not very convenient, but this system has been in place for centuries, and is unlikely to change.

5. Using this method of degrees minutes and seconds, we are able to break our circle into very small segments, using decimals if very accurate measurements beyond a second are needed. An arc of 33 degrees, 45 minutes and 10,56 seconds would be written as 33° 45' 10,56". As a pilot you will rarely have to work in units smaller than minutes

6. This method is a bit of a nuisance when working with a pocket calculator, because most of them are decimal only (1/10). Any scientific calculator allows you to convert any value in decimals to degrees, or vice versa, the value in degrees being called sexagesimal (1/60), but more of this later.

The Nautical System
Whole circle = 360 degrees (360°)
1 degree (1°) = 60 minutes (60')
1 minute (1') = 60 seconds (60")

Basic Direction on the Earth

7. W e know that the earth rotates on an Axis which a line joining two points on the earth which is diametrically opposed. These are called The Poles. The axis of spin passes through the centre of the

earth. They have been called the North Pole and the South Pole. The earth rotates towards the rising sun, and if we face the rising sun, the North pole will be on our left and the South pole to our right. The direction of rotation of the earth is known as East, and the opposite of East is called West. These two directions are at right angles to the spin axis of the earth which runs North/South. These four directions are known as the Cardinal Points. The midway directions between North (N), East (E), South (S), W est (W) and North (N) are North-East (NE), South-East (SE), South-W est (SW) and North-West (NW). These directions are known as Quadrantal Points.

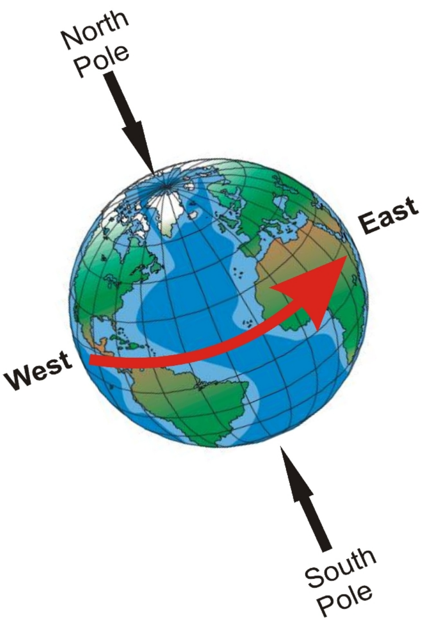


Fig 3.1. Earth's rotation and Cardinal Points

8. W e utilise the Sexagesimal (units of 60) system with TRUE North as the datum line, for direction on the earth. Direction is measured clockwise from North through East, South and W est and back to North, this forms a complete circle of 360°. North is defined as 000°, East 090°, South 180° and W est 270°. Continuing the rotation back to north, North becomes 360° or 000°. W hen North is the datum line the direction of the North geographic pole is referred to as true direction. Direction is always expressed in a three-figure group eg 000° (T), not 0° (T) and 090° (T) not 90° (T).

The Cardinal Points:
North (N)
South (S)
East (E)
West (W)

The Quadrantal Points:
North-East (NE)
South-East (SE)
South-West (SW)
North-West (NW)

Latitude and Longitude

9. In order to determine position, a point of reference is needed. The reason for this is that in aviation it is not always sufficient to say that your aircraft is over Bathurst. Not everyone knows where Bathurst is, and over water you would be hard pressed to come up with a description of where you are! Using the graticule, the position of any point can be accurately defined. In navigation we use a graticule of Latitude and Longitude lines.

10. If it were possible to draw a circle on the surface of the earth joining the Poles, the direction of the line would be defined as True North/ South (N/S). The centre of the circle would also lie at the same position as the centre of our sphere, and the resultant line would be a Great Circle (GC). Remember, it is the largest circle that can be drawn on the surface of our sphere. Any number of these circles could be drawn on the surface, and each one would represent a GC. These semicircles joining the two poles are called Meridians of Longitude. The other half of the same GC is known as the Anti-meridian

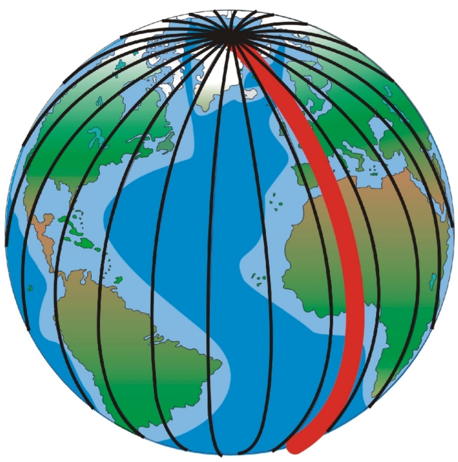


Fig 3.2. Meridians of Longitude

11. To complete our graticule, we need to imagine lines running East/W est (E/W) at right angles to the meridians. Only one of these E/W lines will run through

the centre of the earth, and that will be the one exactly half way between the two poles. This one we call the Equator, and it also divides the earth in two equal parts. W e can therefore say that the Equator is also a GC. All of the other lines at right angles to the meridians will have diameters smaller than that of the equator, and are therefore not GC's, but Small Circles. These lines, because they run parallel to the equator, are also called Parallels of Latitude

Fig 3.3. Parallels of Latitude

12. W e have established the position of the equator, which is the E/W line dividing the earth into two halves. These halves are called Hemispheres, the one on the North pole side of the equator called the Northern hemisphere, and the one to the south called the Southern hemisphere. If we imagine the equator being a flat disc placed in the earth, and we measure any angle from the centre of the earth upwards, say an angle of 30°, and draw this line, or small circle, on the surface of the earth, the line would be called the 30° North parallel.

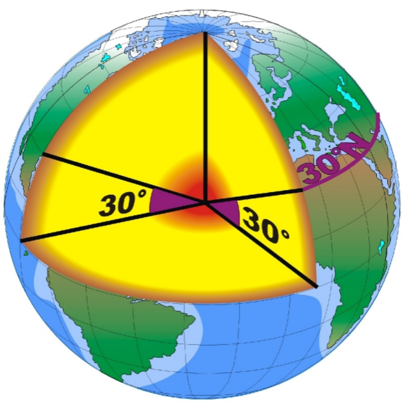


Fig 3.4. Parallel 30°S

13. All other parallels constructed in this way would be given the value of the angle between the flat disc of the equator and the cone formed by drawing the line on the earth surface. The line on the surface of the earth so constructed is termed the Parallel of Latitude (lat).

14. The equator is given the value of 0°, as it divides the sphere into the two hemispheres, and the poles will then be 90°. As both poles will be 90°, it is necessary to specify the hemisphere, so the North pole is known as 90° N, the South pole being 90° S. the same applies to all other parallels of latitude - they are given the value of the angle, and identified by hemisphere.

15. Port Alfred is located on the 33° 35' 00" parallel in the southern hemisphere, and this can be written as 33° 35' S, or simply 33 35S, leaving out the degree and minute indications. Remember that it is very rarely necessary to use seconds unless you want to be very accurate, or are using modern navigation equipment that may require such levels of accuracy.

16. Now that we have established the parallel on which any place is located, we can give its exact position by identifying the meridian which passes through that place. In para 4.6 we saw that any number of these meridians, or GC's, can be drawn. It was important, therefore, to choose a particular meridian as a datum from which to work, known as the Prime Meridian. The one in use today was chosen in 1884, and is that one which passes through the observatory at Greenwich in England.

17. This datum would also be used as the datum for time, once called Greenwich Mean Time (GMT), but now referred to as Universal Co-ordinated Time (UTC). Another factor which contributed to its selection was the fact if it were midday over the Greenwich meridian, it would be midnight on the other side of the earth, ie on the anti-meridian. At midnight the date changes, so the anti-meridian of the Greenwich meridian is known as the International Date Line. Another point which influenced its selection is the fact the anti-meridian passes through as much open ocean as possible, keeping the administrative problems in those parts of the world to a minimum. Imagine having two dates in the same country, on the same day? More of this later.

18. Once the Greenwich meridian was adopted as the prime meridian, it was given a value of 0°. The anti-meridian was given the value of 180°, being on the other side of the sphere. The great circle formed by the prime meridian and it anti-meridian also cut the sphere into two hemispheres, the Eastern Hemisphere on the eastern side of the prime meridian, and the Western Hemisphere on the western side. It is also referred to as a line of Longitude (long).

19. Going back to the center of the earth, any angle measured horizontally from the line joining the prime meridian and the center of the earth is given that angular value at the surface. Once again, as was the case with N and S, the hemisphere is identified as E or W . Say an angle of 80° is measured from the Prime Meridian westward, that Meridian will be called the 080°W Longitude.

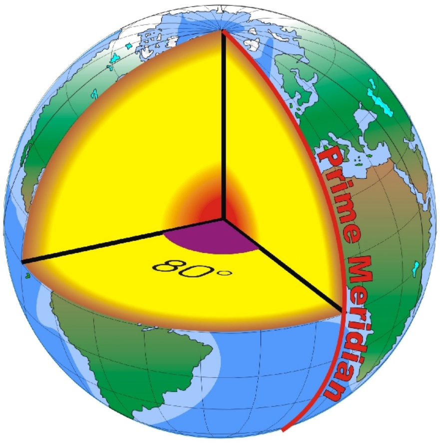


Fig 3.5. Longitude 080°W

20. The meridian that passes through the aerodrome at Port Alfred is 026° 53' E of the Greenwich meridian, and is normally written as 026 53E.

21. Any point on earth can now be fixed by reference to the unique intersection of its parallel of latitude and it meridian of longitude. The numbers of these lines are known as the Co-ordinates of the point, and, by custom, when co-ordinates are given, latitude is always given first, then longitude. The co-ordinates of Port Alfred aerodrome are therefore 33° 35'S 026° 53'E, or in the simpler form, 33 35S 026 53E. London Heathrow, for example is 51° 28' 11"N 000° 27' 08"W (or 51 28 11N 000 27 08W). Aircraft of today move around at fairly high speeds, changing position rapidly so it becomes impractical to give the position in seconds. It is common practice, on practical grounds, not to give position accuracy greater than to the nearest one minute. Heathrow therefore becomes 51 28N 000 27W .

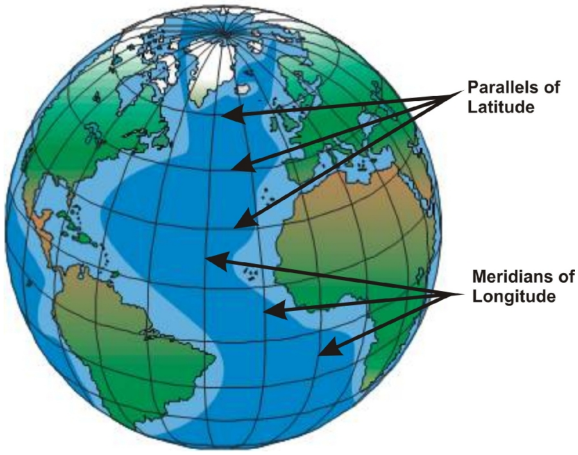


Fig 3.6. Graticule of Parallels of Latitude and Meridians of Longitude

Latitude is always a two digit group:
03 15S or S03 15
Longitude is always a three digit group:
003 15E or E003 15

22. The angular difference between two latitudes is called Change of Latitude (ch lat) or Difference in Latitude (d lat). Sometimes it is important to indicate the direction of change; which can only be North or South. The ch lat between 30S and 30N will be 60°. If 2 points are in the same hemisphere, the ch lat between them is equal to the difference in their values. The sense of movement (N or S) will depend on from which point you are moving. If 2 points are in opposite hemispheres, the ch lat between them is equal to the sum of their values. Again, the sense of movement (N or S) will depend on from which point you are moving.

23. The angular difference between two longitudes is called change of longitude (ch long) or difference of longitude (d long). The sense in which the change occurs is either East or West. Thus from 080°W to the 010°E meridian, the ch long is 090°E. Change of longitude calculations are particularly important in Navigation problems because several formulae used to calculate direction or distance on the Earth use ch long as one of their terms. If two points have longitudes in the same hemisphere, the ch long between will be the difference in their values. The sense of movement

will depend on which point you are moving from to which. Remember decreasing easterly values mean a westerly direction, and decreasing westerly values mean an easterly direction. The problem is slightly more complex if the two points have longitudes in different hemispheres. Again, the ch long can be calculated in this case by adding the values.

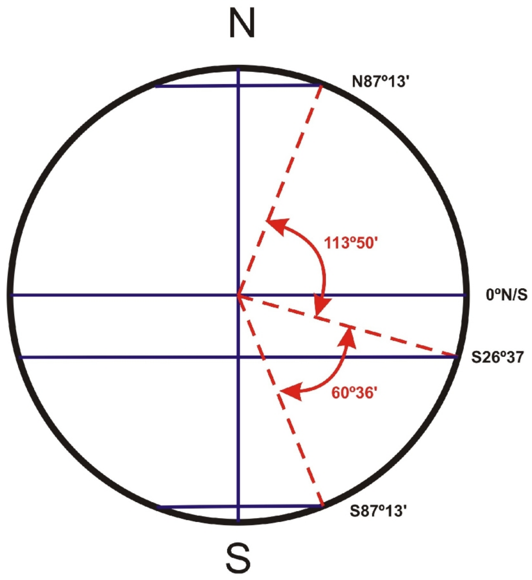


Fig 3.7. Change of Latitude

24. The change in latitude from 26°37'S to 87°13'S is 60°36' in a southerly direction and the change of latitude from 26°37'S to 87°13'N is 113°50' in a northerly direction.

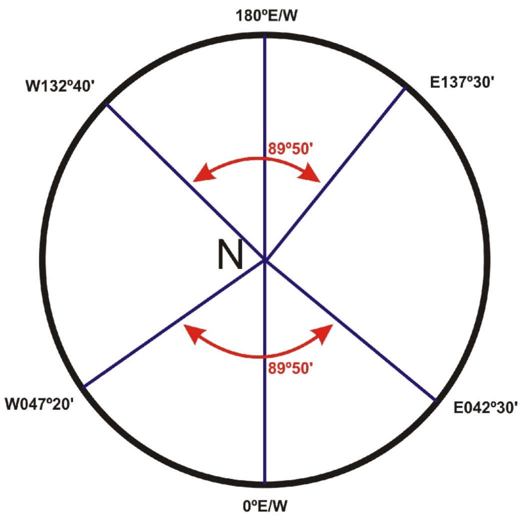


Fig 3.8. Change of Longitude

25. The change of long from 042°30'E to 047°20'W is 89°50' in a westerly direction and the change of long from 132°40'W to 137°30'E is 89°50' in a easterly direction.

Great Circles and Rhumb Lines

25. So far we have seen that the equator and all of the meridians, together with their anti-meridians, form GC's. They are not the only GC's that can be drawn on the earth. As long as the centre of the GC passes through the centre of the earth, dividing it in two halves, it is a great circle. It is possible therefore to draw a great circle joining any two places on the surface of the earth. The shortest arc of the GC between those two places will represent the most direct, and shortest, route between them. An exception to this is if they were geographically opposite each other, like the poles, where every meridian is a GC.

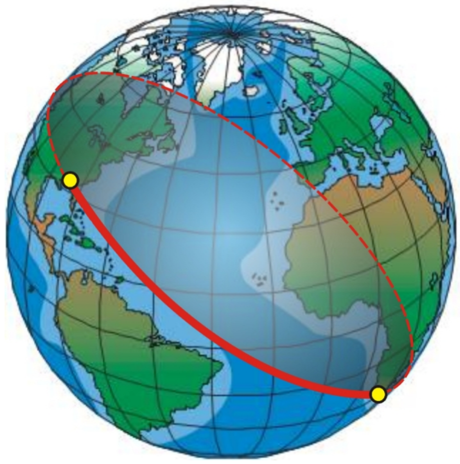


Fig 3.9. Great Circle

The shortest distance between two points on the earth is along the shorter arc of the Great Circle passing through them

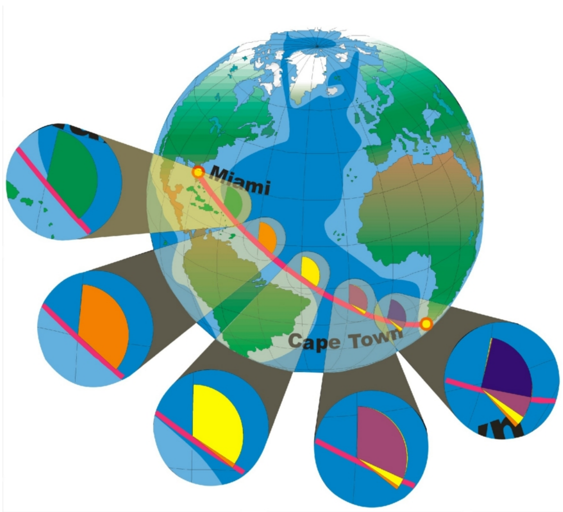


Fig 3.10. Great Circle Track

26. If the GC drawn between two places is not N/S or along the equator, it will be cutting the N/S

lines of the graticule at ever-changing angles. This means that if we were to fly along a GC track, we would have to continually change our heading.

Flying along a GC between two places has the ADVANTAGE of the shortest distance, but the DISADVANTAGE of constantly changing direction.

27. If we were to fly a constant heading between the two places, we would no longer be flying a direct route, nor will we be flying the shortest distance. The only advantage is that our direction remains constant. This line is called a Rhumb Line (RL), and over short distances there is very little significance in the difference.

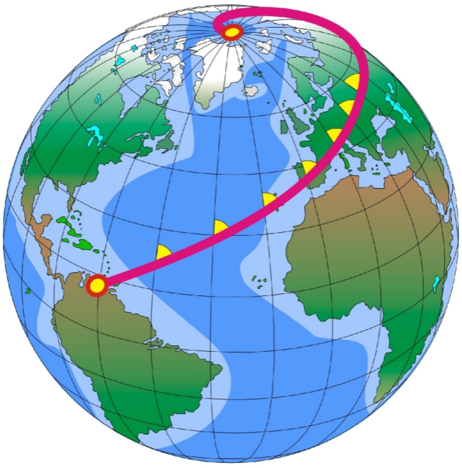


Fig 3.11. Rhumb Line

Flying along a RL between two places has the DISADVANTAGE of greater distance, but the ADVANTAGE of constant direction.

Convergency

28. Meridians are Great semi-circles joining at the poles. They converge from the equator towards the poles and diverge from the poles towards the Equator. At the equator they are parallel, there is no Convergency, at the pole the meridians meet at a single point and Convergency is thus ch long, in other words the largest. Convergency is defined as the angle of inclination between two selected meridians at a given latitude.

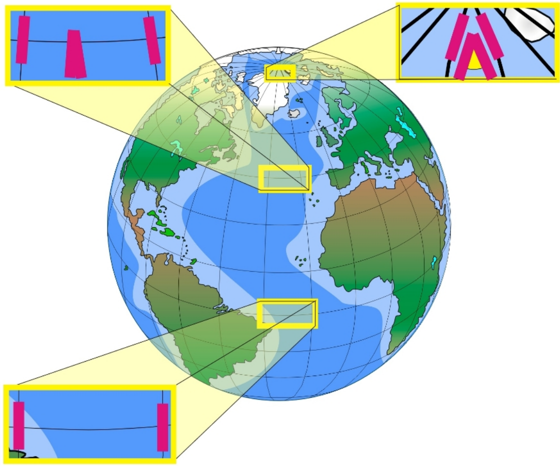


Fig 3.12. Convergency

Scale

29. Scale is the relationship between the length of a line or the distance between two points on a map and the distance between those same two points on the surface of the earth. Scale could be a statement of words, a graduated scale line or a representative fraction. A statement of words is straight forward; 1 inch equals 10 nautical miles. A graduated scale is normally printed on the chart. Scale is reported as a representative fraction with the map distance as the numerator and the ground distance as the denom inator. As the denom inator of th e representative fraction gets larger and the ratio gets smaller, the scale of the map decreases. The numerator, CL, must always be "1" and the denominator is the earth's distance in the same units. If the scale is 1:1 000 000, one unit on the chart represents 1 000 000 of the same units on the earth. A CL of 1 centimetre represents an ED of 1 000 000 centimetres, just as 1 inch represents 1 000 000 inches with the same scale.

Chart length and earth distance must be in the same units

30. It is useful to remember at this time that you could be asked to calculate the scale, the Chart length or the Earth distance. If you write the given scale as a representative fraction, get all units the same, you will end up with a simple mathematical cross-multiplication formula. It can be explained by means of an example.

Example:

How many Nautical miles is represented by 11 cm on a 1:5 000 000 map?

$$Scale = \frac{CL}{ED}$$

$$\frac{1}{5000000} = \frac{11cm}{Xnm}$$

$$X = \frac{11X5000000}{2.54X12X6080}$$

$$X = 296.787$$

31. As seen above, it is useful to remember some conversion units such as 2.54 cm = 1 inch, 12 inches = 1 foot and 6080 feet = 1 nautical mile.

MAPPING

32. A map of the earth's surface is our primary instrument. Maps designed for navigation are usually referred to as charts, but the terms Topographic map (Surface features like roads, relief, rivers and railways are portrayed on this type of map) and chart can be regarded as the same thing. For a chart to be useful it must accurately portray the shape and size of ground features, and the distances and directions between different places which we measure on the chart must be accurate. The problem that we have is that it is not possible to accurately portray the details of a round object onto a flat piece of paper. Different methods of making charts will produce different results.

ORTHOMORPHISM (CONFORMALITY)

ORTHOMORPHISM means showing correct bearings at all points on the map. Orthomorphic maps require that:

Scale must vary at the same rate in all directions over a small area.

Lines of latitude and longitude must all cross at right angles ie 90°.

33. There are many ways in which maps are made, but it can be described very basically as taking a reduced earth, much like a transparent school globe, placing a tube of paper around the earth, placing a light in the centre of the reduced earth, and projecting the image onto the tube of paper. The image then becomes our chart. A chart made in this way is called a Cylindrical Projection. A Mercator chart is an example of a cylindrical projection.

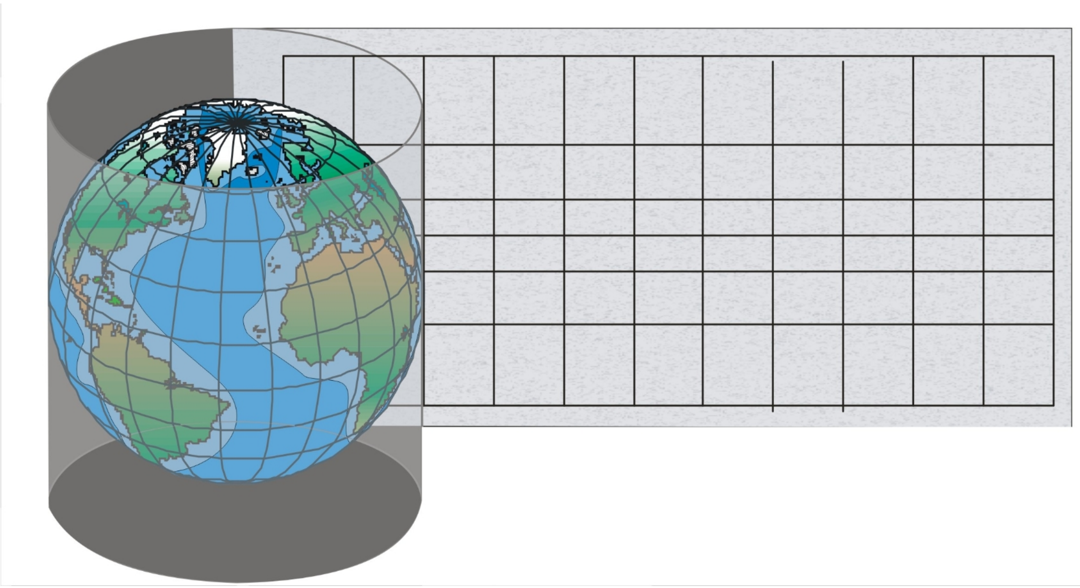


Fig 3 13. Cylindrical Projection

34. As you can see from above, only that part of the chart which touches the reduced earth (in this case the equator) will be correct. There is expansion as we move up or down from the contact point. For this reason the Mercator can only be used on or near the equator.

35. By changing the shape of the paper to a dunce cap, placing it over the reduced earth with the pole as the apex, the projection will be slightly different. A chart made this way is called a Conical Projection. The cone will also only make contact with the reduced earth at one point, so only at that parallel of latitude will everything such as scale, size, features and areas be correct, as was the case with the equator in the Cylindrical Projection. The point where the cone makes contact with the reduced earth is called the Parallel of Origin and is known as the Standard Parallel. This is the simple Conic projection. By changing the shape and size of the cone, by making the cone steeper or flatter, the cone can be made in such a way that it will make contact with any line of latitude, or parallel. In this way, map makers (or cartographers, to give their correct title) are able to make accurate charts of any part of the world.

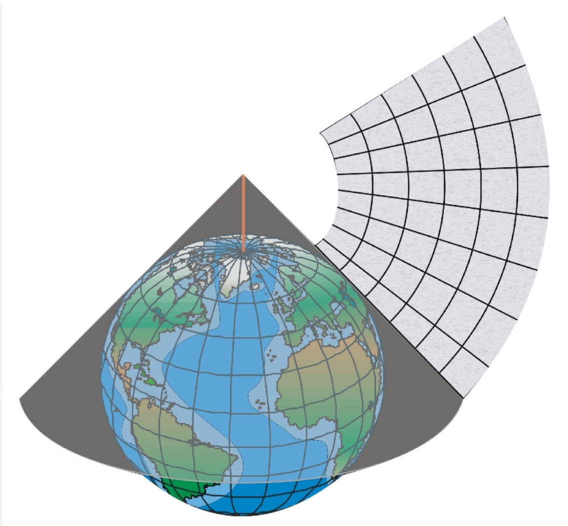


Fig 3.14. Conical Projection

36. By flattening the cone completely, or in other words, using a flat piece of paper, the cartographer can place the paper on either of the poles, and a chart made in this way is called a Polar Stereographic map. Obviously this can only be used at or near the poles, so for all practical purposes we will ignore this one. Due to the fact that you will most likely be flying your aircraft in the mid latitudes, we will concentrate only on the Conical Projection, and more specifically, the Lambert's Conformal Conical Projection.

37. In the previous paragraph the word "Conformal" made its appearance. Latitudes and longitudes must intersect at right angles, directions must be shown correctly and scale must vary at the same rate in all directions, for a chart to be conformal. Any chart used for aviation purposes must possess the properties of Conformality (also called Orthomorphism, which is an awful word!). The Lambert's chart does have these properties, hence the name.

38. The Lambert's differs from the simple conical chart in that instead of having one Standard Parallel, it has two. This is achieved by pushing the cone into the reduced earth so that it cuts the surface of the reduced earth at two parallels. This achieved by mathematics (which we won't go into!). It means that there are now two areas on the chart, along each of the standard parallels, where everything depicted on the chart will be the same as that on the reduced earth. This makes the chart a far more functional. Apart from the fact that directions are correct, scale is correct over a larger area of the chart, and land shapes and sizes are correct. Between the two Standard parallels we have what is called the Parallel of Origin. This is used for mathematical calculations which those of you going on to do the CPL will have to master. A line joining two places on the Parallel of Origin will be an exact Great Circle, whilst all other lines drawn on the chart are close enough to being a GC to be regarded as one. Rhumb lines are curves, as can be seen by the lines of latitude, and are of no importance to the pilot. W e fly Great Circles, so this is the chart of choice.

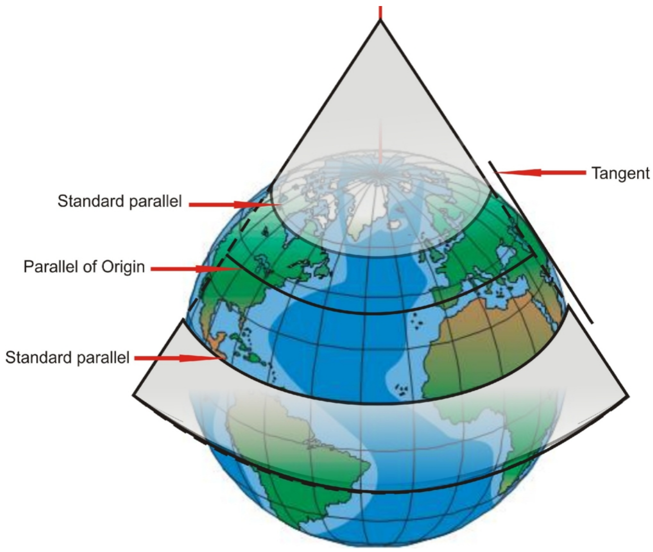


Fig 3.15. Lambert's Conformal Conical Projection

Properties of the Lambert's Conformal Conical Projection

39. The chart has the following properties:

a. Meridians. Converge towards the poles, exactly as they do on earth, but they are straight lines, and not curved as they are on earth.

b. Parallels. The parallels, or lines of latitude, curve towards the equator, making them rhumb lines, which they are on the earth.

c. Scale. Scale is correct along the two Standard Parallels, and the expansion of scale outwards from the two SP's, and the scale contraction from the SP's to the Parallel of Origin is so small that the scale over the whole chart can be considered the same.

d. Direction. As a straight line on the chart is regarded as a GC, measurement of direction is correct, and is easy to accomplish. All the meridians are straight lines converging to the nearer pole, so the determination of True North is easy.

e. Great Circles. Great circles appear as curves concave to the parallel of origin but are nearly a straight line. For practical purposes, a great circle is a straight line.

f. Rhumb Lines. Rhumb lines are curved lines, concave to the pole.

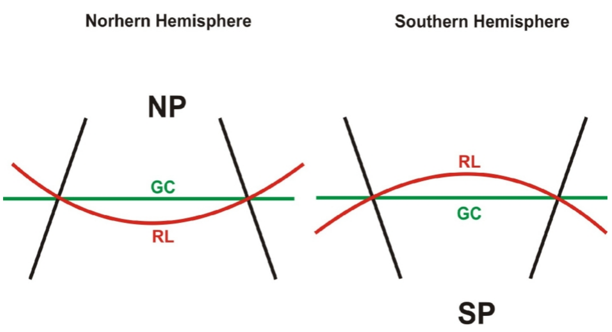


Fig 3.16. Great Circle & Rhumb Line on a Lamberts Conformal Projection

Direction

40. The Meridians of Longitude point to True North and are clearly indicated on the chart, it is easy to measure any direction from there. You simply place your protractor on the chart, with the centre of the protractor on the line you wish to measure, align it with the nearest meridian, north towards the geographic North Pole, and you can read off the True value of any line on the chart. The value is always measured clockwise, from true north to the line you are measuring.

41. This doesn't help much as the aircraft compass is influenced by the position of the Magnetic North pole. This is due to the earth being a great magnet whose Magnetic poles do not coincide with the North and South Geographic poles. The Magnetic North Pole is situated close to Hudson Bay in Canada and is constantly moving very slowly. It can thus be said that the Magnetic North Pole is situated to the W est of the True North Pole. The angle between True North and Magnetic North at any position can be calculated, and this is shown on the chart as a dotted line which is called Magnetic Variation, or just Variation. These values can be anything between 0° and 180° depending on the position of the two poles relative to the position on earth. If the position of Magnetic North is to the left of True North from any position the Variation is said to be W est, Variation it is to the W est of True North.

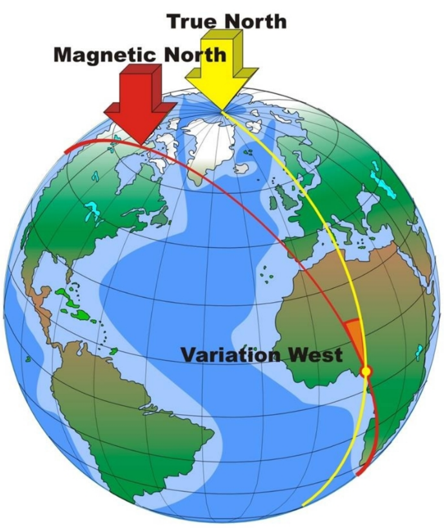


Fig 3.17. Variation West

42. If Magnetic North is to the right of True North, Variation is said to be East, Variation is to the East of True North.

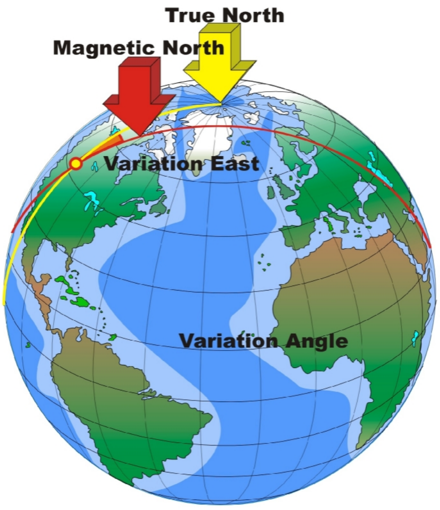


Fig 4.18. Variation East

A line indicating equal Variation on a chart is called an ISOGONAL.

A line indicating zero Variation on a chart is called an AGONIC line.

43. If you have to convert a True Heading to a Magnetic one, the value of Variation must be applied correctly. If you have a Variation which is W est then the Magnetic Heading will be GREATER than the True Heading. If the variation was East, then the Magnetic Heading would be LESS than True Heading (Fig 3.19).

44. All of South Africa falls into a zone where Variation is W est, so Magnetic Heading will always be greater than True Heading. This is easily remembered by the saying:

Variation West - Magnetic Best
Variation East - Magnetic Least

45. Another problem is that the magnetic poles are not stationary, but move around quite a bit from year to year. The rate of change in position is known, and this information is printed on the chart. All you need do is check on the date of printing, multiply the correction factor by the number of years since the chart was printed, and correct the Variation accordingly. For example: Say it is 2001, Chart printed in 1992, Mean Annual Change = 7' W estwards, the correction is 9 x 7' = 1° 3' W estwards. This you must Add to the Variation West printed on the chart.

Aircraft Magnetism

46. Our problem of finding a Heading to steer does not stop with Variation. The whole aircraft itself is a magnet, and the magnetic field of the aircraft will also influence the position taken up by the compass needle. The influence of the aircraft itself is called Deviation, and has to be calculated by a process called a Compass Swing. You don't have to know how to do a compass swing, only that it is necessary, and has to be done at specified times.

47. The magnetic influences within the aeroplane come from a variety of sources. During construction there is a lot of rivetting and hammering and banging going on, and this induces the earth's magnetic field into the aircraft. From your schooldays, you may remember that stroking a metal bar with a magnet will make a magnet of the bar. The same happens to the aircraft - it is "stroked" by the earth's magnetic field. Added to this there are numerous electrical components in the aircraft, each of them creating its own electro-magnetic field, the sum of which is called aircraft magnetism. It is this magnetism which causes Deviation.

48. Deviation causes the compass needle to deflect either left or right of Magnetic North. Deviation is dependent on aircraft heading, and is not the same on all headings, as was the case with Variation. It also varies from aircraft to aircraft, because each aircraft will have its own particular magnetic field. The value of Deviation can be found on the Compass Correction Card and must be applied to the calculated Magnetic Heading. Once deviation has been corrected, the result is Compass Heading, and that is what you will have to steer in order to follow the track you originally drew on your chart.

49. Deviation is also given in degrees East or W est, and is the number of degrees the Compass Heading is to the East or W est of the Magnetic Heading (Gig 3.19). Application of Deviation can be remembered in much the same way as variation:

Deviation West - Compass Best
Deviation East - Compass Least

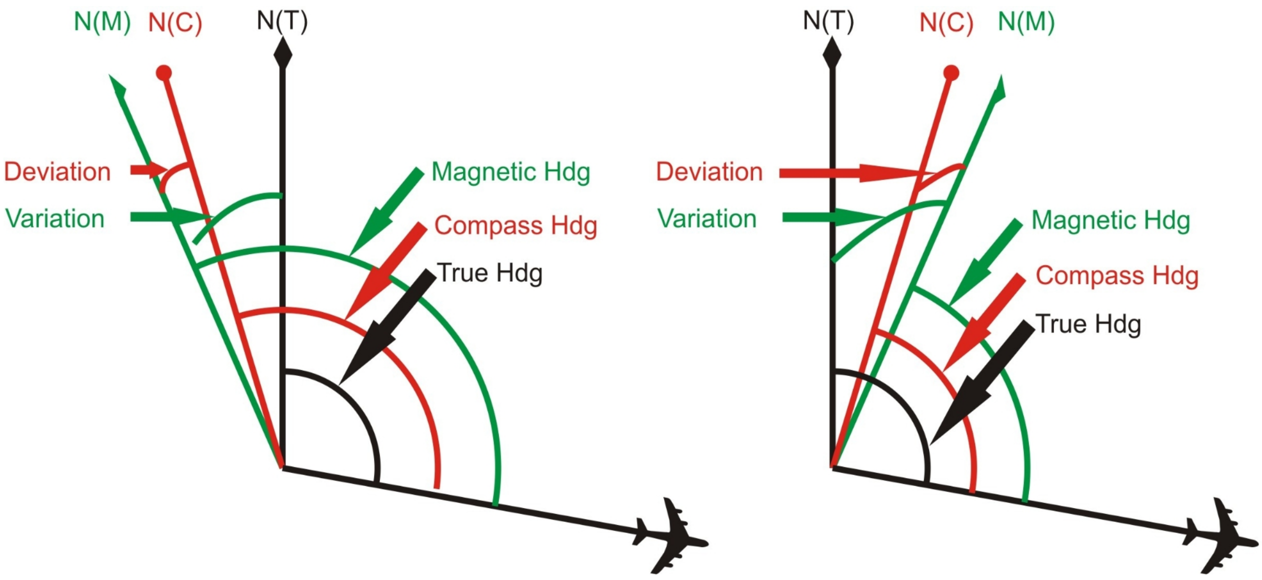


Fig 3.19. Variation and Deviation

Example:

True heading is 120E(T), the variation is 22EW and the deviation is 5 EE. W hat is the magnetic and compass heading?

Answer:

Variation is west of true north, therefore magnetic heading will be greater than true heading. 120 E(T) + 22 EW (Variation West Magnetic Best) = 142 E(M).

Deviation is east of magnetic north, therefore compass heading will be less than magnetic heading. 142E(M) - 5EE (Deviation East Compass Least) = 137 E©.

50. The magnetic compass in the aircraft is very sensitive due to its construction; short magnets are used to facilitate turning in the silicone fluid and it has a high pivot point offset from its centre of gravity to reduce dip. Because of this, it is also affected by turning and acceleration errors. Care must be taken when using the magnetic compass, as readings can only be relied upon when the aircraft is in steady, straight and level flight. Placing a GPS, Nav computer, or your watch (because of their batteries) near the compass will affect it. The only problem is that this error will not be known, and cannot be calculated. In fact any metal object placed near the compass will cause the needle to deflect, so don't pack things onto the dashboard. Apart from interfering with the compass, they are not properly stowed!

Acceleration Errors

51. Acceleration errors are most noticeable when the aircraft is flying on EASTERLY- and WESTERLY headings. There are no acceleration errors on North/South Headings. In the Southern Hemisphere, an acceleration would show an apparent turn to the closest pole, which in this instance is the SOUTH POLE. A deceleration would indicate an apparent turn to the Equator, in other word's to the North. Thus the mnemonic : SAND – South : Accelerate North: Decelerate.

Turning Errors

52. Turning errors are found because the magnets in the instrument lags behind in the fluid inside the compass as you turn your aircraft. They are most noticeable on North/South headings and are zero on East/west Headings. If you therefore turn using tour magnetic compass, you will have to compensate for this lag. If you turn on to a northerly heading in the Southern Hemisphere, you m ust overshoot that heading by roughly 30°. This would come down to about 20° at headings 030° and 330° and down to 10° at headings of 060° and 300° respectively. W hen turning onto East or W est you roll out on your heading. Turning on to Southerly Headings you would undershoot by the same margins. The mnemonic to remember is ONUS in the Southern Hemisphere (Overshoot turning North Undershoot turning South) and is opposite in the Northern Hemisphere .

Planning

53. W hen planning a navigation exercise, or a cross country as it is more commonly called, you will start off by measuring your intended track, getting the True Track. In no wind conditions this will also be your required True Heading Hdg (T). Variation must then be applied to convert the Hdg (T) to a Magnetic Heading Hdg (M). Finally, once you know which aeroplane you will be flying, you apply Deviation to Hdg (M) to get the required Compass Heading Hdg © to steer.

54. To make it a little easier to ensure that each of the above steps are taken in the correct sequence, and that Variation and Deviation are applied in the correct sense, the mnemonic:

C D M V T
Can Dead Men Vote Twice

will certainly help. For those of you who may feel a bit queasy about using the word "dead", use Cadbury's Dairy Milk, Very Tasty! By using the two rhymes, Var W est - Mag Best and Dev W est - Comp Best, you can't make a mistake with the proper application of the two corrections. If in doubt, W RITE out a table. Both Variation and Deviation may be given with a positive (+) or negative sign (-) instead of specifying whether it is East or W est. Remember that a positive (+) sign indicates East, and a negative (-) indicates W est. So when given Deviation as +3, it actually means 3° East. It is NOT an instruction to add the value to Hdg (M) to get Hdg ©. Always use the rhyme to make certain.

Distances

55. The distance unit used in aviation is the Nautical Mile. W e have our naval brethren to thank for this, as it was first used at sea for maritime navigation. It evolved from the lines of longitude, and is the average length of 1 minute of longitude, 1° being 60 NM. As there are 90° between the equator and the pole, the distance between the two is 90° x 60 = 5 400 NM. This represents a quarter of the way around the earth, so 4 x 5 400 = 21 600 NM, which is the circumference of the earth.

56. The length of a nautical mile is 1 852 metres, or, rounded off in feet, 6080 ft. This is close enough for any calculation you may be called upon to make. The navigation rulers available at all flight shops are calibrated in nautical miles, and all you have to do is select the correct scale when measuring your track distances.

57. Although pilots are normally interested in larger units of distance, ie, Kilometres (km), Statute Miles (sm) and Nautical Miles (NM), it is required that the student to be able to use smaller units and to be able to convert between Metric and Im perial measures. Most of the conversions can be made with sufficient accuracy using the Navigation Computer (CX2 or equivalent).

1 metre (m) = 100 centimetres (cm) = 1 000 millimetres (mm)
1 centimetre (cm) = 10 millimetres (mm)
1 metre (m) = 3.28 feet (ft)
I foot (ft) = 12 inches (")
1 inch (") = 2.54 centimetres (cm)
1 yard (yd) = 3 feet (ft)
1nm = 6 080 feet (ft)
1nm = 1 852 metres

58. The simple navigation definition of the Kilometre is 1/10,000 the of the average distance on the Earth between the Equator and either Pole, Thus there are 10,000 km between the Equator and either Pole and the circumference of the Earth is 40,000 km. For conversions between Kilometres and Imperial units:

1 Kilometre (km) = 3280 feet (ft)
1 metre (m) = 3.28 ft.

59. The Statute Mile (sm) is defined in a Royal Statute of Queen Elizabeth the First (of England). Although the Statute Mile is widely used on the ground (eg, in the UK and the USA) it has limited application to aviation. Indeed, its most common use is to inform passengers in UK or US aircraft how fast the aircraft is travelling in terms of the same units they use in their cars. The average distance from the Equator to either pole is 6200 sm; the circumference of the Earth is 24,800 sm.

1 sm = 5 280ft

Practical Navigation

60. When doing practical navigation, we start off with a suitable chart. Make sure that you have the correct chart for the task you wish to perform.

61. Another aspect to consider is the scale of the chart. It does not help to select a chart where the scale is too small (1:2 500 000). If you do so, then topographical detail will be very limited as it is almost impossible to cram 2 500 000 inches of ground detail (or a little over 34 nautical miles) into 1 inch of map. On the other hand, a chart with a larger scale, such as the 1:50 000, will provide you with all the topographical information you need (only 50 000 inches ground distance, or 0,7 nautical miles, to 1 inch of map space). The drawback is that you will have to carry a lot of paper!

62. The type of flight you are going to undertake must determine the choice of chart. If you are going to be flying at fairly high levels, then a 1:500 000 will do the trick. Lower level work could require a 1:250 000, and very detailed low level work might even need a 1:50 000. In most cases the 1:500 000 should be fine.

Chart Reference

63. Around the edge, and printed on the back of the 1:1 000 000 and 1:500 000 charts you will find all sorts of information. The Chart Title, Scale, Hypsometric Tints and Topographical References are found on the front, while at the back information about the Aeronautical Symbols used on the chart is to be found. This will help you understand what type of information the chart is able to provide.

Depiction of Relief on Maps

64. Four methods are used to show the height and shape of land forms: spot heights, layer tinting, contours and hill shading. Most maps will use at least two methods (commonly contours and spot heights, as is the case with the 1:1 000 000 and 1:500 000), 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 in feet above mean sea level printed alongside. 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 shows 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. They are drawn at regular intervals of height and figures, which may be 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. These are usually only found on large scale charts like the 1:50 000 and the 1:250 000.

Topography

65. The larger the scale, the more detail on the chart. Topographical features on the small scale charts (1:1 000 000) will be restricted to only major features such as cities and towns, roads, and rivers. The large scale charts (1:50 000) will be able to show far more detail and will include items such as huts, windmills, cultivated lands, trees and bush, shops, hotels, schools, police stations and even dipping tanks!

Aeronautical Symbols

66. The smaller scale charts (1:1 000 000, 1:500 000 and the 1:250 000), which have been printed for use by pilots, have Aeronautical Edition or ICAO printed in the top right corner. These charts show all the aeronautical information relevant to the chart such as Aerodromes, Radio Facilities, Navigation Lights, Miscellaneous Aeronautical Symbols and Abbreviations used in aviation. These symbols, with explanations, are found on the back of the chart. An example of this information is shown in Fig 3.20.

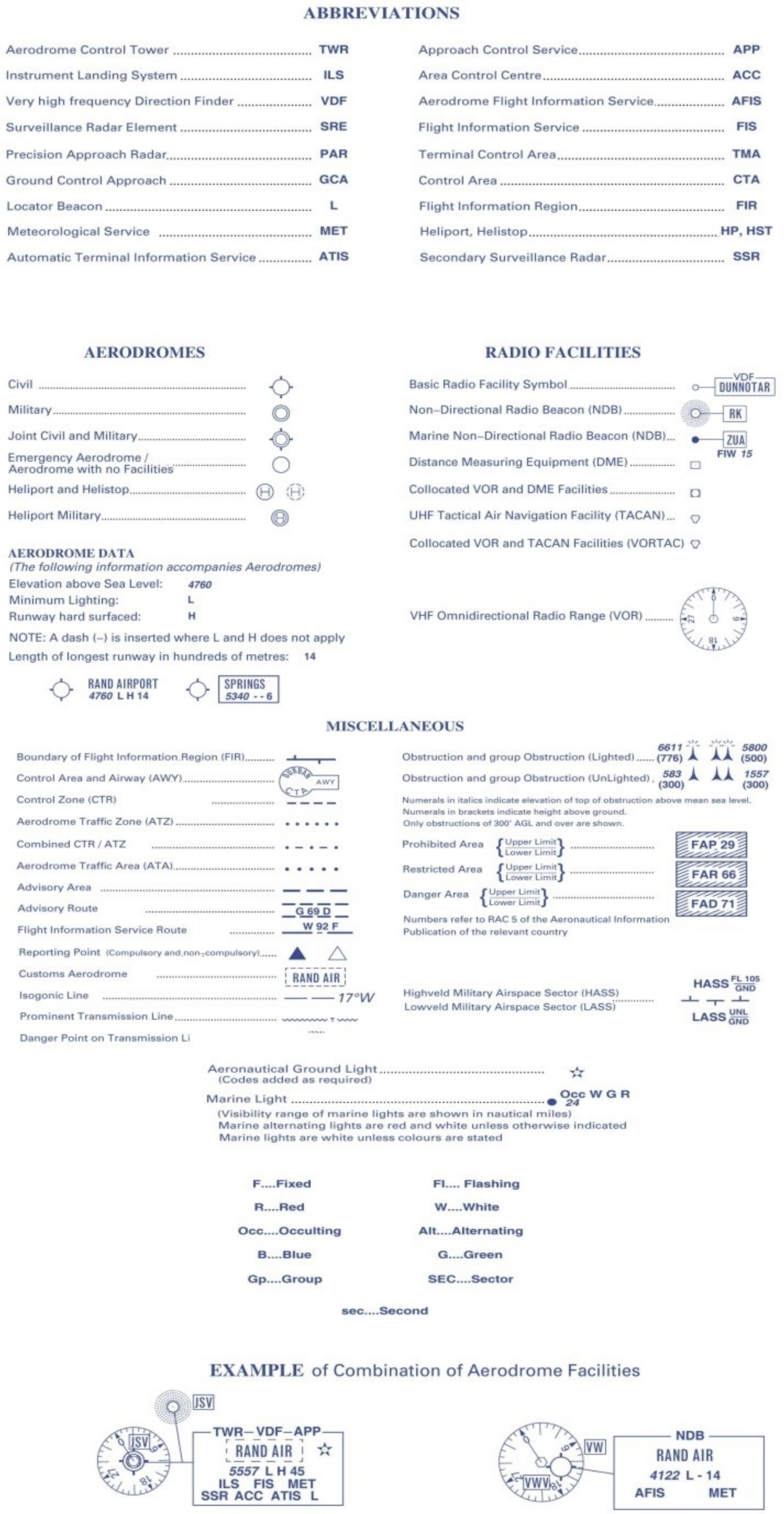


Fig 3.20. Typical Aeronautical Symbols

Speed

67. There are a number of speeds you will need to know and understand in order to plan and calculate any navigation exercise. An easy way of remembering the various speeds is to remember the following:

ICE Tea is a Pretty Cool Drink

If we now take that and arrange the capitals in the following way it will be easy to remember which speed is which, and how we go about calculating it:

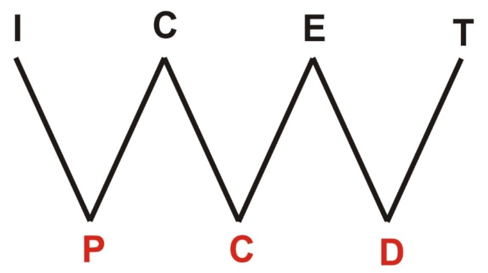


Fig 3.21. ICE Tea is a Pretty Cool Drink

Starting on the left we have I for Indicated Airspeed (IAS). When IAS is corrected for P (position and pressure error) we get C, or Calibrated Airspeed (CAS). CAS is the American version of Rectified Airspeed (UK usage), but they are one and the same thing. When CAS is corrected C (compressibility) the result is E, or Equivalent Airspeed (EAS). Finally, when EAS is corrected for D (Density i.e. temp & pressure) we end up with T, or True Airspeed (TAS).

Track

68. Track is the term used to identify the line along which we wish to fly. We call it Intended Track during planning. When airborne, once we have established a position, or fix, as it is called, the line along which we have actually flown is called Actual Track, or Track Made Good. When planning, we measure our intended track using our protractor. The value we read off the outer scale is True Track. If we wish to convert the true track to Magnetic Track, we have to add Variation. Variation is indicated on the chart as a broken line running roughly east-west, and identified by the value of the variation present at the time of printing. Near Port Alfred the variation is indicated as 23°W. Using the mnemonic Variation West - Magnetic Best, this is added to True to get Magnetic.

69. Because the Magnetic North Pole is constantly on the move, variation is constantly changing. At the bottom of the chart, printed in blue Italics, you will find something like this: Lines of equal magnetic variation for 1988. Annual change 5' Westwards. If you are using the chart in 2002, then the variation information printed on the chart will be 14 years old. At 5' per year, it means that the variation will now be 23° + 1° 10', or 24° W when rounded off. In other parts of the country this is different, so make sure you are using correct, up-to-date information. in other parts of the world, variation may be East, and the values can vary from zero to 180°. In Southern Africa, variation will always be W est, and you can expect values between about 15° and 25°.

70. Once we have ascertained our magnetic track, we have to consider the wind that we are likely to encounter. This may blow us off course, so we have to correct for this possibility. To do this we calculate Drift, which we then apply to our intended magnetic track to get Magnetic Heading to Steer. This will also provide us with our estimated Ground Speed, which, when applied to the Distance to Go, we will get Leg Time, which when added to our departure time will give us Estimated Time of Arrival (ETA).

TRIANGLE OF VELOCITIES

71. Before we get too carried away with any calculations, let us take a good look at the Triangle of Velocities. This is the basis of all navigation calculations, and a good understanding of it is essential.

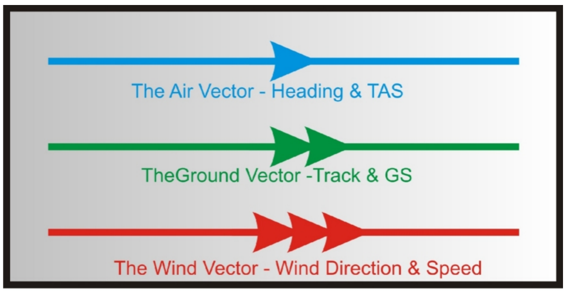


Fig 3.22. Components of the Triangle of Velocities

72. W hen we fly we maintain a Heading (HDG). At the same time the aeroplane is moving through the air at a True Air Speed (TAS). The fact that we have direction and magnitude (speed), we have a vector, this vector we call the Air Vector.

73. The air in which we fly is constantly moving, and it too has a direction and magnitude. This is the Wind Velocity (W/V). The wind is always given as the direction FROM which it is blowing. The strength is always given in knots. The vector itself is known as the Wind Vector. A wind of 315/20 will be blowing from 315° True, and the air mass would have moved 20 nautical miles in one hour .

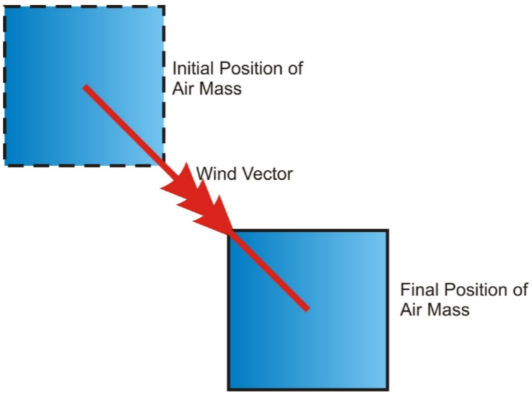


Fig 3.23. A Wind of 315/20

74. If an aeroplane had been flying in the air mass for a period of one hour, it would have drifted off in the direction of 135° (the reciprocal of the wind direction) and would have been moved a distance of 20 nautical miles (wind speed is 20 knots, or 20 nautical miles per hour).

75. Now if we add the two vectors together we end up with the third vector which makes up the triangle. This third vector is the actual path of the aircraft over the ground, and is made up of Groundspeed and Actual Track, or Track Made Good. The angle between the HDG and the Track will be the Drift Angle.

HDG/TAS + W/V = TR/GS

76. The aeroplane started off from A towards B on a HDG of 090°. If there had been no wind, the aeroplane would have ended up at B. But because of the wind blowing FROM 315°, the aeroplane is blown in the direction of 135° to position C. The vector joining A and C is the resultant of AB + BC. The aeroplane has drifted off to the right (Drift is always FROM heading TO track), and flown faster than would have been the case if there had been no wind. To have arrived at B, a correction would have to be made to the LEFT to correct for the RIGHT Drift.

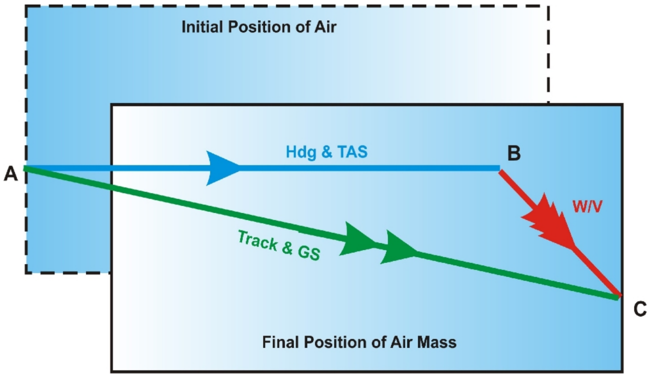


Fig 3.24. The Triangle of Velocities
HDG/TAS + W/V = TR/GS

77. Once you have established Drift, you can make the necessary correction in order to steer the correct heading to get to B. This correction is always made into wind. The fact that you have turned the nose of the aircraft into the wind, even if only by a few degrees, will result in a lower Groundspeed. Using your newly calculated GS and knowing the distance to go, you can now calculate how long it will take, giving an ETA.

Establishing Position

78. Once you are airborne, you will rely very heavily on your chart, and the basic method of navigation is map-reading. This will be taught to you in the air by your flying instructor. You will constantly compare the map and ground features, and this requires fairly good visibility. In conditions of poor visibility, or at night, you will have to rely more and more on navigation aids and your instruments. On an Instrument Rating course, or on the Commercial Pilot Licence course you will be taught the techniques required to navigate in poor, or zero, visibility. Right now, visual navigation and map reading is what you will be required to master.

79. There is a method of navigation called Dead Reckoning, or DR. It is actually Deduced Reckoning, but the former is more popularly used. The word deduce means to reach a conclusion by reasoning, or to conclude. That is exactly what this is all about. You use the latest information you have about speed, direction and wind, apply it to your last known position, and then deduce where you are going to be at a certain time. More about this later.

NAVIGATION COMPUTER

80. There are several electronic navigation computers available on the market nowadays, such as the CX-1 and CX-2 Pathfinders, and the Sport's E6B. Each of them has a very comprehensive instruction manual. They are certainly the way to go if you are serious about flying. For the purpose of the PPL it is not necessary to spend all that money as the manually operated "Whizzwheel" does everything the others can do - without the possibility of a flat battery! An example of the manual flight computer is the E6-B FLIGHT COMPUTER, which is the one used in the examples shown in the following paragraphs.

81. A simple way of explaining the workings of the Whizzwheel is to think of the inner rotating disc with the inner scale as being cockpit, and the outer scale being what is obtained outside the aircraft.

82. Another important thing to remember is that there are number of windows in the inner disc. The one on the left is above the words "Altitude Correction" and the two on the right are above the words "Airspeed Correction". Always make sure that you set up the figures you need to work within the correct window. Altitude for Altitude, and Speed for Speed. Both sides ask for Pressure Altitude and Temperature, so it easy to end up using the wrong window. The result will be an answer you definitely were not looking for!

Finding TAS when RAS is known (TAS < 300 kts)

83. In most modern aircraft in use today, the speeds given in the Aircraft Operating Manual have already been corrected for pressure and position error. For a TAS value of below 300 knots the air is generally regarded as being non-compressible, and the value of pressure measured at the pitot head will be correct.

84. You rotate the inner disc of the W Whizzwheel until the Outside Air Temperature (OAT) on the outer side of the Airspeed window is aligned with the Pressure Altitude (P Alt) in thousands of feet inside the window. Remember that P Alt is the altitude when you have 1013 hPa set on the altimeter sub-scale).

85. You then go to the value of your RAS on the inner disc (inside the cockpit), and opposite that value you read of the value of TAS on the outer scale of the Whizzwheel.

Example:

Pressure Altitude 22 000 ft, OAT -30°C, RAS 150 kts. W hat is the TAS?

Solution:

In the Airspeed window, set 22 (P Alt x 1000) opposite -30°C on the Air Temperature °C scale. Opposite the RAS value on the inner disc (150 kts), read off the TAS on the outer scale (212 kts). Different types of W Whizzwheel will give slightly varying answers, but they will be close enough.

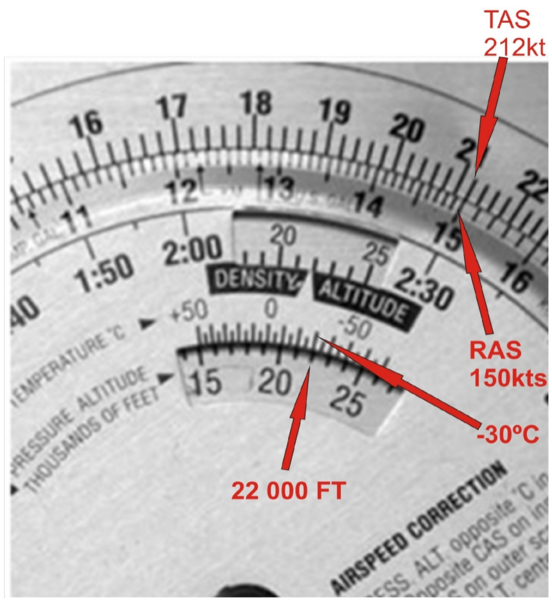


Fig 3.25. Calculating TAS

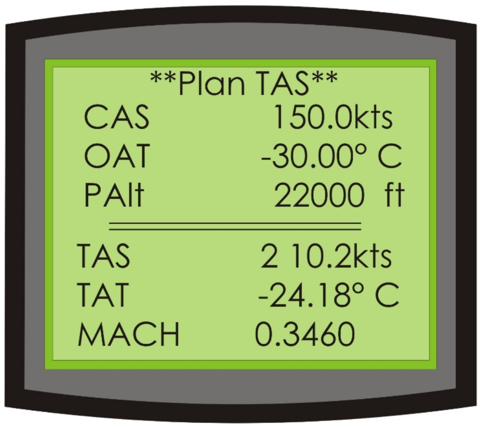


Figure 3.26. Plan TAS
Using the Pathfinder CX-2

86. At altitudes and speeds where TAS is more than 300 knots, compressibility will become an issue, as there will be extra pressure over and above normal Pitot pressure. A compressibility factor has to

be used to correct the value found on the W Whizzwheel. It is not a constant, but increases as the speed of the aircraft increases. Tables are available with the correction factors.

Calculating Groundspeed

87. If you have covered a certain distance in a certain time, you can calculate Groundspeed by placing the Distance Flown on the outer scale over the Time Taken on the inner scale. If you then go to 60 on the inner scale, the value on the outer scale opposite 60 will be your Groundspeed.

Example:

You cover a distance of 84 nautical miles in 42 minutes. W hat is your Groundspeed?

Solution:

Set 84 on the outer scale opposite 42 on the inner scale. The value on the outer scale opposite 60 on the inner scale will be groundspeed. In this case it is 120 knots.

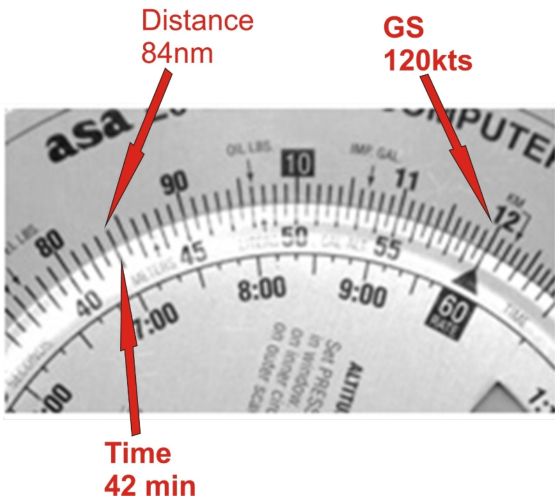


Fig 3.27. Calculating Groundspeed

88. Using the W Whizzwheel in this fashion is the same as solving the formula:

$$\frac{84}{42} = \frac{X}{60}$$

or 84 X 60 ÷ 42 = 120

89. There is another method using a scientific pocket calculator. All of these have a function button marked DMS or ° ' " . In order to convert 42 minutes into a decimal value, you enter 0 (for hours), press the DMS button, then enter 42 (the minutes) and press the DMS button again. You will have a decimal value of 0,7. If you divide 84 by 0,7 you will also get 120. This is using the formula: Distance divided by Time = Groundspeed.

90. If you have one, using the GS Page on a Navigation Computer will also give you the answer you are looking for. All you need do is select the correct page, and then enter the values at the prompts.

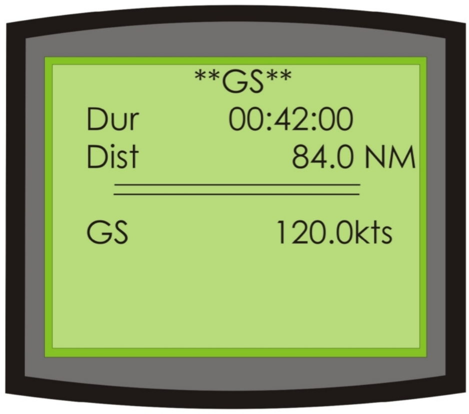


Fig 3.28. GS
Using the Pathfinder CX-2

91 From all of the methods used, this is the easiest, but everything easy comes at a price. The average price of a navigation computer is in the region of R790,00 (2001 prices), and as they are all imported, prices will continuously rise. But then again, the W Whizzwheel costs R 275 anyway.

Distance Flown

92. All Distance, Speed and Time problems are solved out in much the same way when using the Whizzwheel. In the case of finding Distance Flown in a particular time, the known GS is set up on the outer scale opposite 60 on the inner scale. This is the distance covered in 60 min, or 1 hour. To find the distance flown in any given time, read off on the outer scale the distance flown opposite that time on the inner scale.

Example:

You are flying at a GS of 180 knots. W hat distance will you cover in 32 minutes?

Solution:

Set 180 on the outer scale opposite 60 on the inner scale. The value on the outer scale opposite 32 on the inner scale will be distance flown. In this case it is 96 nautical miles.

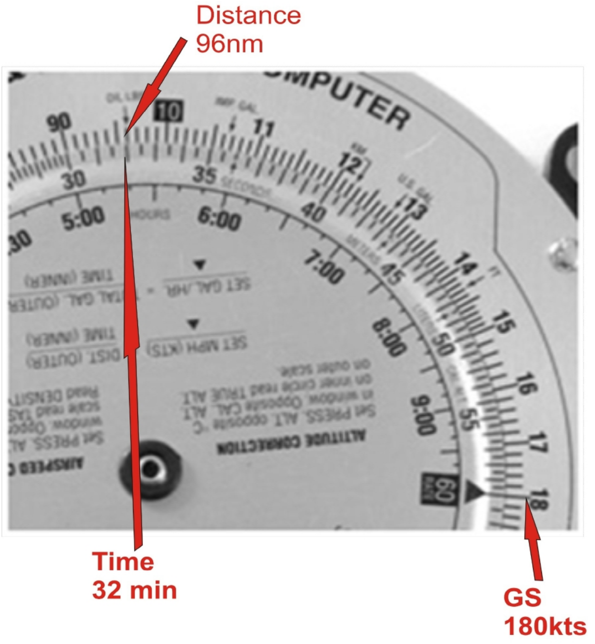


Fig 3.29. Distance Flown

93. Using the W Whizzwheel in this fashion is the same as solving the formula:

$$\frac{180}{60} = \frac{X}{32}$$

or, 180 x 32 ÷ 60 = 96

94. You could also use the pocket calculator by applying the formula: Speed multiplied by Time = Distance Flown. Enter 180, then press X, and then enter time by pressing 0 (hrs), press DMS, then 32, press DMS, then the = sign, and the answer is 96.

95. On the Navigation Computer, select the Dist Flown page and enter the values at the prompts.

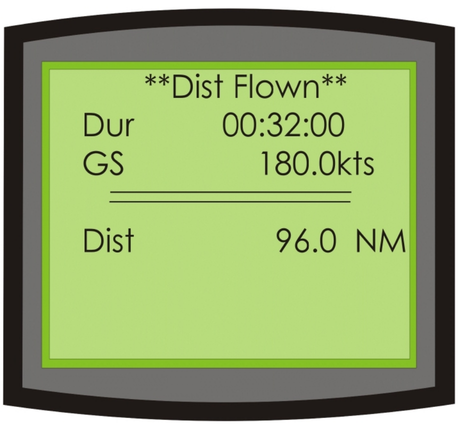


Figure 3.30. Distance Flown
Using the Pathfinder CX

Leg Time

96. To find the Leg Time for a specific distance with a known groundspeed, set up the GS on the outer scale over 60 on the inner scale, and read off the time on the inner scale opposite the distance to be flown on the outer scale.

Example:

You are flying at a GS of 105 kts. W hat will be time required to fly a distance of 145

Solution:

Set up GS (105 kts) on the outer scale opposite 60 (1 hour) on the inner scale. Opposite 145 on the outer scale (distance to go) read off the time required on the inner scale. The answer is 83 minutes. Inside the 80 indication you will see 1:20 which is simply a conversion to hours/minutes. 83 minutes is therefore 1 hr 23 minutes.

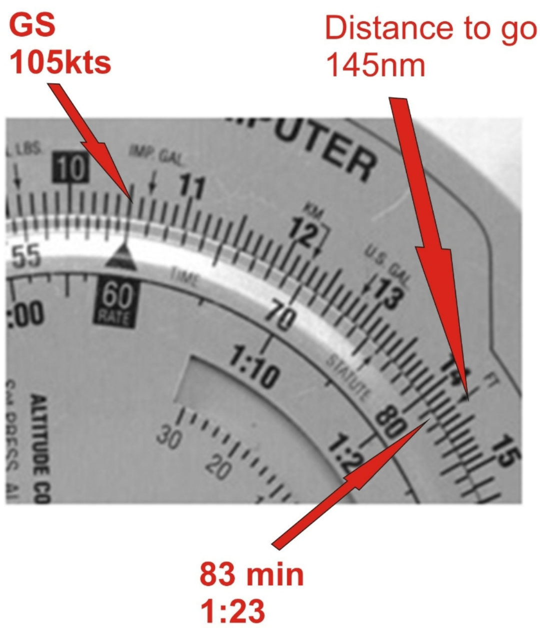


Fig 3.31. Leg Time

97. The W Whizzwheel is once again making use of the Distance, Speed and Time relationship, and in this case:

$$\frac{105}{60} = \frac{145}{X}$$

or, 60 x 145 ÷ 105 = 82,86, rounded off to 83.

98. Using the pocket calculator, divide 145 (distance to go) by 105 (GS) and you get an answer of 1,38095. This is the decimal value of the time in hours. Either multiply by 60 to get minutes (82,86 min), or press the INV button (which gives a second

function of any key) and then DGM. The answer will now be in hours, minutes and seconds: 1hr 22 min 51,4 sec. As you will be working to the nearest minute, 1 hr 23 min is the same as all of the other calculations.

99. Finally, using the navigation computer, select the Leg Time page and enter the required information at the prompts. The answer is 1 hr 22 min 51 sec, and rounded off, you get 1 hr 23 min once again.

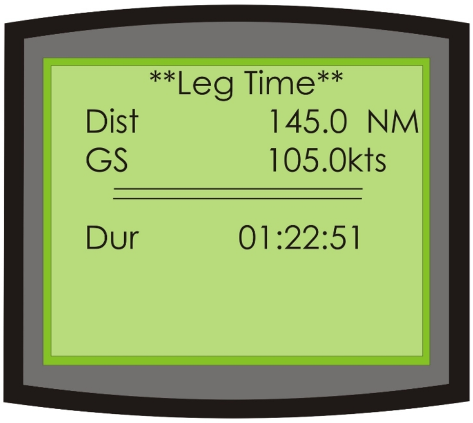


Figure 3.32. Leg Time
Using the Pathfinder CX-2

Fuel Required

100. Once speeds and times have all been calculated, the next item on the agenda is to find out how much fuel will be required for the leg. The procedure is much the same as the others - set up the fuel flow per hour (available in the Aircraft Operating manual) on the outer scale opposite 60 on the inner scale. The fuel required will be found on the outer scale opposite the leg time on the inner scale.

Example:

You are flying an aeroplane which has a fuel consumption of 12,5 gallons per hour. How much fuel will be required for a leg of 1 hour 26 minutes?

Solution:

Set up Fuel Flow (12,5 gals/hr) on the outer scale opposite 60 (1 hour) on the inner scale. Opposite 86 (1 hr 26 min) on the inner scale (leg time) read off the fuel required on the inner scale. The answer is 17,9 gallons. It cannot be 179 as a quick check on the answer (1,5 hr x 12,5 = 18,75) will confirm where the decimal has to be placed. This is one of the problems with the W Whizzwheel - you have to place the decimal. But by using rounded off numbers as in the example, you can check it quite easily.

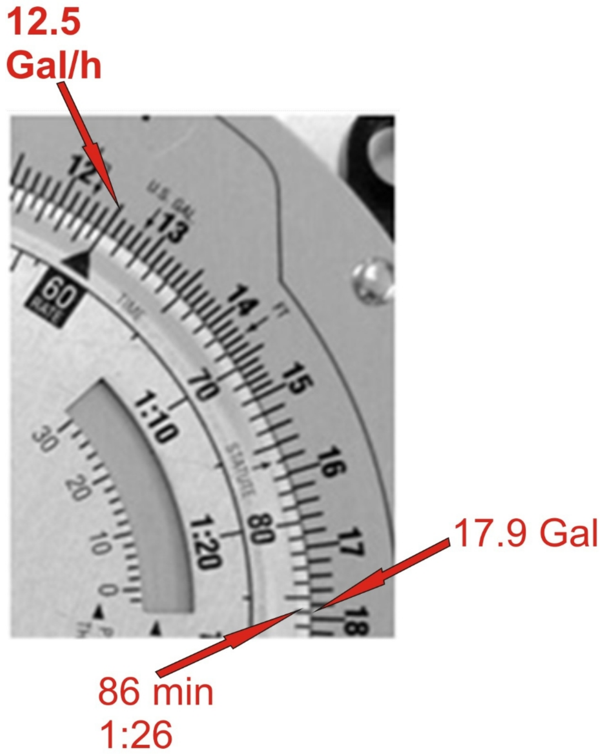


Fig 3.33. Fuel Required

101. The W Whizzwheel is once again making use of simple cross-multiplication:

$$\frac{12.5}{60} = \frac{X}{86}$$

or, 12,5 x 86 ÷ 60 = 17,9.

102. Using the pocket calculator, multiply 12,5 (distance to go) by 1 hr 26 min, converting the time using the DMS button (which will give you 1,43). 12,5 x 1,43 = 17,9.

103. Finally, using the navigation computer, select the Fuel Burn (American term for fuel consumption) page and enter the required information at the prompts. The answer is 17,9.

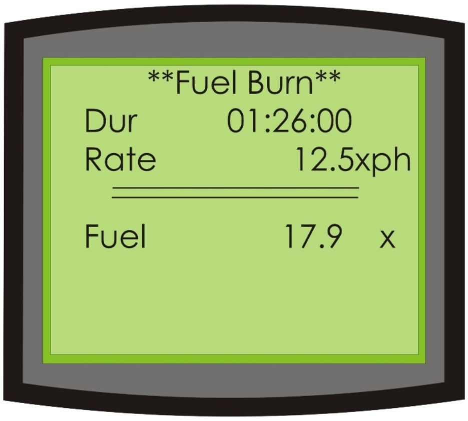


Figure 3.34. Fuel Burn
Using the Pathfinder CX-2

Fuel Flow

104. You might find yourself in a situation where you know how much fuel has been used in a certain time, and you wish to know what fuel consumption the aeroplane is achieving. The method is very similar to those already used - on the outer scale the fuel used opposite the time on the inner scale, and read off fuel consumption per hour on the outer scale opposite 60.

Example:

Your aircraft has consumed a total of 73 gallons in 1 hour and 47 minutes. W hat is the fuel consumption per hour?

Solution:

Place 73 on the outer scale opposite 107 (1 hr 47 min) and read off the fuel consumption over 60. Answer is 41 gal/hr.

Fig 4.35. Fuel Flow

105. The W Whizzwheel is using simple cross-multiplication again:

$$\frac{73}{107} = \frac{X}{60}$$

or, 73 x 60 ÷ 107 = 40,9, rounded off to 41.

106. Using the pocket calculator, divide 73 (fuel used) by 1 hr 47 min, converting the time using the DMS button (which will give you 1,783). 73 ÷ 1,783 = 40,9, and rounded off we have the same answer, 41 gal/hr.

107. Finally, using the navigation computer, select the Fuel Rate (Flow Per Hour) page and enter the required information at the prompts. The answer is 40,9.

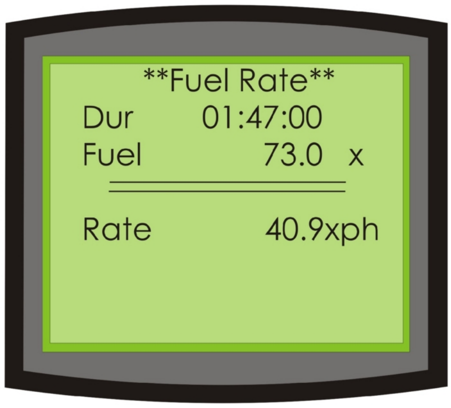


Figure 3.36. Fuel Consumption
Using the Pathfinder CX-2

From the above it can be seen that whenever you are confronted with a problem involving time, whether it be speed, distance, or fuel, there are numerous ways of solving the problem. Find the method with which you are the most comfortable, and stick with it.

Altitude Problems

108. You will see in Chapter 3 (Flight Performance and Planning) that the Aircraft Operating Manual, Section IV, Performance Charts, requires Density Altitude to be used when determining aircraft performance. A chart is provided for this purpose, but there are other means of determining Density Altitude if you do not have the Aircraft Operating Manual near at hand.

109. Using the W Whizzwheel, above AIRSPEED CORRECTION you will find two windows, the top one marked Density Altitude. in the bottom window you have Pressure Altitude in thousands of feet, which is set against Air Temperature °C. Then using the top window, you simply read off the Density Altitude.

Example:

You are to fly at a flight level of 10 000 feet (F100) where the outside air temperature is 0°C. W hat is the Density Altitude?

Solution:

In the bottom window set up 10 (10 thousand feet) opposite 0, which is temperature. then go to the top window and read off Density Altitude. Each mark on the scale represents 1 000 feet, so the answer lies between 10 000 and 11 000 feet. Although the actual value is rather difficult to interpret, 10 500 to 10 600 feet will be close enough.

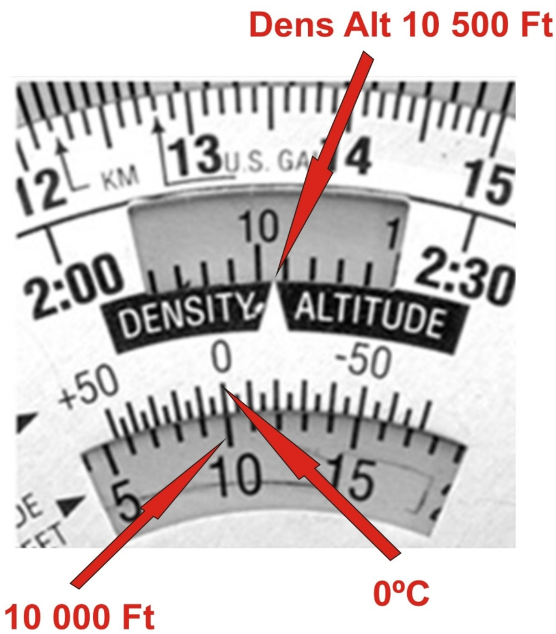


Fig 3.37. Determining Density Altitude

110. A more accurate answer can be obtained from the Navigation Computer. Here you select Density Alt and enter the information at the prompts. On older models this will have to be done on the Plan TAS page. The Pressure Altitude of 10 000 feet is entered (using all the digits), Temperature of 0°C is entered. The Density Altitude is 10 564 feet (so our 10 500 wasn't too far off). This is higher than P Alt because a temperature of 0° C is hotter than ISA. Under ISA conditions the temperature should have been -5° C.

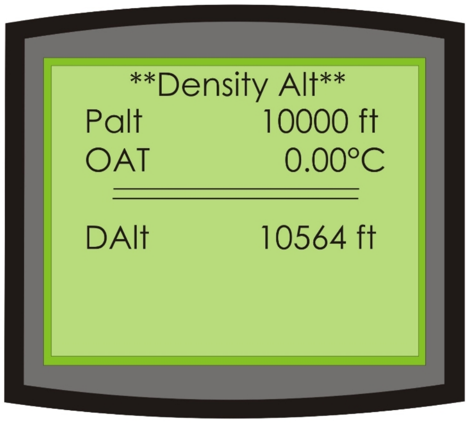


Fig 3.38. Density Altitude
Using the Pathfinder CX-2

111. So we are faced with two problems. Our Density Altitude is higher than P Alt which means that the engine will be producing less power, and the aircraft will have to accelerated to a TAS of 117,3 before we have 100 indicated on the ASI. This is a very serious problem when taking off from an airfield which is "Hot and High" - hotter than ISA, with a high Density Altitude.

An example of "Hot and High" is Johannesburg (elev 5 558') on a day when the temperature is 35°C.

Density altitude will be 9 000'.

BE CAREFUL!

112. A final method which can be used is to take the difference between the actual outside air temperature (0°C in this case) and the ISA temperature at that level (See Chapter 5 : Meteorology, and you will see that -5°C is the ISA temperature in this case), and multiply the difference by 120. 5 x 120 = 600. Because the actual temperature is 5° hotter than ISA add the answer to Pressure Altitude to get Density Altitude. In this example:

10 000 + 600 = 10 600 feet.

113. If the temperature is colder than ISA, then you have to subtract the answer from Pressure Altitude to get Density Altitude.

114. Another problem we encounter with altitude is that our altimeter will not give the correct indication of height above mean sea level if the temperature is not ISA. In Meteorology (Chapter 5) you will see that

flying from a hot area to a colder area, the altimeter will over read - in other words, the aircraft is closer to the ground than the altimeter indicates.

115. The W Whizzwheel can be used to give a clearer picture as to how much lower we actually are. Above the words ALTITUDE CORRECTION you will find a single window. In the window Air Temperature in °C can be aligned with Pressure Altitude in thousands of feet. Then going to the inner scale you find the Indicated Altitude that appears on the altimeter, and opposite that, on the outer scale, you will have True, or Actual Altitude.

Example:

You are flying at Flight Level 100, or 10 000 feet above the 1013 hPa datum. The outside air temperature (OAT) is -10°C. If the altimeter indicates 10 000 feet, what is you true altitude above the selected datum?

Solution:

In the Altitude Correction window set 10 (the Pressure Altitude in thousands of feet) opposite -10°C (OAT). Now on the inner scale (inside the aeroplane) find 10 (in this case 10000 feet). Opposite it on the outer scale (outside the aircraft)you will find a value of 9 800. Remember you have to add the decimals or the zeros. This is your Actual Altitude above the datum, which is 200 feet lower than the indication. This is because the OAT of -10°C is colder than ISA (which would have -5°C).

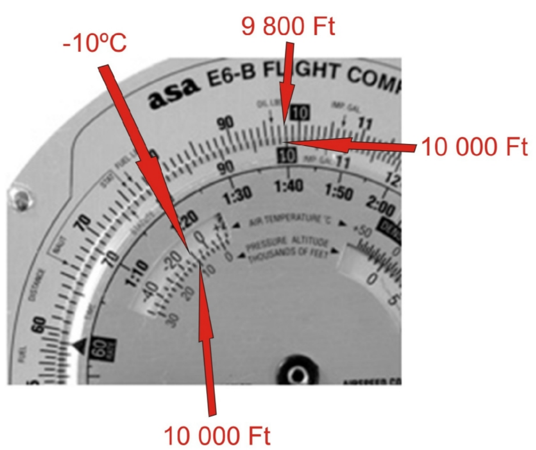


Fig 3.39 True Altitude

Hot To Cold, Don't Be Bold

Time

116. The earth rotates from west to east about its axis as it orbits the sun. Our measurement of time is based on this rotation of the earth.

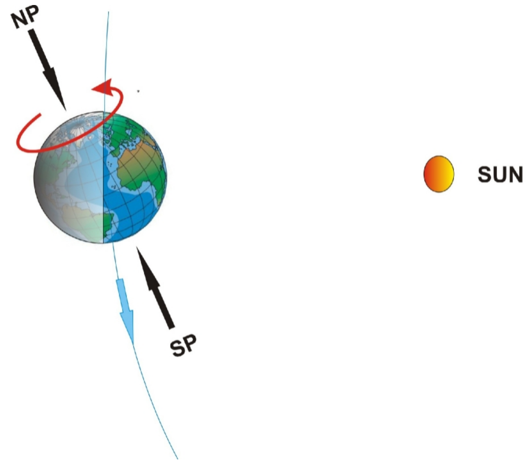


Fig 3.40. Rotation of the Earth

117. In one day, the earth makes one complete rotation of 360° with respect to the sun, a solar day. The time of day is a measurement of this rotation and indicates how much of that day has elapsed or, in other words, how much of a rotation has been completed.

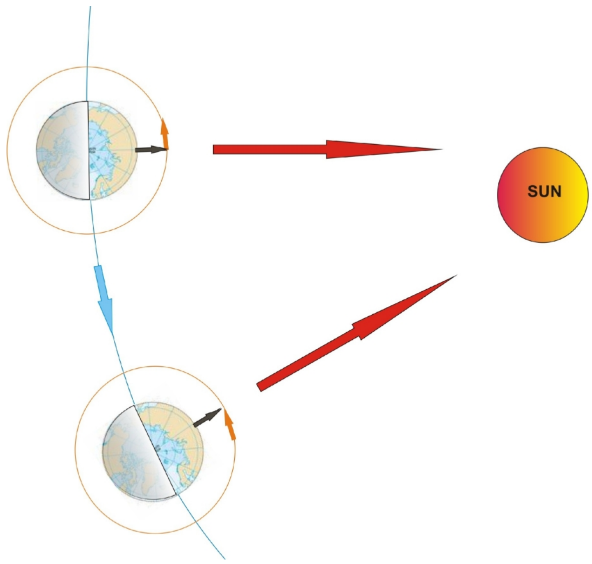


Fig 3.41 Measurement of a Solar Day

118. Pilots become very time orientated human beings. Everything we do in an aeroplane is related to time in some way or another. Before the advent of aircraft, people used to make do with Local Mean

Time (LMT). This was determined by the passage of the sun overhead any place on earth. As the sun passed overhead, it was midday. Simple. As people started to travel, this became very impractical, as any place at a different longitude would have a different midday. Because aeroplanes have made the world a much smaller place, it became necessary for a universal time reference system to be used. It was necessary to have some basic position for the calculation of time when travel was involved. The Greenwich meridian was chosen, and the LMT of that meridian (000° E/W) is used as the basis for all international communications involving time. You have probably already heard about a time being referred to as “1300 Zulu” or Universal Time . That is just another way of giving the LMT of the Greenwich Meridian.

119. The world is divided into zones of 15°, the sun takes one hour to travel 15° of longitude. This is called Local Standard Time (LST). South Africa falls into time zone Bravo, which is based on the 30° East meridian, this also South African Standard Time. The sun takes one hour to travel 15°, so time zone Bravo is 2 hours ahead of Universal Time (UTC or UT). South Africa’s Standard Time Factor (STF) is thus + 2 hours.

120. Converting Arc to Time is the same as converting ch long to time. As we already know, the sun takes one hour to travel 15°, so dividing the ch long by 15°, we convert arc to time. When we convert time we must always work in UT. W hen we want to convert LMT to ST, we first convert LMT to UT with arc to time, and then convert UT to ST using the STF.

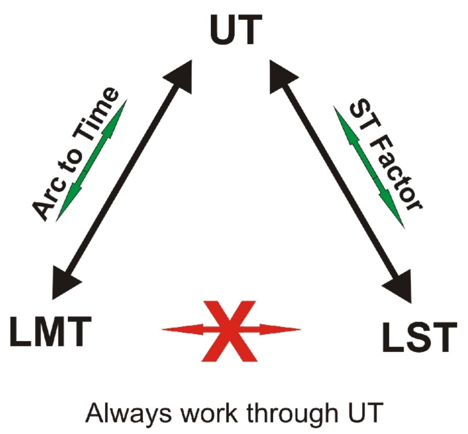


Fig 3.42 Conversion of Time

121. The time of sunrise and sunset is also of great importance to any pilot, especially one who does not have a night rating, or flying an aircraft not equipped for night flying, or operating from an aerodrome where no night flying facilities are available.

122. In any of the cases mentioned above, the pilot may only carry out a flight in light conditions that allow him or her to perform any required duties without the aid of artificial light. Once the sun has set, there is a period of twilight when this is possible, as is also the case just before sunrise in the morning. The duration varies during the year, but by law in South Africa is regarded as extending for a period 15 minutes before sunrise to sunrise itself, and also from sunset for a period of 15 minutes after sunset. This is called an Official Day.

123. This is based on LMT, which is determined by the longitude of any place. Think of Cape Town and Durban. The sun is still shining merrily in Cape Town long after it has already set in Durban. This is due to the different longitudes of the two places, Durban at 3057 East and Cape Town at 1836 East. This is a difference of 12° 35', which means that the sun will pass over Cape Town 49 minutes later than it does over Durban.

Civil Aviation Regulations, Definitions:

“Night” means the period from 15 minutes after sunset to 15 minutes before sunrise, sunset and sunrise being as given in the publication “Times of Sunrise, Sunset and Local Apparent Noon of the South African Astronomical Observatory”.

PRACTICAL NAVIGATION

124. Equipment. The following items of equipment are required for this section of the course:-

- A navigational computer.
- A navigational straight-edge.
- Plotting protractor (square type).
- Dividers
- 2H and HB pencils for plotting and writing, and a soft eraser.

Definitions, Abbreviations & Symbols

125. Before attempting any plotting a study of the following list of definitions, symbols and abbreviations, until their meanings and use are understood, will pay handsome dividends. Many have already been explained in earlier phases of the course.

a. Heading. The direction in which the nose of the aircraft is pointing measured in degrees (000- 360) clockwise from the True, Magnetic, or Compass North, abbreviations being Hdg (T), Hdg(M), Hdg©. (See

Navigation, Chapter 2, Direction). True heading is the only one of the three which is plotted. If Hdg (M) is given, it must be converted to True by taking into account the variation on the chart. If Hdg © is given; it must be converted to True by taking into account variation and deviation.

b. Track. The direction in which the aircraft is moving over the earth, measured in degree (000-360) from True or Magnetic North, abbreviation Tr (T) and Tr (M). Only True track is plotted

If there were no wind, there would be no drift and Track would be the same as Heading. This is also the case with a direct head or tail wind.

c. Intended, Desired or Required track. The planned direction of movement over the earth which you intend to fly.

d. Track Made Good (TMG). The actual direction of movement over the earth of the aircraft as a result of its heading, true air speed (TAS) and wind velocity.

e. DR Track. The expected track of the aircraft over the ground, computed with the knowledge of heading, true air speed and the forecast or anticipated wind velocity. (DR is short for Dead Reckoning).

f. Drift. The angle between heading and track due to the effect of wind. The direction of drift is always from Hdg to TR. If track is greater than heading, i.e. track is to the right of heading; the aircraft is drifting to the right. If track is less than heading, the aircraft is drifting to the left. Drift is measured from Hdg (T) to Tr (T) or from Hdg (M) to Tr (M), but True and Magnetic must never be mixed - for instance you cannot measure drift from Hdg (M) to Tr (T).

g. DR Drift. The expected drift due to the effect of the forecast or anticipated wind velocity when a particular heading is being steered.

h. Actual or Real Drift. The drift actually experienced in flight, that is to say, the angle between the heading steered and the Track Made Good.

I. Rectified Air Speed (RAS). The indicated air speed (in knots) corrected for Position (Pressure) and Instrument error. This correction is usually printed on a card installed near the Airspeed Indicator. (See Instruments, Chapter 4, The Airspeed indicator).

j. True Air Speed (TAS). The speed of the aircraft through the air (in knots). The computer is used to calculate TAS from RAS, pressure altitude and temperature.

k. Ground Speed. The actual speed (in knots) of the aircraft over the ground (i.e. the speed relative to the earth, not the air). NB. If there were no wind, ground speed would be the same as true air speed.

l. DR Ground Speed. The expected speed of the aircraft relative to the ground calculated with the forecast or anticipated wind velocity.

m. Wind Direction. The direction, measured in degrees (000-360) clockwise from True North, from which the wind is blowing.

n. Wind Speed. The speed, in knots, at which the air is moving relative to the ground.

o. Wind Velocity (WV). The combination of wind direction and speed. For example, a wind velocity (W V) of 270/30 kts means that the air is flowing from the West at a speed of 30 knots relative to the ground.

p. DR Position. The expected position of the aircraft relative to the ground, calculated for a particular time. Notice that it is an expected ground position, and is associated with DR track and DR ground speed.

q. Air Position. The position of the aircraft relative to the air at a particular time. It lies on the 'air plot' and shows where the aircraft would be as a result of its true heading and true air speed, if there were no wind.

If there were no wind, the air position at a given time would coincide with the DR position at the same time, and this would also be the actual position of the aircraft at that time.

r. Ground Position. The position of the aircraft relative to the ground at a particular time.

s. Pinpoint. The ground position of the aircraft at a particular time, obtained by direct observation of the ground (i.e. map reading).

t. Fix. The ground position of the aircraft obtained from two or three visual, radio, or by radar or by GPS.

u. Position Line. A line somewhere along which the aircraft is known to be a particular time. For example, if an aircraft received a QTE (true bearing) of 090 from a VDF station at 0900 hours, then at 0900 hours the ground position of the aircraft was on a line 090°(T) from the station but its distance from the station was not known.

v. Isogonal. A line on the chart joining places of equal magnetic variation.

w. Rhumb Line. A line cutting all meridians at the same angle. Note that any straight line on a Mercator chart is a rhumb line because the meridians on a Mercator are depicted as parallel straight lines. Consequently, headings and tracks are rhumb lines when plotted as straight lines on a Mercator. Radio bearings follow great circles which are, with certain exceptions, lines curved towards the nearer Pole on a Mercator.

x. Great Circle. An imaginary circle on the surface of the earth whose plane passes through the centre of the earth. With some exceptions, great circles are curved on a Mercator, but can be taken to be straight lines on a Lambert's Conical Orthomorphic.

y. ETA. Estimated Time of Arrival. The time, calculated by the pilot, when the aircraft should reach a specified position.

z. ATA. Actual Time of Arrival. Self Explanatory.

aa. ETD. Estimated Time of Departure. In plotting, this is the time at which the aircraft is expected to set heading from a specified position.

bb. ATD. Actual Time of Departure. Self-explanatory.

cc. ca. Conversion Angle. The angle between a rhumb line bearing and a great circle bearing.

dd. Convergency. The angle between two selected meridians at a given latitude. Convergency = 2 X conversion angle.

ee. SH means 'Set Heading'
Thus:- 1015 'A' (2420S 0217E) SH 'B' (2335S 0143E) means:-
At 1015 hours set heading from position 'A' (at 24°20'N 02°17'E) to position 'B' (at 23°35'S 01°43'E).

ff. AH means 'Alter Heading'
Thus:-1110 AH 'B' means:-
At 1110 hours alter heading (from a position at 1110) for position 'B'.

Latitude and Longitudes (Lats & Longs)

126. Care should be taken when measuring the latitude and longitude values of a position. The Lat & Long grid on the Lambert's chart is not rectangular. The latitude value is normally expressed first but measure last (see explanation below). It will consist out of:

A two-digit group indicating whole degrees. The symbol for the degrees is (°). A two-digit group for minutes. If decimals of a minute are used the minute group will have three digits. The symbol for minutes is (‘).

There might be a third group indicating arc second of latitude but this is seldom used. The symbol for seconds is (“). Added to this will be the hemisphere, north (N) or south (S), in which you are working.

127. The longitude value is expressed second but measured first (see explanation below). It will consist out of:

A three-digit group indicating whole degrees. For values less than 100 degrees of longitude a zero is added in front of the reading. This will ensure that all longitude readings have a three-digit degree group. The symbol used for degrees is (°). Minutes and seconds are indicated in the same way as for latitude readings (see latitude explanation). Added to the longitude group is an indication for eastern (E) or western (W) hemisphere.

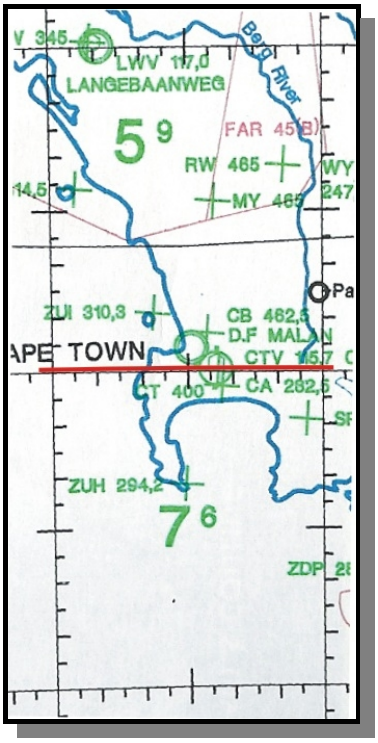


Fig 3.43 Cape Town's Latitude

Cape Town International's latitude reference using degrees, minutes and seconds is:
33°58'05" S   or   S 33°58'05"

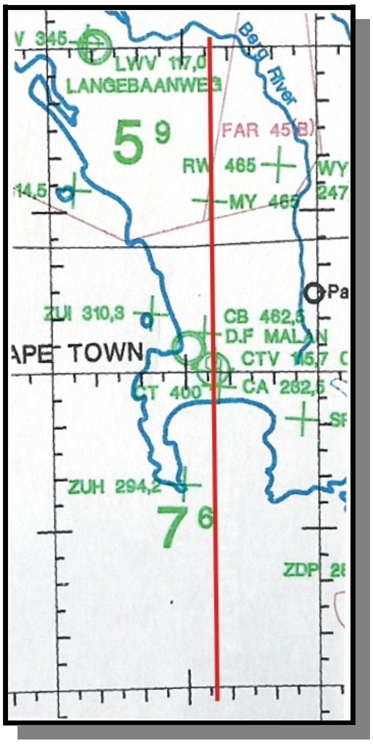


Fig 3.44. Cape Town's Longitude

Cape Town International's longitude reference using degrees, minutes and seconds is:
018°36'17" E   or   E 018°36'17"

128. When considering the curvature of latitude lines and the convergency of longitude lines on a Lambert's chart the measurement of lats & longs becomes tricky. As indicated, measuring the longitude lines first will assist in the accuracy of your measurement. Let's first have a look at why the latitude measurement is prone to errors. In the diagram below, a line is drawn from east to west. In enlargements A and B the line passes through the 50 minute mark but in enlargement C it passes through the 52 minute mark, an error of 2 nautical miles.

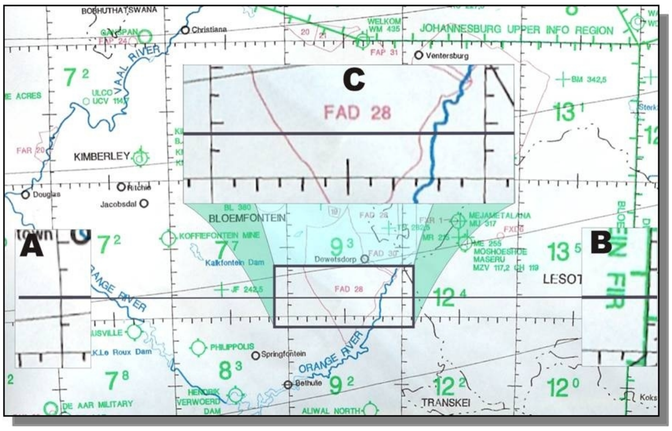


Fig 3.45. Latitude Error on Lambert

129. You may wonder why a line was drawn over five degrees of longitude in the diagram if there are latitude index marks on every longitude line. If this were the map used for examination purposes, this problem would not exist. The map used in the examination is a 1:5 000 000 scale map with a latitude scale on every third longitude line. The 1:3 000 000 map will be used for explanation purposes due to its clarity.

130. For a map with severe curvature of its latitude line the following safe method for measuring Lats and Longs can be used. As an example the lat and long of the JF NDB beacon will be determined. First, draw a vertical line through the JF position to determine the local meridian (longitude line). Ensure that the line passes through the same longitude index marks, to the north and south of JF, as indicated in the diagram. The longitude reference can now be recorded as E025°25,5'. The 025° longitude annotation is not on the diagram but will be printed on the map at regular intervals.

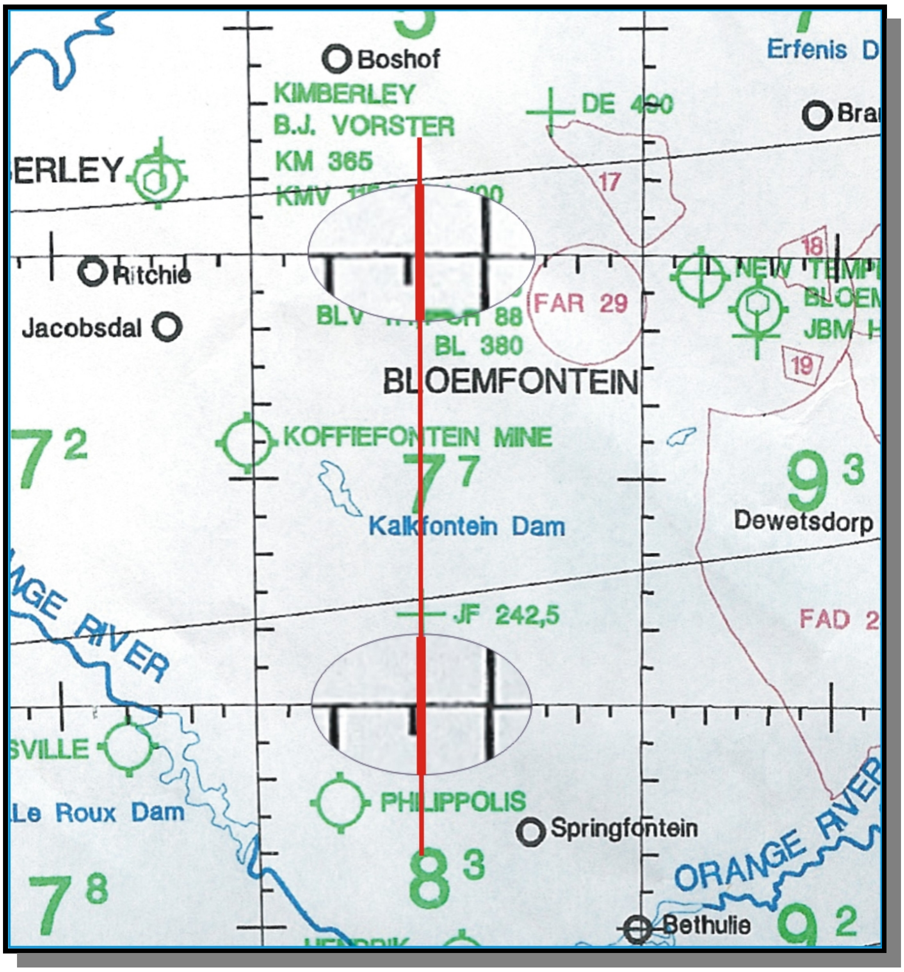


Fig 3.46. Longitude of Jagersfontein

131. Use dividers to measure the distance from S29°00' to JF. Use this distance on one of the longitude lines with index markings to determine the minute reading for the latitude reference.

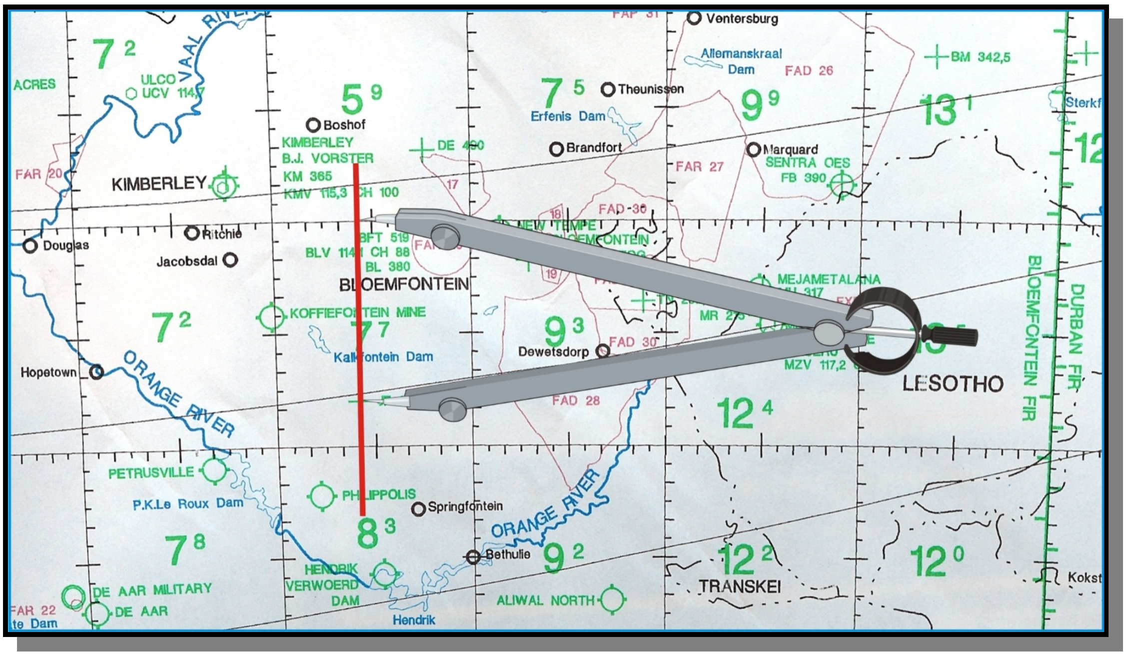


Fig 3.47. Latitude of Jagersfontein

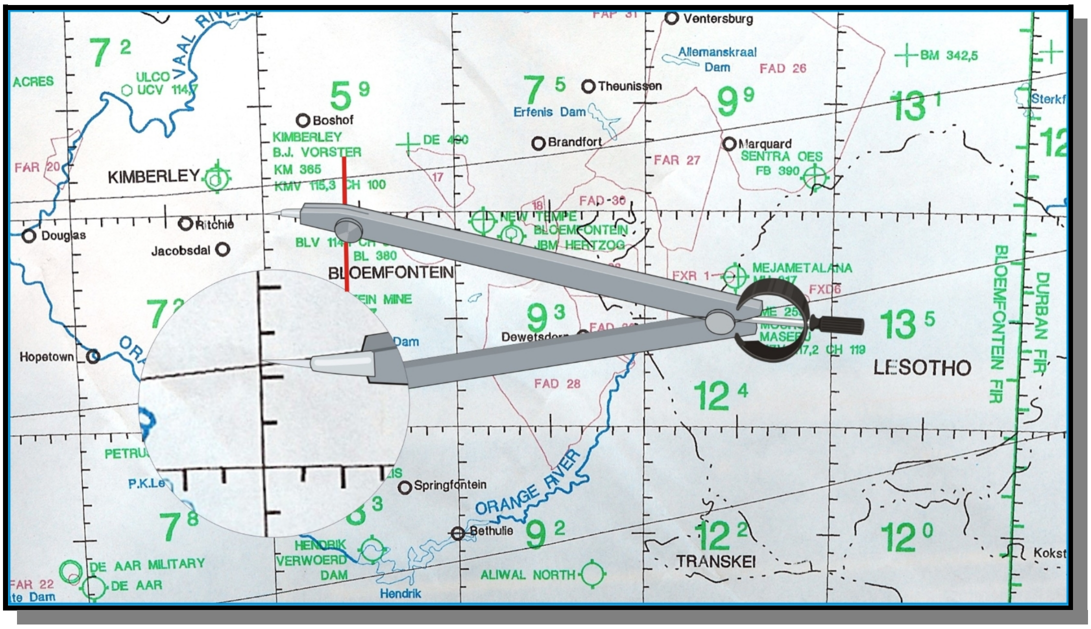


Fig 3.48. Latitude of Jagersfontein

132. The latitude reference can now be recorded as S29°48'. The latitude annotations are not on the diagram but will be printed on the map at regular intervals.

Track Measurements

133. The charts used are the Lambert's. Due the fact that straight lines are great circles on a Lambert's the following should be considered when measuring angles:

Measure great circle tracks at the MID Meridian. This will cater for convergency. To measure the track between Cape Town and De Aar the E021°22' meridian will act as the mid meridian. It is, however, not necessary to use the exact mid meridian, either E021° or E022° can be used.

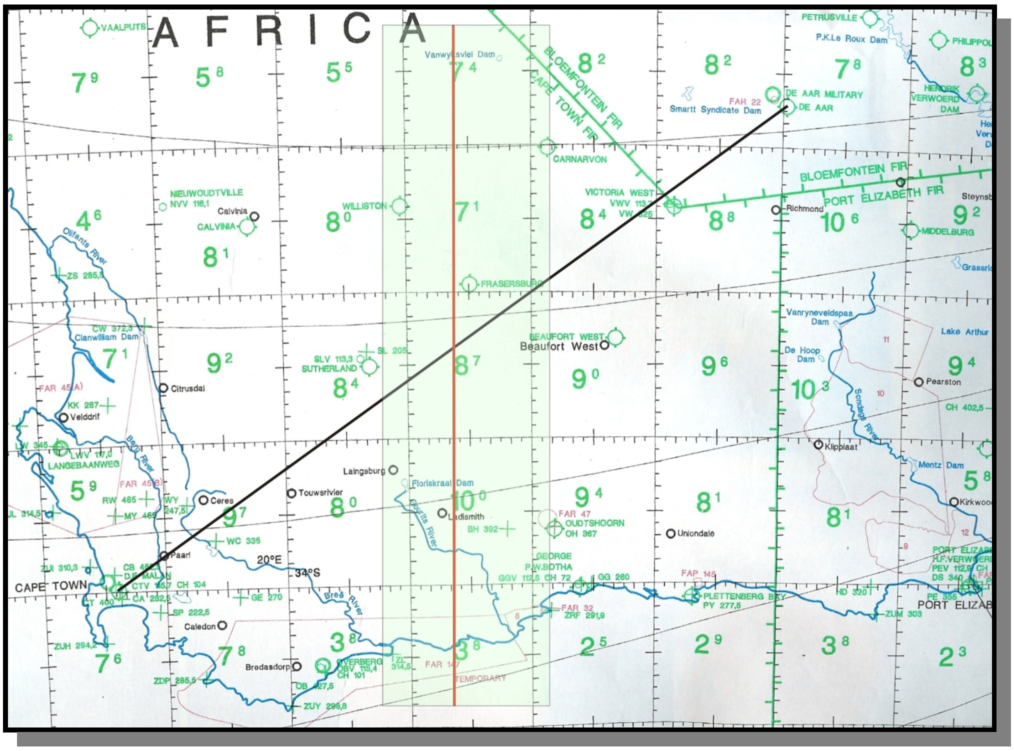


Fig 3.49. Mid Meridian

134. The examination question may ask you to handle a great circle track in one of three different ways.

Mean Heading or Track. If you are asked for the mean heading or track, you should measure the Track at the MID meridian. If the answer is required in a magnetic value, the variation at the mid meridian point must be used. In the example the track between Cape Town and De Aar is 055°T (True direction) and the variation is 22°W making the magnetic track 077°M.

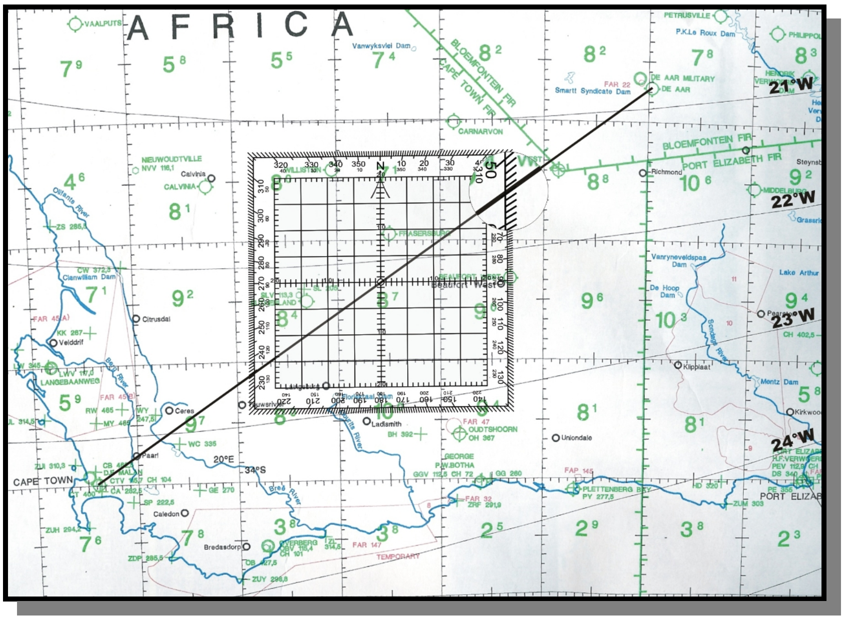


Fig 3.50. Mean Track

Initial Heading or Track. In this case, the track must be measured at the meridian closest to the point of departure if not directly at the point of departure. For conversion to magnetic values the variation at this point must be used. For the flight from Cape Town to De Aar, the initial track will be 056°T and the variation is 23°W making the magnetic track 079°M.

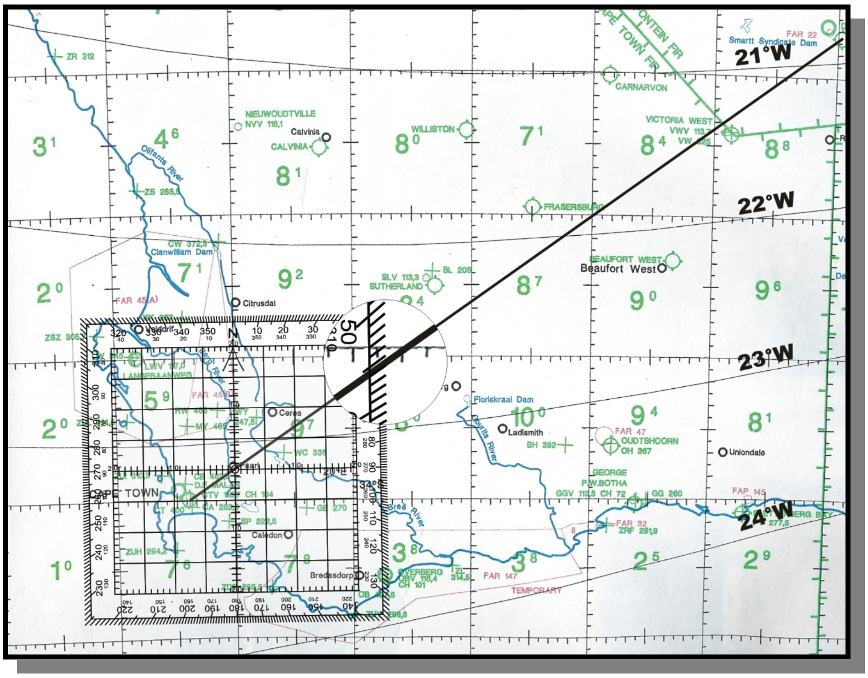


Fig 3.51. Initial Track

Finial Heading or Track. In this case, the track must be measured at the meridian closest to the destination. For conversion to magnetic values the variation at this point must be used. The track can either be extended or the reciprocal can be measured and 180 added. For the flight from Cape Town to De Aar, the final track will be 053°T the variation is 21°W and the magnetic track 074°M.

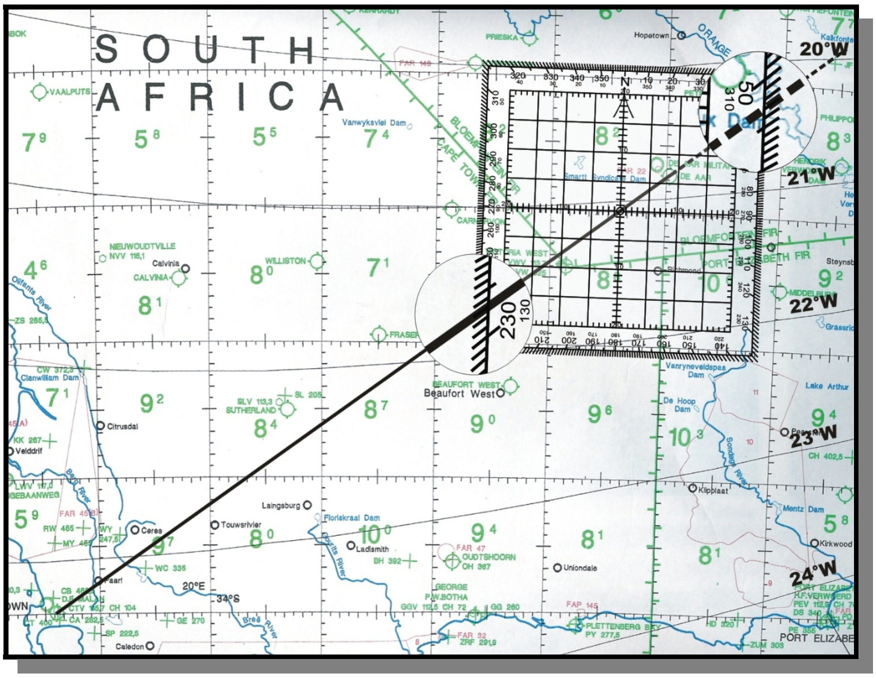


Fig 3.52. Final Track

Distance Measurement

135.	Use the latitude scale at the MID latitude. This will help overcome any scale variation across the map. For long distances it is better to measure a set distance at the mid latitude. One degree is equal to 60 NM.

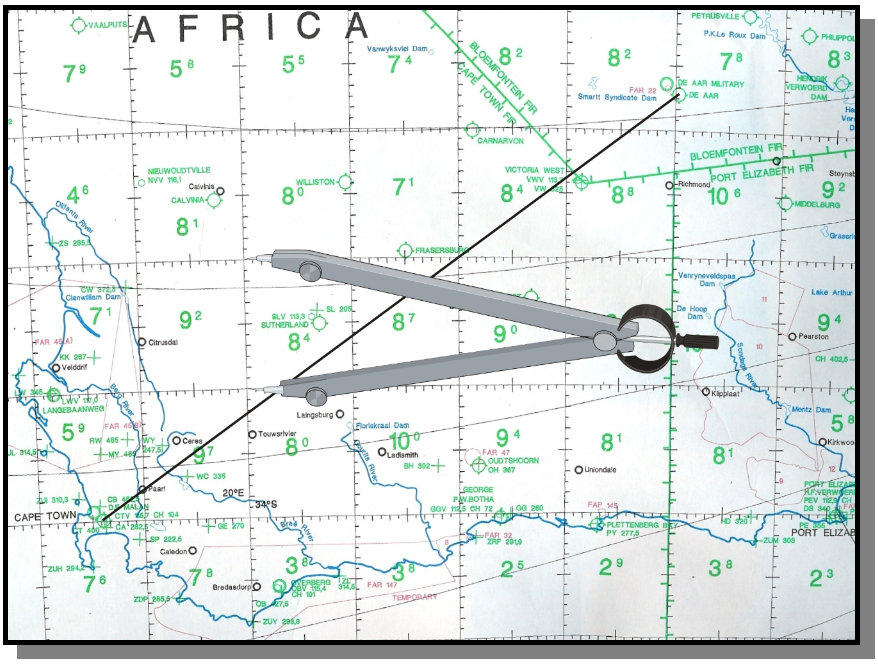


Fig 3.53. Measuring Distance, 60 NM

136. This distance is then “walked off” on the track.

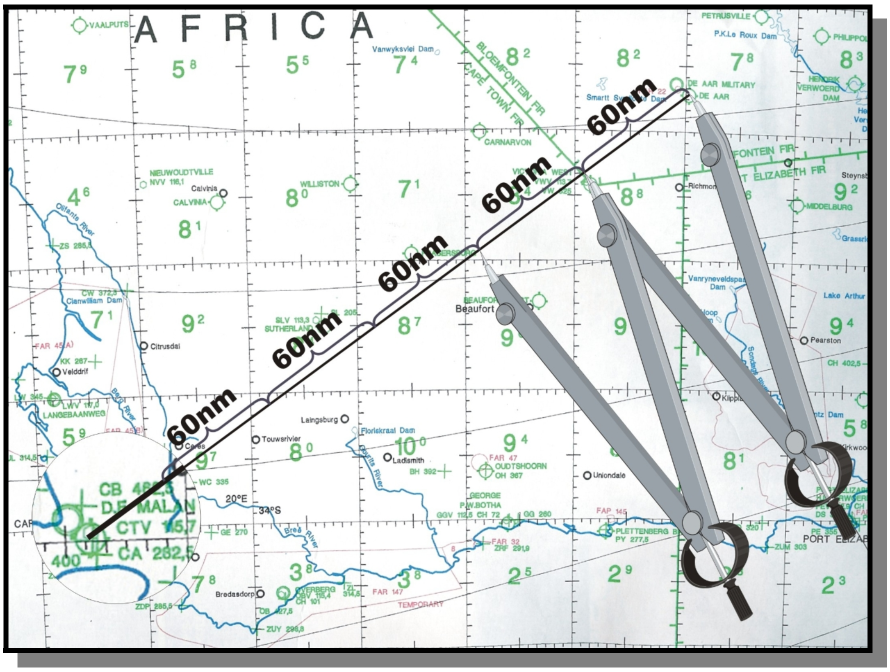


Fig 3.54. Measuring Distance

137. The remaining part of the track is then measured with the divider.

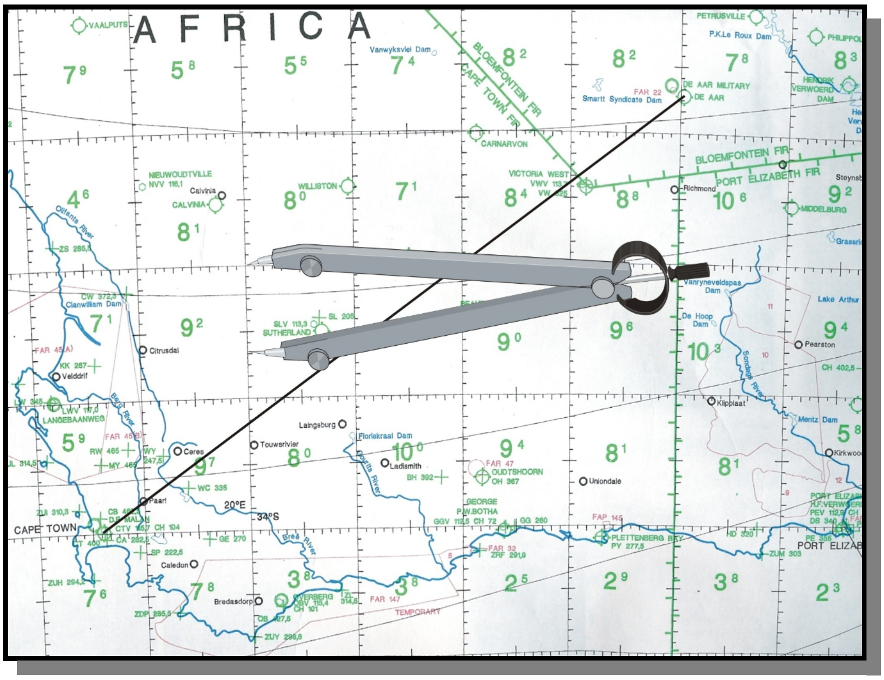


Fig 3.55. Measuring Distance

138. The length of this bit is determined by using the latitude index marks at the mid latitude. In the example, the distance should be 339nm.

1-in-60 Rule

139. If a right-angled triangle has one of its angles = 1°, the opposite side will be sin 1° = 0.0175 times shorter than the adjacent side. At small angles (up to 10°) the length of the hypotenuse approximately equals the length of the adjacent side (sin _ tan a). Expressed another way, the adjacent side (hypotenuse) will be 57.3 times longer than the opposite side. Hence a 1° error in track will result in a 1 NM distance off track after 57 NM travelled. Because not many people like using a silly number like 57, they use an easier number like 60. Thus the 1-IN-57 rule becomes the 1-IN-60 rule. The inaccuracy of using 60 instead of 57 is 5%, but in normal circumstances this is not an issue.

1 Nm off track per 60 nm flown along track = 1° track angle error (TAE)

140. A typical use of the 1-IN-60 rule is for correcting headings when off track.

FORMULA:

$$TAE = \frac{Dist\ off\ track\ X\ 60}{Dist\ flown\ along\ track}$$

$$\frac{TAE}{60} = \frac{Dist\ off\ track}{Dist\ along\ track}$$

Example:

An aircraft is flying from X to Y which is 207nm apart. After the aircraft has flown 97nm, the aircraft is 3nm right of track. W hat will the heading be to alter to fly direct to Y?

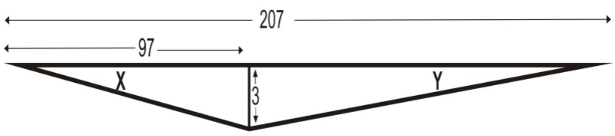


Fig 3.56. 1:60 Rule

$$X(TAE) = \frac{Dist\ off\ track\ X\ 60}{Dist\ along\ track}$$

$$X = \frac{3\ X\ 60}{97}$$

$$X = 1.9$$

$$Y(TAE) = \frac{Dist\ off\ track\ X\ 60}{Dist\ along\ track}$$

$$Y = \frac{3\ X\ 60}{110}$$

$$Y = 1.6$$

1.9 +1.6 = 3.5 = 4 E left.

Vectors

141. Remember the triangle of velocities (Vector Triangle)? A vector is a pair of numbers associated with a speed and direction. An aircraft's velocity describes its speed in a particular direction. Unlike speeds, vectors cannot be added simply: the calculation involves trigonometry directly (Pathfinder) or using scale drawings (Whizzwheel). Two vectors are involved in aviation: aircraft velocity and wind velocity. The relationship of these two vectors can be represented by a triangle, where two sides are proportional to the aircraft and wind velocities respectively. The third side represents the result of the vector addition.

Constant RAS Climb

142. The ASI is pegged at a particular value (RAS) for the entire climb. As height is gained, TAS will increase. Accordingly, climb rate will decrease. The purpose of the calculation is to find the average TAS during the climb.

Assumptions:

No distinction is made between QNH altitude and pressure altitude (flight level). The change in height is simply the difference between the two altitudes. The average TAS is reckoned to be that TAS occurring 2/3rds of the way up.

Constant RATE Climb

143. In theory, the RAS is reduced during the climb to maintain a constant climb rate. While this is not a practical way of flying - indeed it may be the beyond the capability of the aircraft to maintain a constant reasonable climb rate - CAA may nevertheless ask the question. The calculation is identical to the CONSTANT RAS method, except that the average TAS is reckoned to be that TAS occurring half way up.

Descent

144. The idea is to fly as high as possible for as long as possible. The top of descent will therefore be as close to the destination as reasonably possible, given an acceptable rate of descent. The calculation requires knowing or deciding upon the following factors:

RAS in the descent
Rate of descent in fpm
Cruising level prior to descent

Target height at end of descent

CAS RAS (rectified airspeed)
TAS = average TAS for the entire descent
Distance = Time to descend * average TAS

145. In the exams you may have to calculate either the rate of climb (ROC)/rate of descent (ROD) or the distance to top of climb (TOC)/top of descent (TOD). A simple method to do both is to draw a triangle. They will give you either a climb/descent groundspeed and a Pressure altitude to climb to/descent from. You will also be given a distance out from where you must start your TOD. Take descent G/S to calculate time to cover the distance and use that time to calculate rate of descent. Your answer will be feet per minute.

146. Alternatively, they will give you a fixed rate of descent. See how long it would take you to descent/climb through the required altitude and use that time to determine the distance of TOC/TOD.

Deviation Cards

147. All of the headings that are calculated during the planning phase are True which are then converted to Magnetic by applying Variation. Taking the "Can Dead Men Vote Twice" mnemonic into consideration, there is still one more calculation to be done. Each aircraft has its own magnetic field producing compass errors, called Deviation, and allowance must be made for this.

148. Once you know which aircraft you are going to be flying, you need to look at the Compass Deviation Card. This is found near the magnetic compass. An example of the card is produced alongside (Fig 4.57.). On the card you will find the date when the compass swing was done, as well as the signature of the person who did it.

149. The column titles, FOR and STR, are the heading you wish to steer (FOR) and the heading you must steer (STR) in that aeroplane to maintain the intended track. Only headings every 45° are given and anything in between will have to be calculated by the pilot by means of interpolation. A simple example is that if you had calculated a Magnetic Heading to steer of 180°, you would have to steer 177° on the Compass in order to stay on track. This means that the deviation caused by the aircraft's own magnetism on South amounted to 3°. In this case it is 3° East Deviation (Dev East - Comp Least).

FOR	STR	FOR	STR
N	1	S	177
45	44	225	229
E	88	W	272
135	135	315	318
10/1/2002	R Smith		

Fig 3.57. A Typical Compass Deviation Card

150. With a little practice, this will become very easy to do

Planning Your Flight

151. Selection of Charts. An important aspect of flight planning is the selection of the right chart to use. As mentioned earlier, choose the correct one for the job at hand.

152. Route and Aerodrome Weather Forecasts and Reports. Rules of the Air [91.02.7 (1) (o)], states that no pilot-in-command shall commence a flight unless he or she is satisfied that according to the information available to him or her, the weather at the aerodrome and, in respect of an aeroplane, the condition of the runway to be used, will not prevent a safe take-off and departure or a safe landing at the destination aerodrome or alternate aerodrome, as applicable. Furthermore, the Aeronautical Information Publication (AIP), ENR 1 General Rules and Procedures, 1.2.2 states that outside a control zone or an aerodrome traffic area the ascertainment of whether or not weather conditions permit flight in accordance with VFR is the responsibility of the pilot-in-command.

153. What all this means is that you need a weather forecast for EVERY flight. If you are going to do circuits and landings at a particular airfield you can usually see for yourself whether the conditions are acceptable, but for a navigation exercise away from home, or to another aerodrome, a proper met report from a met office is essential. En route winds will also help you plan your navigation far more accurately, and ease the workload in the cockpit when airborne.

Assessing the Weather Situation.

154. Once you have obtained the weather forecast, you must look at your intended route and

check that none of the forecasted weather is going to affect your choice. You may have to reconsider the route to avoid any thunderstorm build-up; fog, mist or poor visibility; and possible turbulence. Anything of consequence will be shown on a Significant Weather chart, examples of which appear in Chapter 5 (Meteorology).

Plotting the Route.

155. Considerations of Controlled/Regulated Airspace, Airspace Restrictions, Danger areas, etc. The use of AIP and NOTAMs for the necessary information on your route and ATC Liaison Procedures in Controlled/Regulated Airspace. You have to look at Fuel Considerations (Refer to Chapter 5, Flight Performance and Planning) and En-Route Safety Altitude(s).

156. Alternate Aerodromes. Alternate aerodromes aren't for PPLs, you say? Well think again. What would happen if you plan to fly to an aerodrome, and on arrival find that the single runway is blocked, or has become unusable? You will then be forced to divert to a suitable alternate. When this possibility arises there are some major considerations:

a. You must have sufficient fuel to proceed to an aerodrome where a safe landing can be made - 91.07.12 (2) and (4) and SA-CATS OPS 91 (same reference numbers).

b. You may not use any aerodrome, as a destination or an alternate, unless such an aerodrome is adequate for the type of aircraft [91.07.3 (1)].

158. You must ensure that there will be sufficient light available to carry out a day landing if the alternate is not equipped for night flying. You will have to land not later than 15 minutes after sunset in such a case [91.07.3 (2)].

159. The Flight Log being used by 43 Air School consists of 16 columns, which have been numbered accordingly in the example below. Each row contains the information relevant to a single leg of the navigation, or cross-country. Let us look at each column in turn.

Flight Navigation Log

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Position	ATA	FL	MTrck	W/V	TTrck	Drift	THdg	Var	MHdg	TAS	G/S	Dist	EET	Position	ETA
FAPA	1016	065	358	090/15	335	11L	346	23W	009	74	79.1	17.1	0:13	TOC	1029

Columns 1 and 15 : Position. This is the position at the start of the leg (Row 1) and the position at the end of the leg (Row 15). An example would be FAPA (Port Alfred), the departure point, and TOC (Top of Climb), the end of the first leg.

Column 2 : ATA. This is the Actual Time of Arrival at each point along your route, which is also the start of the next leg. If it is the first leg of the flight, as is the case in the example, it will be the actual time of the start of the leg, or Actual Time of Departure - 1016Z. The time is always given in Zulu, so once you get used to the idea, it is not necessary to add the "Z".

Column 3 : FL. This is the chosen flight level in thousands of feet. In the example 065 is 6 500 above the 1013 hPa datum, or Flight Level 65.

Column 4 : MTrck. This is the Magnetic Track that you intend to fly. Take the True Track measured in Row 6 (335) and add Variation in Row 9 (23W) to get Magnetic Track. The reason this has been included is to help you to select the correct Flight Level in accordance with Rules of the Air 91.06.33 Semi-circular rule. Your flight level is based on magnetic track (see Condensed Aviation Law for the beginner, Chapter 4, Page 69). A flight level of 065 will be required for a magnetic track which falls between 180° and 359°, and the flight is subject to Visual Flight Rules (VFR).

Column 5 : W/V. This is the Wind Direction and Velocity which is part of the weather information which you are required to obtain prior to the flight. it is always given as a three digit group representing the direction FROM which the wind is blowing in degrees TRUE, a forward slant, and the wind speed in knots (a two digit number). In the example the wind, 090/15, is blowing from 090° True at a speed of 15 knots.

Column 6 : TTrack. Whenever a navigation calculation is done, the starting point for heading is

True Track. This is measured off the chart once the intended track has been drawn onto the chart. It is measured by aligning the protractor with True North at the midpoint of the leg to be flown. In the example, the True Track is 335° T.

Column 7 : Drift. This is the angle of drift after the required True Heading to steer has been determined on the W Whizzwheelor a navigation computer. Drift is always FROM heading TO track, so in the example the Drift is from heading 346° T to track of 335° T, 11L, or 11° to the LEFT.

Column 8 : THdg. This is the True Heading to steer after wind has been applied to intended track by using the W Whizzwheel or navigation computer (346).

Column 9 : Var. This is Variation and is found on the chart as a broken line running more or less east-west. Always use the variation which is closest to the leg you are flying, the variation closest to the mid point of the leg. In this case the variation is 23° W est (23W) and must be ADDED to True heading to get Magnetic Heading (Variation W est - Magnetic Best). As all variations applicable to Southern Africa are W est, it is not necessary to add the "W ", but do so to get used to the idea.

Column 10 : MHdg. This will be the Magnetic Heading that you will have to steer in order to compensate for the wind, and so follow the intended track. You will see that the Magnetic Heading is 009 which would have put you in the other half of the semi-circular rule if you used this to determine your flight level instead of Magnetic Track.

Column 11 : TAS. This is the planned True Air Speed which you will be flying for the leg in knots (74).

Column 12 : G/S. This is the Ground Speed, in knots, that the aeroplane will be flying once wind has been applied to the intended track (79,1).

Column 13 : Dist. This is the Distance in nautical miles to be flown on the leg. This is calculated by using Groundspeed and Time (in the case of a climb or descent), or it is the distance measured on the chart.

Column 14 : EET. This is Estimated Elapsed Time, or Leg Time, which is the time that it will take, at the calculated Groundspeed, to cover the distance in row 13. W hen writing times, use a colon to separate hours and minutes. The example is 0:13 which is 0 hours and 13 minutes (0.13 would be a decimal, which when converted to time, is 7 minutes and 48 seconds).

Column 16 : ETA. This is the Expected Time of Arrival at the end of the leg. This is obtained by taking ATA and adding EET. 1016 + 13 = 1029.

160. Compilation of ATC Flight Plan. Once the planning of the flight has been completed, it is then necessary to compile the ATC Flight Plan. The method is very comprehensibly covered in the Aviation Law book, Condensed Aviation Law For The Beginner, Chapter 9: Filing of Flight Plans. This contains everything you need to know and is the contents of AIC 42.1.

161. Selection of Check Points, Time and Distance Marks. W hen flying a cross country, there may be points along the route where the pilot has to make a compulsory call to ATC. Crossing an FIR boundary is a good example. This will have to be a check point along the route, or to put it in other words, the end of one of the legs on the navigation log. You will have to calculate leg time to the point so that your ETA can be included in your ATC flight plan, and you will have to advise ATC if there is going to be a change in ETA.

RADIO NAVIGATION

DF or VDF (VHF Direction Finding)

162. DF or VDF is ground based radio direction finding equipment which use specially designed receiver aerials to measure the direction from which the received signal is coming. The ATC has a circular scope with the outer scale marked off in the 360 degrees of the compass. W hen any transmission is made, a light indication on this scale indicates to the ATC where the aircraft is in degrees magnetic from the station. Also indicated on the scope is the reciprocal heading, that from the aircraft to the station.

163. ATC is capable of giving either of the two - the magnetic heading that the aircraft must steer TO the station or the magnetic bearing of the aircraft FROM the station. The value of Variation used to convert the two to magnetic is that which is present at the station, not the Variation at the aircraft's position. This is due to the fact that neither the ATC, nor the VDF equipment, has any idea of the Variation at the aircraft's position. The aircraft

distance is not known, only its direction to or from the station.

164. Because the system makes use of VHF radio transmissions, it is obvious that the aircraft will have to be within VHF range of the station for the system to be of any use. That means that range is limited by line of sight. The facility is available at all major airports in South Africa, and it is usually available on the Approach frequency.

165. As far as the accuracy of the system is concerned, VDF bearings are divided into three different classes, dependent on the equipment being used:

Class A bearings are accurate to within ± 2°
Class B bearings are accurate to within ± 5°
Class C bearings are accurate to within ± 10°

NDB (ADF)

166. This system is a simple form of navigation aid which, unlike DF, requires the pilot to do the work. It is sometimes referred to as the Radio Compass. It is short range and operates in the frequency band of 190 to 1750 KHz. It in fact consists of three basic components:

a. A series of Non Directional Beacons (NDBs) which is the ground based component. They are transmitters which transmit radio energy in all directions.

b. The Automatic Direction Finder (ADF) which is the airborne equipment in the aeroplane. It receives the transmitted signals from the ground station, and then indicates the direction of the transmitter.

c. The Bearing Indicator which is the instrument in the cockpit showing the pilot the directional information determined by the ADF. This may be in the form of a Relative Bearing to begin with. It will therefore indicate a direction from the aircraft's nose to the station.

Application

175. Although it is an old system, it is still in use all over the world at smaller airports in the absence of other radio navigation aids at these airports. It can be used in holding patterns and during approaches as well as for en-route navigation.

Principles

188. The ground station transmits a signal which is picked up by the aircraft by two loop antenna's and a sense antenna. The loop antenna has the directional quality required by the system. It works similarly to a hand held Fm radio which will detect the best (strongest) signal available if you turn around in different directions. The weakest signal will be the "null" position and this null position is used in the ADF to locate the station transmitting. A combination of this signal and the use of the signal received by the sense antenna will give a stable and accurate ADF signal. This can then be displayed inside the aircraft on a RMI.

Presentation and interpretation

169. As said above, the reading can be displayed on a Remote Magnetic Indicator (RMI) or a ADF display with a omni – bearing selector which when set on the aircraft's heading will give a relative bearing to the station. It is important to note that the "work" is done at the aircraft and should you wish to plot this bearing, variation at the aircraft should be applied to obtain a true bearing.

Coverage

170. Coverage is worldwide and ADF and NDB beacons in South Africa is identified by a 2 digit morse code denominator like "PA" for instance as the ADF at Port Alfred. Marine beacons can also be used and they have 3 digits in South Africa and normally start with a "Z" (Zulu).

NDB Errors and Accuracy

171. The signal transmitted by an NDB is normally accurate to about 2°, but the signal can be affected by a number of factors:

a. Thunderstorm Effect. Thunderstorms can create an incredible amount electromagnetic energy. This can be heard on a radio as static. The effect that a thunderstorm can have on the signal from an NDB is to completely overwhelm it. This is because the storm is sending out a stronger signal that the NDB and the result is that the needle will point at the storm and not the NDB. Avoid cumulonimbus clouds, and don't rely on ADF indications when flying in the vicinity of one.

b. Night Effect. At night the height of the Ionosphere changes and can cause NDB signals to refract back to earth. The ADF will then be receiving a signal from the NDB, as well as the refracted signal. W hen two signals from the same source (the NDB) are received from two different directions, the signal strength is reduced and the result is that the ADF needle will start to wander. This is worst at dusk and at dawn. Avoid using the ADF within an hour of sunrise and sunset, and if you have to, use the nearest, strongest NDB.

c. Mountain Effect. Mountains can reflect signals from a transmitter, and an aeroplane might then receive the direct signal from the transmitter, as well as the reflected one. As is the case in b. above, the signal arrives from two different directions, creating multi-path reception. The ADF will indicate a bearing somewhere between the two.

d. Coastal Effect. This is a problem when flying out to sea (which you shouldn't be) and using an NDB which is inland of the coast. If the signal from the NDB to the aeroplane crosses the coast at 90° there is no problem, but if it crosses at any other angle, of say 45°, the signal refracts towards the coast. The indication given by the ADF will be inaccurate because the speed of light over water is very slightly faster than over land. This has the effect of bending the bearing, making the beacon appear to be in a different position.

e. Station Interference. NDBs transit in the MF band and this is somewhat overcrowded. An NDB transmitting on the same or similar frequency to the one you have tuned into may cause interference. This is more likely at night when another NDB may be picked up, even if it is out of range, due to the arrival of a reflected sky wave.

Factors Affecting Range

172. The range at which the signals from an NDB may be received is affected by the following:

a. Transmitter Power. There are several different types of NDB transmitters, ranging from long range navigational beacons, to the short range markers in an Instrument Landing System (ILS). The range of the transmitter is determined by the power of the transmitter, and to double the range of any beacon requires a fourfold increase in output power. The power required for the long range beacons can be up to 10 000 watts, giving a range of about 300 NM over land, and up to 1 000 NM over the sea. The output of an ILS marker beacon may be as low as 20 watts, with a range of about 10 NM.

b. Transmission Frequency. The lower the frequency of transmission, the greater the range. A higher frequency will have more wavelengths, and there is greater loss of power with the increased number of wavelengths losing power when making contact with the ground.

c. Atmospheric Conditions. The presence of thunderstorms will reduce the effective range of a signal, as well as the movement of the Ionosphere at night. The signals strength will be most affected at dawn and dusk.

d. Surface. The nature of the earth's surface over which the transmitted signal is travelling will affect the range, with range over land being less than that over the sea with the same transmitter power.

Using the System

173. Once a station frequency has been selected, it must be properly identified before it can be used. NDBs transmit a morse code identification in either a two- or three-letters. Port Alfred transmits a two letter code PA (dit-dah-dah-dit dit-dah), while there are others that transmit a three-letter code, such as the marine beacon at Cape Recife, which is ZTY (dah-dah-dit-dit dah dah-dit-dah-dah).

174. If you are unable to pick up the morse code identification, or IDENT as it called, it is an indication the NDB is out of service. The word TEST (dah dit dit-dit-dit dah) is sometimes transmitted when the system is under test, and the NDB cannot be used for navigation.

Fig 3.58. ADF

Radio Magnetic Indicator (RMI)

175. Radio bearings can be shown on the RMI. This instrument in effect combines the aircraft compass heading and the ADF (relative) bearing. The RMI indicator unit superimposes the radio bearing (a needle pointing to the station) on a magnetic compass rose. This compass rose is fed with heading information from the aircraft compass and therefore it will change with any change of aircraft heading. It is in fact a remote indicating compass. The "12 o'clock" position on the face of the instrument corresponds to the heading of the aircraft in the same way as the ADF. Instead of only the relative bearing being shown, the actual magnetic direction of the NDB is shown. (In effect, the RMI adds the aircraft heading to the relative bearing).

Fig 3.59. RMI

VOR

176. Very High Frequency Omni-Directional Radio Range (VOR) comprising a ground beacon and an airborne installation, automatically and continuously provides the pilot with the magnetic bearing of the aircraft from the beacon. The system is used extensively as an en-route navigation and terminal approach aid.

177. VOR, operating in the frequency band 108.00 to 117.95 MHZ, has a great advantage over any MF system offering similar facilities, for its performance is not affected by static or night effect. However the line of sight properties of VHF transmissions limit the VOR coverage provided for low flying aircraft.

178. In 1960 ICAO adopted VOR as the international standard short range navigation aid, and a large number of aircraft now carry the necessary receiver equipment enabling them to use the numerous beacons throughout the world.

Principle of Operation

179. The VOR provides the pilot with information regarding the position of the aircraft relative to the position of Magnetic North at the beacon. It indicates the Magnetic Bearing that the aircraft is on. To do this two signals are used. These two signals can be likened to a lighthouse which has a strobe light on top, as well as the rotating beam of light. If the strobe light flashes once as the rotating beam pass through North, then an observer to the North of the lighthouse would see the strobe and rotating beam at the same time. An observer to the East of the lighthouse would see the strobe at the same time as the observer to the north, but would have to wait for the rotating beam to pass through 90° before it could be seen. If the time of one revolution of the rotating beam is known, by measuring the time difference between the sightings of the two lights, an observer at any position around the lighthouse would be able to calculate the bearing from the lighthouse.

180. The VOR does just that at a rate of 30 times per second. Two signals are sent out, one is called the reference signal (the strobe on the lighthouse) and the other a variable signal (the rotating beam of the lighthouse). The aircraft equipment calculates the difference between the two incoming signals, and the magnetic bearing, or radial, from the VOR is indicated in the cockpit.

Presentation and Interpretation

181. The VOR can use a horizontal situation indicator (Fig 4.60.) to indicate deviations off course. This is a command instrument which will

tell you to fly right if the deviation is right of the desired radial. It is important to remember that a VOR allows you to intercept Radials (Magnetic bearings from the station). This makes for accurate navigation especially in highly congested flying areas.

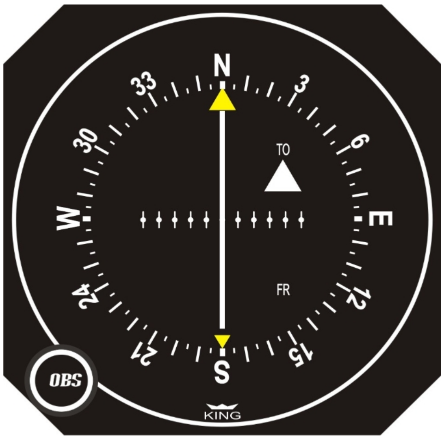


Fig 3.60. VOR

182. The VOR can also be displayed on a Remote Magnetic Indicator (RMI) where the point of the needle would show the radial TO the station and the tail-end would show the radial FROM the station. VOR's are identified by a three digit morse code identification for example PEV, where the last digit will be a V. They can be found on aeronautical maps and charts with the specific frequency for that station printed on the map. Their frequencies can also be found in AIP's and letdown plates.

Coverage

183. Coverage is worldwide and the VOR is very useful on short and long haul flights over land.

Errors and accuracy

184. Seeing that the VOR is a VHF navigation aid it eliminates most of the errors that you find with Medium and Low frequency systems. VHF being a line of sight navigation aid, it can be seen that coverage will thus be mostly determined by the aircraft's altitude. The effective accuracy for a VOR is between 4° and 6°.

Factors affecting range and accuracy

185. This is determined by the placing of the transmitters. They are normally placed in unobstructed places like mountain tops. The VOR's placed in more congested areas like airports for instance, would be less accurate because the signal can be obscured to incoming aircraft at certain stages during the approach.

Distance Measuring Equipment (DME)

186. DME is a UHF navigation aid that operates in the 1000 MHZ band. DME ground beacons provide range information only. It determines the slant range from the aircraft to the ground station. They are normally found in close proximity of a VOR station. It comprises two parts, a transmit/receiver interrogator system in the aircraft and a transponder on the ground. By measuring time and distance the interrogator calculates the distance from the station. The DME range is normally about 50 nautical miles.

187. The principle advantages of DME are world-wide beacon coverage, high accuracy, ease of use and the rapid acquisition of navigational information without the need for special charts.

Position Lines

188. A position line is any line that can be drawn in its correct position on a chart. Examples of position lines are:

a. Physical lines:
   - Railway lines
   - Rivers

b. Radio lines:
   - VOR radials
   - NDB relative bearings
   - DME arcs

189. Being on a position line places an aircraft somewhere along that line. This fact carries no information about the precise position or groundspeed of the aircraft, but in combination with other position lines, these facts can be calculated or plotted on a map:

a. Crossing 2 parallel position lines in a given time allows calculation of the groundspeed.

b. Being at the intersection of 2 position lines places the aircraft at known position, i.e. at a fix.

c. Crossing 2 position lines at different times on a known track and at a known groundspeed can result in a fix.

Crossing 3 position lines at different times at a known groundspeed can result in a fix.

THE "Q" CODE

190. The "Q" code was a system developed by the Royal Air Force in World War II to simplify and shorten radio messages as well as to preserve a certain security in R/T traffic. Only a few of the codes are still in general use QNH, QFE, QSY etc. etc. Four "directional" "Q" codes are used in navigation, some more than others. They are: QTE QUJ QDM QDR which are used for bearings and position lines. They are in common use in the CAA examinations.

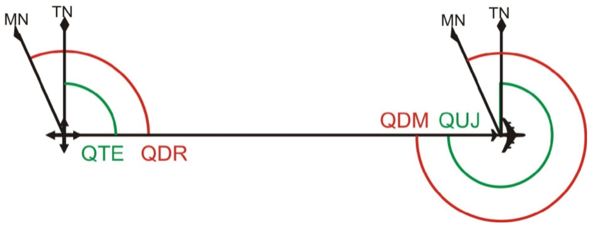


Fig 3.61. The "Q" Code

A QDM is the magnetic bearing from the aircraft to the station.

A QDR is the magnetic bearing from the station to the aircraft.

A QUJ is the true bearing from the aircraft to the station.

A QTE is the true bearing from the station to the aircraft.

All bearings must be converted to QTE to be able to plot them on a map.

Relative Bearings

191. A relative bearing is measured clockwise from the nose of the aircraft. It must be added to the heading to obtain the direction of the beacon. Variation must be applied where the work is done. With an ADF/NDB the work is done at the aircraft, all other bearings the work is done at the station. Use the following diagram as a guide to convert between the Q codes, especially converting to QTE.

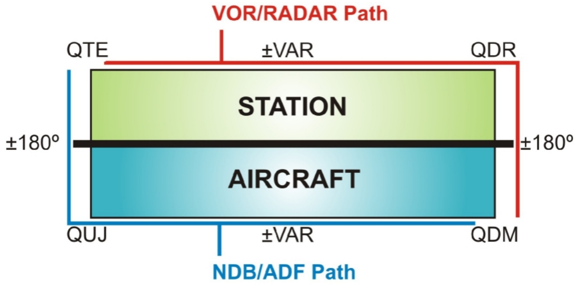


Fig 3.62. Q Code Conversions

Example:

Rel bearing = 085º

Hdg © = 114º

Var at station = 22º W

Var at A/C = 20º W

Dev = 4º E

W hat is the QTE?

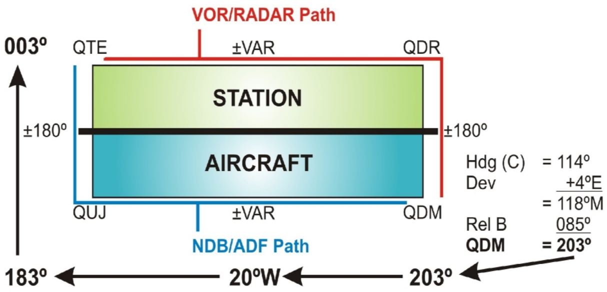


Fig 3.63. Calculating QTE

Accuracy of Position Lines

192. The best accuracy occurs if position lines are crossed at 90°. This is rarely the case, so it is generally accepted that lines can be crossed at 90° ±10°, in which case the error in the calculations will be less than 2% (sin 80° = 0.9848).

Position Line Usages

a. Calculating Groundspeed:

b. Need to know:
Distance between position lines
Time taken to travel between position lines

193. Calculating the time between 2 DME arcs provides an accurate groundspeed if the aircraft is tracking directly toward or away from the DME station. The time taken to travel between 2 straight position lines, or 1 position line and a fix, can also be used to calculate ground speed.

a. Calculating Position - Instant fix:

b. Need to know: Which position lines

c. If the aircraft is placed on 2 position lines at one time, the position is simply the intersection of the two position lines on the map.

Special Drawing Techniques

194. Drawing a parallel line: Parallel lines are best drawn with the Douglas Protractor. Assuming protractor is always used with N on top; keep horizontal lines parallel to line in question. Place centre of protractor where new line is required. Mark the 090° and 270° points on the map, then use a ruler to draw the line between the points.

195. Drawing a parallel line at a given distance from a point: The technique of drawing the parallel line is the same as the above. Mark the protractor with a line or circle at the correct distance from the centre. Move the protractor, keeping it parallel to the reference line, until the distance marker is on the reference line. Draw the 090° - 270° line at this point.

Global Positioning System (GPS)

196. The NAVSTAR Global Positioning System (GPS) is a space based radio positioning system, using a constellation of satellites to provide highly accurate position, speed, and time data. There are three major segments to the system:

197. Space Element. This consists of 24 satellites (21 active with 3 reserves) orbiting the earth every 12 hours. The satellite orbits are designed in such a way that at least four of the satellites will be visible to a receiver at anytime, anywhere on earth

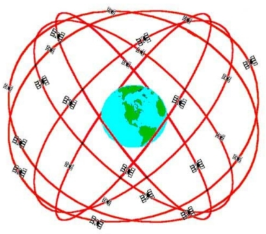


Fig 3.64. Space Segment Orbital Pattern

198. Ground Control Network. This is the ground control system which monitors and controls the satellite system. There is a Master Control Station in Colorado Springs in the USA, and several monitoring stations around the world. They track the accurate potions of the satellites, and update each satellite as to its exact position.

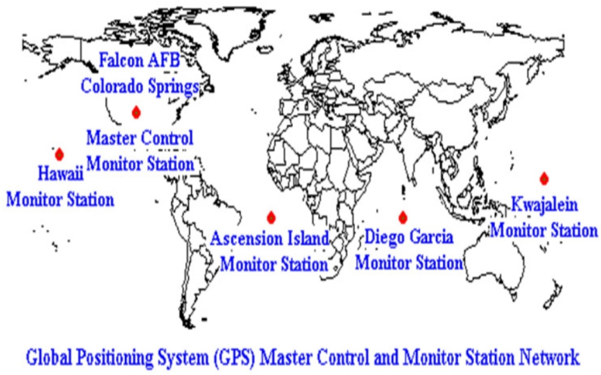


Fig 3.65. GPS Ground Control System

199. User Element. This is the GPS receiver in the aircraft which receives and identifies the incoming signals from the satellites which are in view of the receiver.

Fig 3.66. GPS

200. The system is available globally, continuously, and under all weather conditions to users at or near the Earth's surface. As the receivers operate passively there can be an unlimited number of simultaneous users. GPS has features designed to deny an accurate service to unauthorized users. These are controlled by the US Military.

201. Each satellite broadcasts radio frequency ranging codes and a navigational data message. The GPS receiver measures the transit time of the signals and can then determine its range from a satellite. The data message enables the receiver to

determine the exact position of the satellite at the time of transmission, and by calculating the range from 3 or more satellites, a fix can be obtained. If information is received from 3 satellites a two-dimensional fix can be computed. If 4 satellites provide data, then a three-dimensional fix, ground position and altitude, can be computed.

202. Errors and Accuracy. The Geodetic Problem. With the advent of satellite navigation, it was realised that the old survey methods used to determine position on earth were very, very inaccurate. W hen maps were first constructed, cartographers used what could be described as a flat earth, converted the information using mathematical models, and a latitude and longitude grid was used for indicating position. Using satellite navigation, the basis of position reporting is the centre of the earth, and old survey positions can be hundreds of metres out. Elevation was not part of the old methods, and when information is transferred on to a flat chart, there is distortion, much like trying to flatten out a naartjie skin after it has been removed.

203. Until the entire earth has been re-surveyed using a standardised system, errors in co-ordinates will be present in charts produced by bordering countries whose surveys were undertaken using one or more of the many survey methods that were in use. The system by which South African charts are being converted is known as the “W GS-84". It has been estimated that to convert all of the world’s charts to W GS-84 will take until the middle of this century. And to add to the problem, an even newer method is currently in use in Europe, the European Terrestrial Reference Frame 1989 (ETRF89), which increases the accuracy tenfold.

204. Refraction. Only one of the four satellites needed for a 3-D fix can be directly overhead. This means that the other three will be at various elevations as low as 20°. This means that the incoming signal from a low satellite will be passing through the ionosphere for a lot longer than a high satellite (see Fig 4.x). The ionosphere also does not have the same density at all latitudes and longitudes, so incoming signals will be penetrating different densities. The smaller the elevation angle, the greater the error, with the average between 10° and 80° being about 25 metres.

205. Atmospheric Refraction. This is dependent on the water vapour present in the atmosphere (not liquid water such as rain). The errors could be accurately calculated if local meteorological measurements are available, but they usually aren’t. The errors here are smaller than those of ionospheric refraction, but are at their worst at the lower altitudes where the concentration of water vapour is greatest. Aircraft above F300 can virtually ignore this error, but at low altitudes it averages out at about 10 metres.

206. Multipath Propagation. Being a radio signal, the signal from a GPS satellite can also be reflected from land or sea surfaces, so several different signals may arrive at slightly different times, or from different directions (see Fig 4.x). The receiver cannot differentiate between them, and apart from careful location of the aerial, nothing much can be done about the error. A hand held receiver would have a very unsatisfactory aerial location, and will also pick up reflected signals from the wings or other parts of the aircraft.

207. US Department of Defence. The system is a military one, which civilians may use. Unless you are an ally of the USA, you will not have the codes necessary to remove any artificial errors that they may introduce into the system. This is to prevent enemies of the USA using the system as a guidance system for weapons. W hen located at a fixed position, the position indicated by the GPS will move randomly. This is called Selective Availability (SA), and the aim is to limit civil users to an accuracy of about 100 metres (under normal operation civil accuracy is approximately 40 metres). The 100 metre (328 feet) accuracy applies to the horizontal, but in elevation can go up to 156 metres (511 feet). They have also stated that the horizontal error will not exceed 300 metres (984 feet) at the 99,99% probability level. All this means is that errors will not always be this large, but it must be assumed that they MAY be. Fig 4.x shows the SA wander of a typical, stationary receiver. It is obvious that the system cannot be used for accurate approaches, but only for en-route navigation above 500 feet AGL.

208. In terms of current legislation, only fixed, fitted GPS equipment may be used in aviation. This does not include handheld receivers.

Ground Radar

209. There will be times when you will be flying in, or close to, the radar environment of a major airfield. Radar (from Radio Detection And Ranging) is a primary system used by ATC to provide all sorts of services to aircraft. This includes separation,

vectoring and sequencing - sorting out the order in which aircraft must move - and to do this they need to know exactly where each aircraft is. Depending on the type of airspace you are in, you may or may not receive radar assistance from ATC, and as a VFR pilot you will be responsible for seeing and avoiding other aircraft. ATC will only pass on information which it deems relevant.

210. Principles. Primary radar uses one transmitter which also serves as the receiver. A very short pulse of radio energy is transmitted and if a reflective object is in the path of the radio beam, then some of the radio energy may be reflected back to the receiver. The time taken for the energy to travel to the reflector and back, divided by 2, can then be converted to range. This is then displayed on the radar screen in the control tower. By rotating the transmitter slowly, the whole sky can be monitored by the controller.

211. Application. The use of primary radar is multiple. It can be used by ATC as described above, for weather detection, ground mapping for navigation as well as for Instrument Landing Systems (ILS).

212. Presentation and interpretation. This may vary from type of use. ATC radar will give a 360° coverage of a segment of the airspace around an airfield for instance. This would use a Planned Position Indicator (PPI). This displays distance and direction from the airport. It might be a display that looks forward with the aircraft at the bottom middle of the screen as used in weather radar or it might have a directed lobe as used with ILS.

213. Coverage. It is normally associated with airfields and long range detection sites for ATC. Seeing that weather radar is onboard, it can be used anywhere for weather detection or ground mapping for navigation.

214. Errors and accuracy. It is normally very accurate seeing that this is high technology equipment. ILS systems are specially calibrated to high degrees of accuracy to ensure safe approaches and landings.

Secondary Surveillance Radar

215. The Secondary Surveillance Radar (SSR), or Transponder as it often referred to, is an example of a secondary radar system. The primary airfield radar discussed above does not need any involvement by the aircraft, and relies solely on receiving a radar echo reflected by a target. In a secondary radar system, a transmitted radar signal is used to trigger a response from equipment in the target, in this case the aeroplane fitted with the transponder.

216. SSR is used by air traffic control ground installations to identify radar returns. The system is operated in conjunction with primary radar, the two aerials being either co-mounted, or arranged to scan the same target at the same time. The ground transmitter, known as the interrogator, transmits a coded interrogation signal which is received and decoded by transponders in the aircraft. Depending on the mode to which the transponder is set, a coded reply signal is transmitted back to the interrogator. This reply signal is decoded and shown on the radar display along with the primary radar response.

217. In this way, ATC is able to identify any aircraft which has its transponder on, and can also obtain altitude information from the aircraft without any response from the pilot being necessary.

218. The system allows the pilot to dial in the transponder code allocated by ATC in a four digit selection. Care must be taken when changing the codes. There are three codes which are used to indicate to ATC that something has gone wrong on board without having to resort to using the radio. These three codes are:

7500: used to indicate Interference, ie a hijacking.
7600: used to indicate Communications failure.
7700: used to indicate an Emergency.

219. These are also referred to as the ICE codes, and if they are selected, ATC will react accordingly and start the necessary procedures to assist where possible.

TYPICAL EXAM QUESTIONS

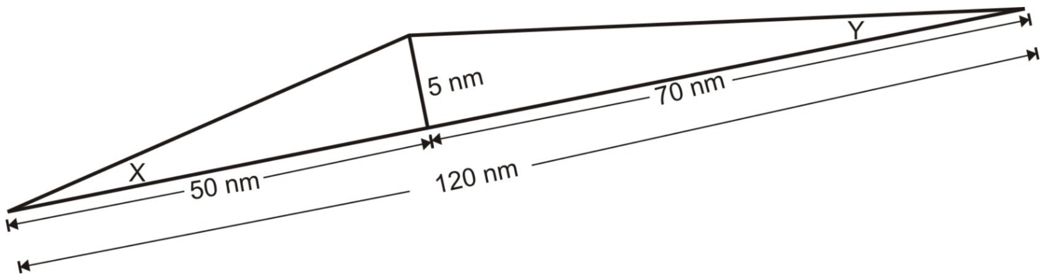
Here are some examples, the first one is a simple calculation.

1. You pinpoint yourself 5 nm left of track. You have travelled 50 nm and you have 70 nm to go. W hat will the new heading be in order to arrive overhead your destination if you have been maintaining 072(M)?

a. 066º(M)
b. 078º(M)
c. 082º(M)
d. 062º(M)

Answer and explanation:

W e solve this problem by means of the 1-in-60 rule. First draw a diagram.



W e have to solve angle "X". This we do by means of the 1-in-60 rule formula.

$$X = \frac{\text{Dist off track } X\ 60}{\text{Dist along track}}$$

$$X = \frac{5\ X\ 60}{50}$$

$$X = 6^{\circ}$$

W e have to turn 6º to the right to compensate for the left drift we have experienced and we add the drift to our heading, 072º + 6º = 078º. This will be the heading to fly parallel to our track. To fly direct to our destination, we have to solve angle "Y".

$$Y = \frac{\text{Dist off track } X\ 60}{\text{Dist along track}}$$

$$Y = \frac{5\ X\ 60}{70}$$

$$Y = 4.3^{\circ}$$

To fly direct to our destination, we add the 4.3º to the 078º heading that we have calculated to fly parallel to our track, we add the angle because we are going to drift to the left. 078º + 4.3º = 082.3º.

The answer is therefore "c".

The second question is an example of solving the triangle of velocities from a chart:.

2. An aircraft was overhead PORT ALFRED (S33° 34' E026° 54') at 0752 on track for VICTORIA W EST (S31° 23' E023° 07'), heading 310° (T). At 0840 the aircraft obtains a relative bearing of 083° COOKHOUSE (S32° 45' E025° 47'). The groundspeed is:-

a. 75 kts.
b. 88 kts.
c. 95 kts.
d. 98 kts.

Answer and explanation:

First we have to calculate the QTE.

True heading	310º
Rel bearing	+ 083º
	393º
	- 360º
	033º QUJ
	+ 180º
	213º QTE

Retrieve the rest of the information needed to calculate the G/S from the chart. Draw in your track from Port Alfred to Victoria W est and write our time overhead Port Alfred, 0752, at Port Alfred. Place the centre of your protractor on Cookhouse, align it with the meridian (North) and draw the position line, 213º, from Cookhouse. W rite down the time of the position line, 0840. Determine the time interval between the position line and Port Alfred, 0840 - 0752 = 0:48. Measure the distance between Port Alfred and the position line, 71 nm. Calculate the Groundspeed; 71 nm in 0:48 = 88.75 kts.

The answer is therefore "b".

The third question is an example of plain theoretical fact.

3. One nautical mile is defined as:-

a. The average length of the arc of one minute of latitude.
b. The average length of the arc of one degree of latitude.
c. The average length of the arc of one minute of longitude.
d. The average length of the arc of one degree of longitude.

Answer and explanation:

Straight fact. One nautical mile is defined as the length of an arc of a great circle on the surface of the earth that subtend a one minute angle at the centre of the earth, one minute of a great circle equals one nautical mile. Meridians are great circles, therefore one minute change of latitude equals one nautical mile. Parallels of latitude are not great circles, except for the equator, therefore one minute change of longitude does not equal a nautical mile. One minute change of longitude on the equator equals one nautical mile, the equator is also a great circle.

The answer is therefore "a".

The fourth type of question relates to the practical application of facts.

4. W hen conducting a cross country trip it is important to know your ...., in case you need to return to your departure airfield.

- a. true track
- b. magnetic track
- c. reciprocal track
- d. deviation

Answer and explanation:

Reciprocal track, is simply your own track to your destination, plus or minus 180°s. It is important to know your reciprocal track in the event that you need to return to your departure aerodrome.

The answer is therefore “c”.

Try the following questions using the processes prescribed in the preceding questions.

1. Meridians on a Lambert Conformal Conic Projection Chart,

- a. are position lines
- b. are straight lines converging at the nearer pole
- c. are isogonals
- d. are straight parallel lines

2. An aircraft with a true airspeed of 150 knots, has a direct tail wind of 20 knots. W hat is the aircraft's ground speed?

- a. 130 knots.
- b. 170 knots.
- c. 150 knots.
- d. 190 knots.

3. GPS is a navigation system that:

- a. relies on signals from one master station and a number of slave stations
- b. cannot provide altitude information
- c. uses satellite technology
- d. is always reliable

4. Lines on a chart connecting places with zero variation are called.

- a. agonic lines
- b. magnetic bearings
- c. isogonals
- d. great circle line

5. The time UTC is 0100. W hat time is it at a location 45 degrees longitude to the east?

a. 2200Z.
b. 2200LMT.
c. 0400Z.
d. 0400LMT.

6. Track 225° (T), Drift 6° left, Variation 21°W . The magnetic heading to steer is:-

a. 231(T).
b. 252(T).
c. 252(M).
d. 231(M).

7. TAS 100 kts, W /V 005/15, Track 345° (T). The groundspeed is:-

a. 86 kts.
b. 96 kts.
c. 106 kts.
d. 116 kts.

8. Track 115° (T), Heading 110° (T), TAS 115 kts, Groundspeed 105 kts. The W /V is:-

a. 069/14.
b. 249/14.
c. 159/14.
d. 059/14.

9. The scale of a Lambert's Conformal Conic projection is correct::-

a. Only at the parallel of origin.
b. Only at all the parallels of latitude.
c. Only at the standard parallels .
d. Only at the prime meridian.

10. An aircraft, maintaining a heading of 295° ©, obtains a relative bearing of 345° from an NDB. If the aircraft's variation is 20° W and deviation is 3° E, the bearing to plot from the NDB is:-

a. 098°.
b. 278°.
c. 263°.
d. 083°.

ANSWERS

1	2	3	4	5	6	7	8	9	10
b	b	c	a	d	c	a	a	c	d

ANSWERS EXPLAINED

1. A Lambert Conformal Conic Projection is a method used to produce a chart that involves superimposing a cone over a portion of the earth and then using a section of that cone to represent a specific area (see figure 15). The following are properties of a Lambert Projection:

   Straight lines most closely represent an arc of a great circle.
   Minimum distortion, distance is fairly uniform over the entire chart.
   Lines of latitude are curves that are concave towards the nearer pole - north or south.
   Lines of longitude converge towards an imaginary point over the nearer pole - north or south.

2. Airspeed is the speed an aircraft travels through the air. Ground speed is the speed an aircraft travels over the ground. Wind will affect an aircraft's ground speed, but will not affect its airspeed.

3. The GPS navigation system uses signals sent from satellites to determine an aircraft's position.

4. In some locations true north and magnetic north will be aligned. These places will possess zero variation. Lines on charts that connect locations with zero variation are call agonic lines.

5. The local mean time for a particular location will vary depending on seasonal factors and geographic location. Confusion would result if every location used its own local mean time, therefore, pilots always use Universal coordinated time (UTC). This is the time in Greenwich England. One can convert local mean time to UTC by:

   subtracting one hour for every 15 degrees of longitude, if the location is east of the prime meridian,
   adding one hour for every 15 degrees of longitude, if the location is west of the prime meridian.

   Universal coordinated time (UTC) is also known as ZULU time.

   W hen converting LMT to UTC, remember:

   East is least - subtract one hour for every 15 degrees of longitude, if the location is east of the prime meridian.
   W est is best - add one hour for every 15 degrees of longitude, if the location is west of the prime meridian.

6. The drift is 6° to the left, you have to turn into the wind to be able to maintain your track, you therefore need to add the 6° to the track, 225°(T) + 6° = 231°(T). To get magnetic track we apply variation to the true track, variation west magnetic best. 231°(T) + 21°W = 252°(M).

7. W e have to solve the triangle of velocities, you can either use the "pathfinder" (Plan Leg, Hdg/GS) or the "whizwheel" to solve this problem.

8. Again we have to solve the triangle of velocities. Again you can either use the "pathfinder" (Act Leg, Unknown Wind) or the "whizwheel" to solve this problem.

9. The scale of a Lambert's Conformal Conic projection is correct::-

10. To be able to calculate the bearing to plot, you have to determine your heading true first:-

295° Compass
+ 3° Dev E
298°(M)
- 20° Var W
278°(T)

Now you calculate your QTE:-

345°(RB)
+278°(T)
623°
- 360°
263°
- 180°
083°QTE

The following questions do not offer any options, There may be more than one correct answer, so use your knowledge and the Navigation text to find possible solutions.

1. In navigation, a line with a constant bearing is called a?

2. W hen magnetic variation is indicated as "East", it means that:-

3. The angular difference between true north and magnetic north is called:-

4. W /V 045/12, track 101°(T), drift 6° right, TAS 95 kts. The groundspeed is:-

5. W hen referring to direction on the earth the quadrantal points are:-

6. W hen compass deviation is indicated as "W est", it means that:-

7. Track 184° (T), Drift 5° left, Variation 22°W , Deviation 4°W . The compass heading is:-

8. Airfield elevation 2 800ft, QNH 1023. The pressure altitude is:-

9. If the local time at airfield A, longitude E018°45', is 0818 then, if both positions are in South Africa, the time UTC, at airfields B, longitude E021°45', will be:-

10. Using the following information, W /V 220/10, Hdg 176°(T), TAS 100 kts, the track and groundspeed is:-

11. On a chart constructed using the Lambert's Conformal Projection, A rhumb line track:-

12. An aeronautical chart which portrays the earth's features with very little distortion, is known as:-

13. Track 115°(T), Heading 110°(T), TAS 115 kts, Groundspeed 105 kts. The W /V is:-

14. The axis about which the earth rotates is between:-

15. FL 105, temperature ISA +1°, RAS 85 kts. The TAS will be:-

16. An aircraft is to fly from A to B, distance 235 nm, TAS 90 kts, tailwind 5 kts, cruise fuel flow 8.5 USG/Hr, assume 3 USG is required to take-off and climb to cruising altitude and the reserve fuel requirement is 9 USG. The total fuel required is:-

17. The reference for measurement of latitude is:-

18. W hen referring to direction on the earth the cardinal points are:-

19. An aircraft in the southern hemisphere is to maintain a constant heading of 270° (M) on a magnetic compass. If the aircraft's speed is increased the compass would:-

20. At 1415 an aircraft was overhead a VOR maintaining radial 215° en route for B, heading 210° (M). At 1430, the pilot decides to return to the VOR. The heading to steer is:-

21. An aircraft is flying from Alpha to Bravo, total distance 96 nm. After flying for 40 nm a fix is obtained which places the aircraft 3 nm right of track. The track error is:-

22. Overhead PILANESBERG, (S25° 32, E027° 12'), at 0730 UTC, en route MAPUTO, (S25° 55' E032° 34'), FL095, OAT -5°C, RAS 103 kts, W /V 240/10. The ETA for MAPUTO is:-

23. An aircraft is flying from EAST LONDON, (S33° 03' E027° 50'), to COOKHOUSE NDB, (S32° 45' E025° 49'), drift 8°L. The relative bearing required from the COOKHOUSE NDB to maintain the track is:-

24. An aircraft flies from A to B, distance 133 nm, in 1 hour and 12 minutes. If there is a headwind of 12 kts the TAS is:-

25. Aircraft heading 175° ©, variation 18° W , Deviation 4° W . The aircraft's true heading is:-

26. Pressure altitude 5000 ft, temperature ISA +23°C. The density altitude is:-

27. Convergency is defined as being:-

28. At 0830 an aircraft was overhead NELSPRUIT (S25° 30' E030° 55') on track for PILANESBURG (S25° 22' E027° 12'). At 0924 the aircraft crosses radial 020 W IV (S25° 50' E029° 12'). The groundspeed is:-

29. Track 145° (T), W /V 220/20, TAS 125 kts, variation 22°W . The magnetic heading to steer is:-

30. One kilometre is defined as:-

Answers to the straight questions.

1. Rhumb line.

2. Magnetic north is located east of true north.

3. Variation.

4. 88 kts.

5. 045°, 135°, 225° and 315°.

6. Compass north is to the west of magnetic north.

7. 215°(C).

8. 2 500ft.

9. 0630 UTC

10. Using the whizwheel, the track is 172°(T) and the groundspeed is 93 kts.

11. Cuts every meridian at the same angle.

12. Topographical.

13. 069/14.

14. True north and true south.

15. 100 kts.

16. 33 USG

17. The equator.

18. 000°/360°, 090°, 180° and 270°.

19. Show an apparent turn to the south.

20. 040°(M).

21. 4.5°.

22, 0948 UTC.

23. 352°.

24. 123 kts.

25. 153°(T).

26. 7 760 ft.

27. The angle between adjacent meridians, the inclination between two meridians at a specific latitude.

28. 102 kts.

29. 176°(M).

30. One ten thousandth of the distance from the equator to either pole,.